# Monitoring Strategies for Effective AC Mitigation Integrity Management

Jamey Hilleary
Elecsys International
846 N. Mart-Way Ct.
Olathe, KS 66061
USA

## ABSTRACT

The technology available for monitoring induced alternating current (AC) levels and additional corrosion risk factors for AC corrosion risk has continuously evolved along with the recognition of AC as a significant factor in pipeline corrosion. This paper covers the current state of the art regarding monitoring AC levels and AC corrosion risk on buried structures as well as monitoring the effectiveness of AC mitigation deployed to alleviate the risk of corrosion due to AC interference. Significant topics include induced AC interference, AC and DC current density factors, AC voltage for safe touch and as the driving force for elevated current density, and AC drain to ground and grounding efficiency. Cost-effective and best practices monitoring strategies are discussed as well as the value of continual assessment of AC and DC values relating to ongoing corrosion risk.

Key words: Alternating current interference, current density, electrical grounding, compliance measurements

## INTRODUCTION

Corrosion risk due to AC interference has been known to be a possibility for decades but really came to the awareness of pipeline industry professionals starting around 2000 to 2004. Prior to that time there were some lab simulations as well as some suspected incidents in actual field situations, but many in the industry resisted accepting this as a real risk even as late as 2012 or later. Part of the reluctance to view AC interference as a genuine corrosion risk was that corrosion directly attributed to AC interference had not really been seen in the century of buried pipeline management, as well as a lack of understanding as to how this interference produced or accelerated corrosion on the pipeline. In the late 1990s and early 2000s there were some pipeline leak incidents that upon detailed inspection and analysis were able to rule out other possible corrosion factors and to point the finger directly at AC interference.

The common factor among the early verified AC corrosion incidents was seen to be high-performance epoxy coatings. These coatings, particularly “fusion-bonded epoxy” came into widespread use in new pipeline construction in the late 1980s and early 1990s. The hallmark of these types of pipeline coating are exceptional protection characteristics, durability, and cost-effective application. This type of coating could be applied by the pipe segment supplier in the factory, then the pipe segments shipped, unloaded, assembled, and buried with very little damage to the coating. Additionally, the protection characteristics were so good a minimal amount of cathodic protection was required to protect long stretches of pipeline from “normal” corrosion risks. Essentially, the high dielectric strength of the coating has the added effect of trapping the AC interference on the pipeline and concentrating the drain to ground at the small pipeline coating faults, nicks, and scratches (coating holidays) resulting from the shipping, handling, and installation of the pipe segments[1]. This concentrated AC discharge resulted in a corresponding rapid rate of metal loss. As the AC induced corrosion became better understood it was determined the greatest risk for corrosion was at small coating holidays in the 1cm$^2$ (0.155in$^2$) to 3cm$^2$ (0.465in$^2$) where the AC discharge to ground is concentrated.

A significant challenge in evaluating and controlling the corrosion risk associated with induced AC interference is the wide variance in magnitude of the interference in the AC interference areas. AC voltage and current density levels can vary widely daily, weekly, and seasonally (Figures 1, 2, 3, and 4). The critical AC density levels most tracked for evaluating corrosion risk are directly related to the load on the high-voltage electrical transmission lines that are typically the source of induced AC interference. The current load on the electrical transmission line varies as electrical usage shifts from cities to suburbs, weekdays to weekends, and particularly as seasonal changes affect the use of air conditioners and heating systems.

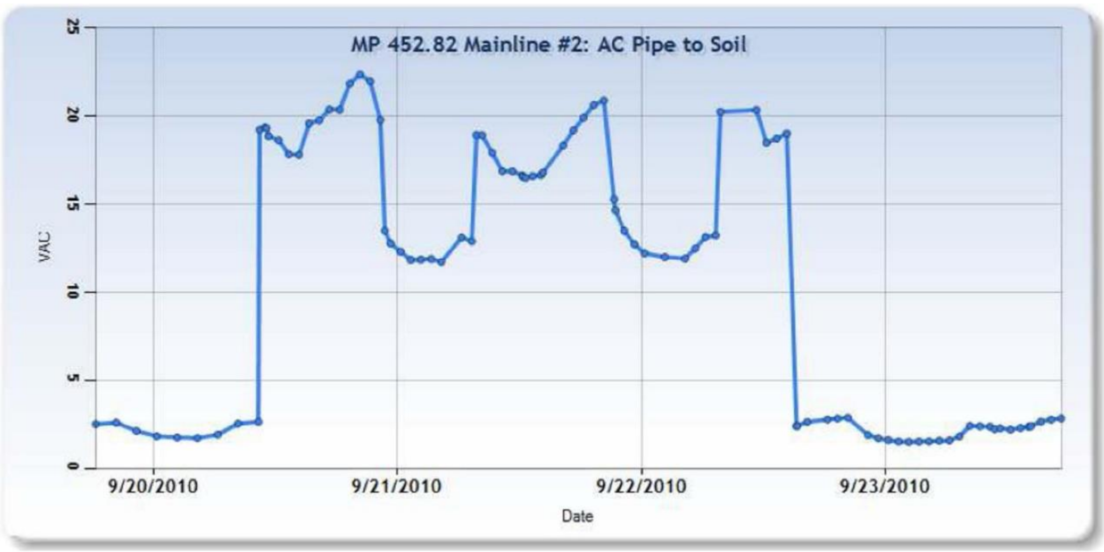


**Figure 1: Graph showing AC voltage fluctuations over a 3-day period of disconnected mitigation**

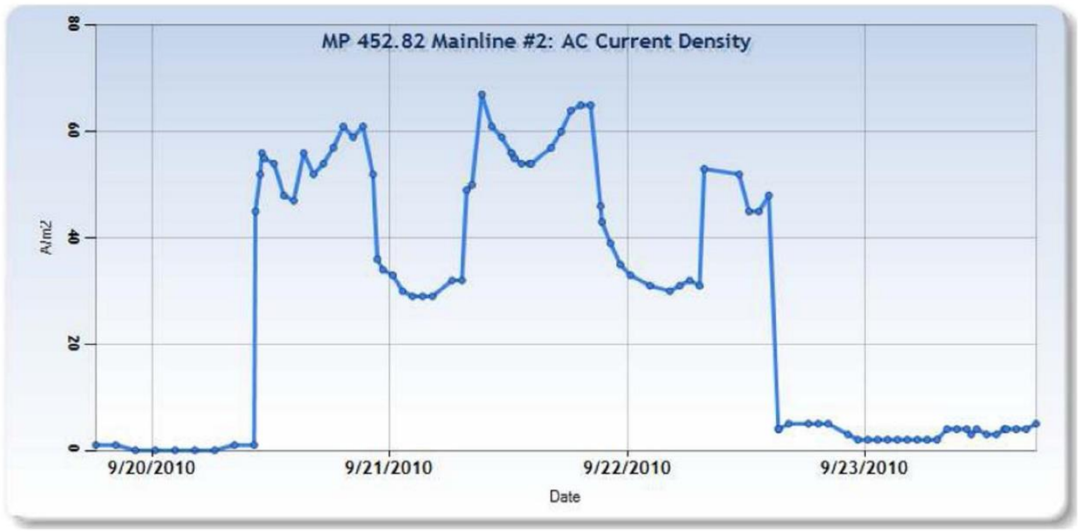


**Figure 2: Graph showing AC density fluctuations over the same 3-day period**

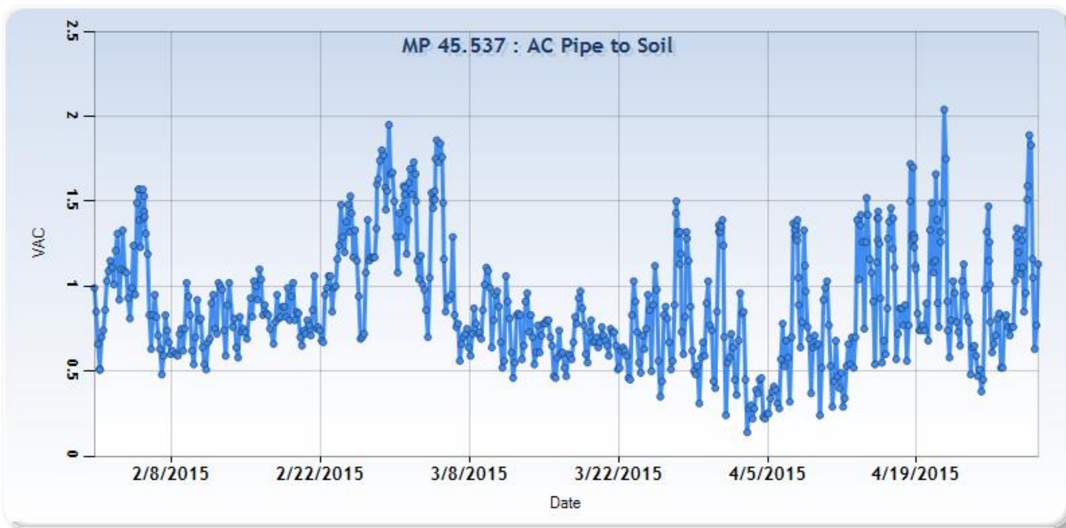


**Figure 3: Graph showing AC voltage fluctuations over a 4-month period**

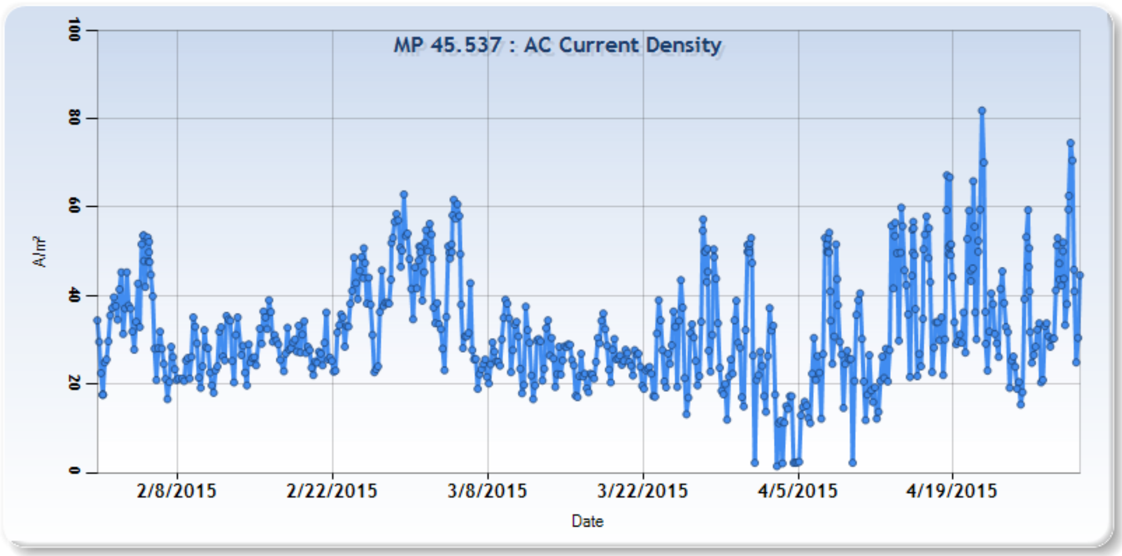


**Figure 4: Graph showing AC density fluctuations over the 4-month period**

As this corrosion phenomenon was more widely accepted and explored, specific risk thresholds, particularly regarding AC density and DC density, were defined and many pipeline operating companies began establishing their own internal criteria for mitigating the risk of AC induced corrosion. Additionally, many engineering firms began specializing in evaluating AC corrosion risk and AC mitigation system design.

## EVALUATION AND MITIGATION OF AC INTERFERENCE

The typical AC interference problem begins where a pipeline and high voltage transmission power lines converge, then run parallel, then diverge (Figure 5).

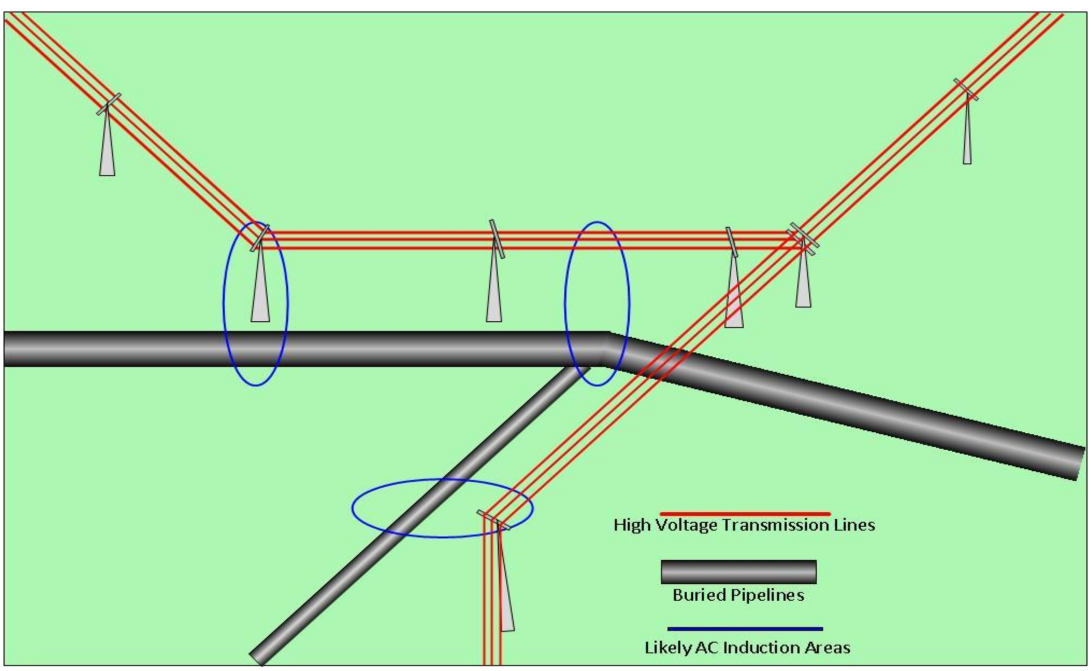


**Figure 5: Diagram indicating likely induction points for AC interference**

In a parallel corridor most of the energy from the powerline ends up back on the powerline, but at the convergent and divergent points some of the energy remains on the pipeline and must find another way off the pipeline. This is the AC that can present a shock hazard if exceeding 15VAC and can present corrosion risk due to elevated current density. Determining the magnitude of risk for corrosion in these areas involves measuring AC voltage potentials, AC and DC current densities, soil resistivities, and using the pipeline and powerline geometry to determine the areas of greatest risk and to design an effective grounding system. Grounding the AC usually involves decoupling devices that pass the AC to ground while keeping the DC cathodic protection current on the pipeline, or using zinc ribbon, magnesium anodes, or other grounding structures that will also return DC protection current to the pipeline. Depending on many factors including the soil resistivity variance, complexity of the area structure geometry, length of the AC interference area, and other factors designing an effective mitigation system can be a daunting task.

## NACE SP21424 STANDARD[2]

Following several false-starts the SP21424 standard governing AC corrosion risk was published in 2018. In addition to describing the electrical and geographic conditions contributing to AC corrosion risk, this standard laid out some specific criteria establishing acceptable corrosion rate, AC voltage levels, AC and DC current density levels, and monitoring requirements. A good portion of the requirements and recommendations detailed in this standard were derived directly from industry “best practices” that had been developed, shared, and implemented by many of the major pipeline operating companies over the previous several years. This standard is still undergoing reevaluation and a separate “test methods” document is being developed as well. The criteria listed in the standard will be the focus of the measurement and monitoring strategies discussed in this paper.

### Corrosion Rate

The standard lists corrosion rate as the first element to control. Essentially, the standard indicates if the operator can demonstrate the corrosion rate is within the accepted range of the SP0169 general corrosion/cathodic protection standard the mitigation of AC corrosion risk is sufficient. Indeed, if corrosion rate can be accurately measured and effectively controlled the problem is essentially solved. Controlling corrosion rate at the areas of highest risk can define a blueprint for maintaining safe voltage and current density levels at areas of lesser risk.

There are several methods for measuring metal loss and calculating corrosion rate. Weight loss coupons can be located at high AC areas along the pipeline and bonded to the pipeline in order to share the same cathodic protection and AC interference conditions affecting the pipeline. Electrical resistance (ER) probes can be installed and monitored providing similar metal loss measurements with the added benefit of corresponding the metal loss measured with other measurements (i.e., AC and DC density values, etc.) occurring simultaneously. In “piggable” pipelines, some smart pigs can accurately measure both internal and external wall loss, providing a similar added value to the external metal loss measurements.

### Current Densities

The corrosion risk factor attributed to AC corrosion that has received the greatest attention is AC density. Fairly early in the study of AC corrosion it was determined maintaining AC density levels below 30A/m$^2$ eliminated most of the corrosion risk from induced AC interference. Additionally, the early case studies indicated that corrosion risk was a bit unpredictable in instances where the AC density exceeded 30A/m$^2$ but was under 100A/m$^2$. These early studies indicated AC densities more than 100A/m$^2$ were likely to cause corrosion in most instances. This is the second criteria element referenced in the standard. The standard indicates AC density should be under 100A/m$^2$ if the DC density is less than 1A/m$^2$ and less than 30A/m$^2$ if the DC density is greater than 1A/m$^2$. AC density can be calculated using the AC voltage value, expected coating holiday size, pi, and soil resistivity but is now more often directly measured using a coupon bonded to the pipeline. The standard does not mandate a coupon size but suggests a 1cm$^2$ area size most closely represents the greatest corrosion risk on the pipeline.

As more research and testing was done prior to the publication of the standard, it was determined that DC density is a contributing factor in that AC density range between 30A/m² and 100A/m². When aggressive AC discharge is occurring at a coating holiday it affects the soil at the point of contact, lowering the spread resistance and enabling a concentration of DC density at the discharge area. As the DC concentration rises, the AC discharge increases, and this cycling back and forth with AC and DC densities elevating produce corrosion that would not be otherwise anticipated in many instances. Controlling the DC density level at the coating holidays is referenced as the third criteria element in the standard. As with AC density, DC density is typically measured using a coupon bonded to the pipeline.

**AC Voltage**

The fourth criteria element listed in the standard is AC voltage. In the standard it is noted that the voltage level is the driving force behind the AC density that is the real corrosion factor common to all of the AC corrosion scenarios. It is noted in the standard that the voltage must be mitigated to meet the <15VAC range specified for "safe touch" in the SP0177 standard, and it is also noted that the voltage may require mitigation to even lower levels to achieve the current density level required for elimination of the corrosion risk.

**AC Drain to Ground**

Grounding of induced AC voltage is not specifically addressed in the standard from a measurement or criteria standpoint, but it is essential for meeting the AC voltage and density measurement thresholds indicated in the standard and paramount to maintaining pipeline integrity. Induced AC is commonly drained from the affected structure using an anodic grounding material such as zinc ribbon or magnesium anodes; or using decoupling devices connecting the structure to a grounding system. The use of anodic materials enables the structure to maintain suitable cathodic protection while dissipating the interfering AC by returning protection current drained along with the AC back to the structure. Decouplers block the DC on the structure while passing the AC to the grounding system. The magnitude of current drain can be measured along with the other relevant values, providing indication of the efficiency and effectiveness of the grounding system. If the steady-state drain to ground measured at specific areas does not correspond with eliminating enough of the interfering current, additional mitigation may be necessary. Additionally, measuring drain to ground provides easy diagnosis of mitigation system failure resulting from failure of system components or third-party damage or disconnection.

**Measurements and Monitoring**

The last element for compliance to the SP21424 standard references monitoring the controlled values (corrosion rate if used, AC and DC densities, and AC voltage) for a "representative period of time" to ensure all expected fluctuations in voltage and current density levels are- captured and evaluated as within acceptable ranges. With the fluctuations that can be expected with significant changes in power line load levels, soil resistivity, and changes over time as new power substations are put online a "representative period of time" can become hard to define.

## MEASUREMENTS AND MONITORING

Corrosion attributed to induced AC interference can be very aggressive, creating pinhole leaks in new pipe in a matter of months. Because of this, it is imperative comprehensive monitoring is applied assuring all variables contributing to the corrosion risk are evaluated for mitigation effectiveness. Monitoring corrosion rate is typically done with weight-loss coupons or electrical resistance probes (ER probes). For this application ER probes offer some advantages. First, they can be manufactured in the 1cm² area size most closely connected to induced AC corrosion. Second, if monitoring additional parameters such as the standard cathodic protection related voltage potentials, or the AC and DC density measurements, any change in corrosion rate can be correlated with changes in other monitored values. This strategy enables the user to differentiate corrosion due to inadequate cathodic protection for instance, from corrosion due to elevated current densities. Third, ER probes can be easier to use as they do not require the user to remove, clean, and weigh the coupon to evaluate the corrosion rate. ER probes are best evaluated over an extended period of time to filter out some “jittery” measurements when taken at too frequent of intervals. The graph below is from the output of an ER probe showing metal loss on the yellow line, and calculated corrosion rate in “mils per year” (MPY) on the red line. The corrosion rate calculation uses an average of 30 previous samples subtracted from the most recent sample at each measurement interval. The difference is extrapolated to reflect the corrosion rate on an annual basis (Figure 6). Measuring corrosion rate at the areas in the corridor at greatest risk of corrosion can provide data to be applied in managing the corrosion risk across an entire AC interference corridor. If the AC and DC densities are measured concurrently at the highest risk areas and the corrosion rate is down to an acceptable level per SP0169, the current density levels measured at those highest risk locations can be applied at the lower risk sites across the corridor. If maintaining the same or lower current density values at the lower risk areas, it can be safely assumed the corrosion rate due to AC interference at the lower risk sites will be at or below acceptable levels. Deploying and using ER probes is costlier than monitoring electrical values alone. A cost-effective monitoring strategy is identifying the highest risk areas, applying comprehensive monitoring including corrosion rate, DC voltage potentials (on and off potentials), AC and DC densities, AC voltage potential, and if at a mitigation “grounding” location the AC drain to ground (Figure 7). This comprehensive monitoring at the highest risk locations enables less costly monitoring (standard test station monitors or data loggers) to be used at adjacent test points and selected test points throughout the affected area. This strategy enables the user to streamline the monitoring necessary to assure compliance with the standard and more importantly to ensure the pipeline integrity in the affected areas.

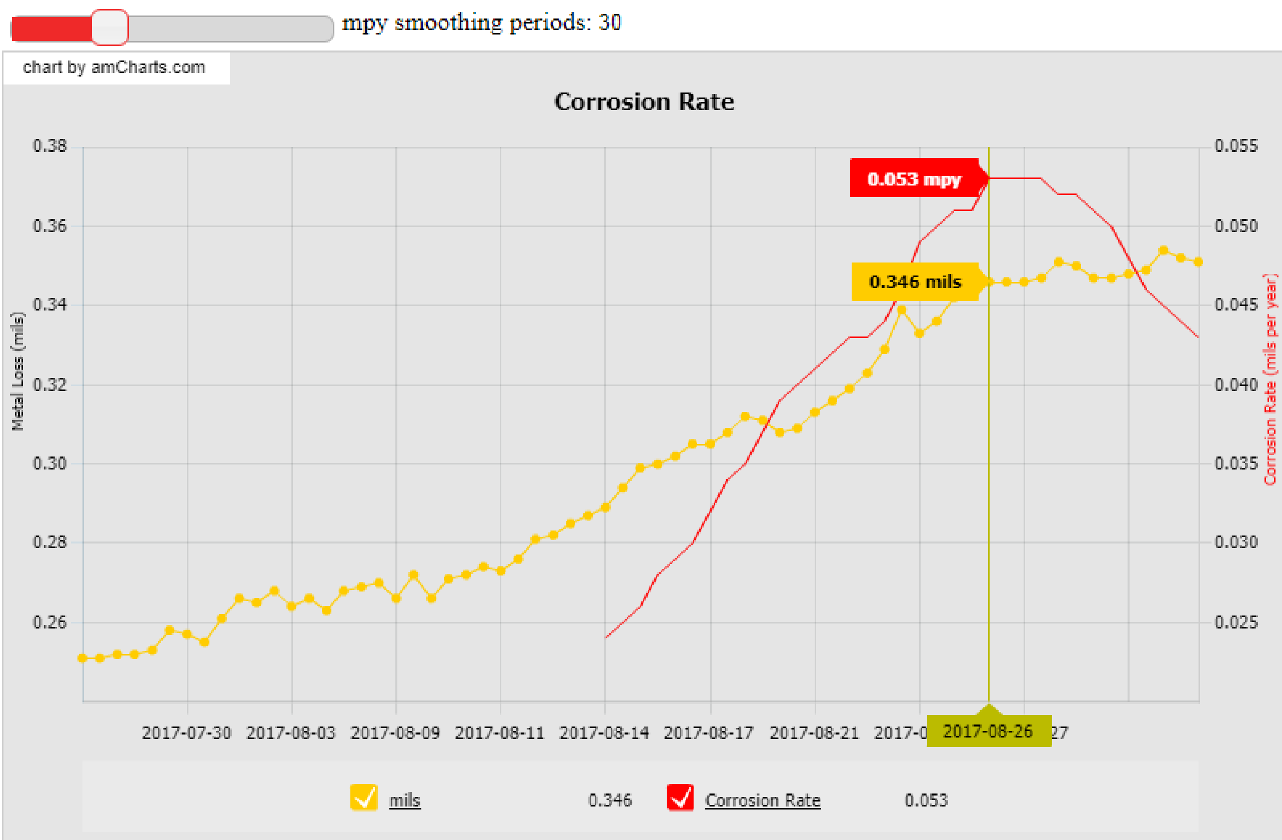


**Figure 6: Graph of metal loss (yellow line) and calculated corrosion rate in “mils per year” (MPY)**

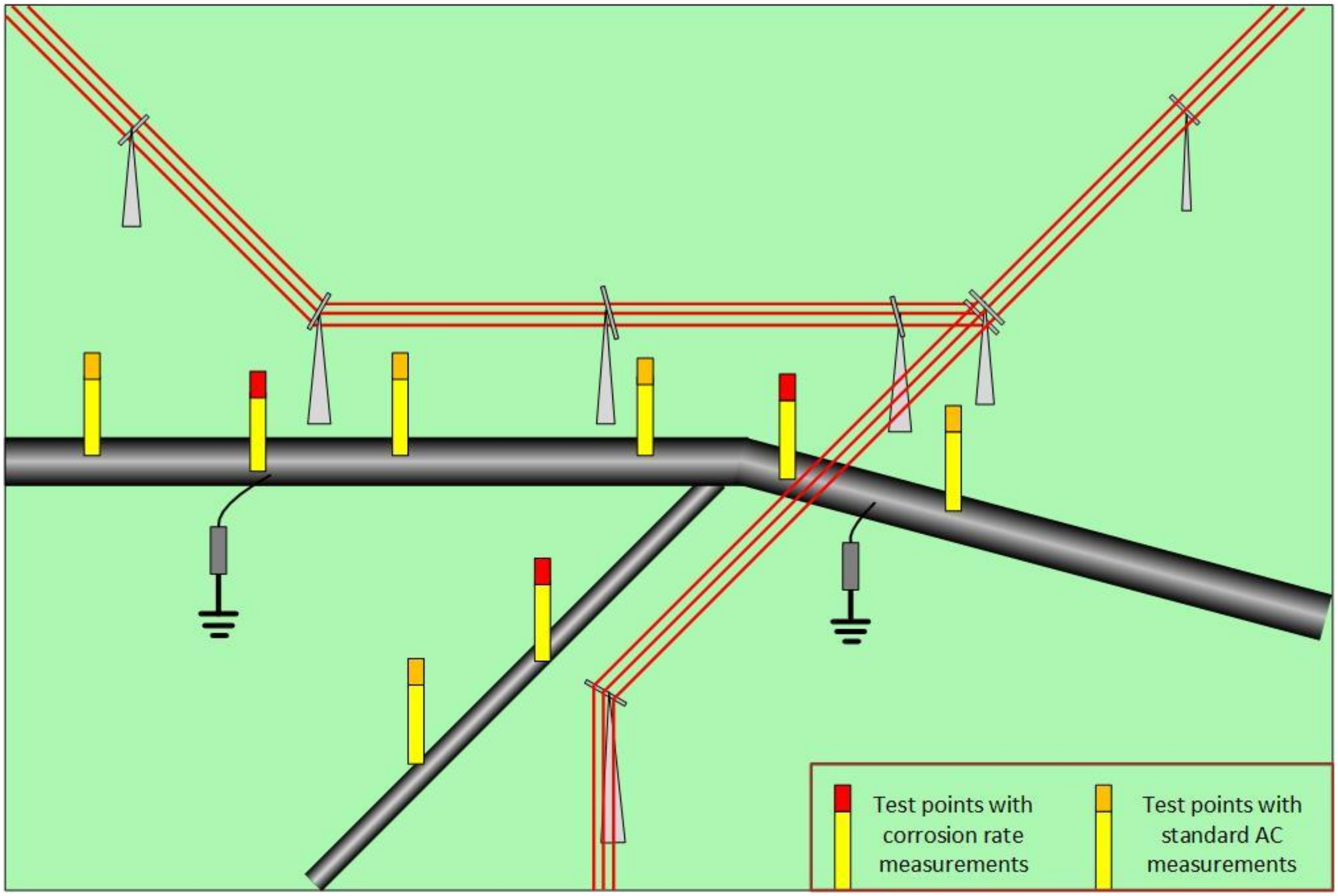


**Figure 7: Diagram indicating optimum locations for standard AC monitoring and AC monitoring with corrosion rates**

**Measurement Frequency**

The measurement frequency and corresponding volume of data acquired varies. Typically, when obtaining baseline data for designing the mitigation system a higher volume of data is acquired to provide a comprehensive view of the magnitude of variation in critical AC parameters in the affected area. Often, high-speed data-logging devices are used to formulate this baseline. Following the design and implementation of the mitigation system a less aggressive, but continuous data acquisition strategy is employed. Again, data-logging devices or remote monitoring devices with frequent reporting or data-logging capability are useful tools. The requirement in the standard to measure the critical parameters for a representative period of time to capture the magnitude of all the fluctuations dictates an extended measurement period. As seen in the graphs in figures 1-4, daily, weekly, monthly, and seasonal fluctuations of severe magnitude are commonplace in induced AC interference scenarios. Additionally, power companies are continually expanding their footprint through the addition of new and larger substations following the expansion of demand as cities and suburbs expand further into rural areas. As these systems expand increased high voltage load on the associated transmission lines, as well as increasing fluctuations of the load levels in affected areas, make tracking and maintaining suitable voltage and current levels on pipeline structures more difficult. These scenarios provide a good argument for perpetual, ongoing measurements to assure target values are maintained, and that inadequate performance of the mitigation system does not result in a corrosion risk or safety risk due to unexpected high levels of AC interference.

## SUMMARY

Though a lot of work has been done regarding understanding induced AC corrosion, there is still work to be done in creating a true standard method of evaluating and effectively mitigating the corrosion risk associated with this interference. That noted, over the past decade the industry developed best practices in an ad hoc manner that were codified into the SP21424-2018 standard that provides guidance today. As is the case with many of the standards in our industry, there are several ways to accomplish the desired outcome, and a one-size-fits-all approach may not be feasible. Each area affected by induced AC interference is unique. The combination of variables including coating integrity, voltage and current magnitude, cathodic protection levels applied, soil resistivity, and environmental factors such as precipitation, heat, and cold all factor in to affect every area differently. Awareness of the critical parameters, notably AC density as the most important piece, can direct the user to focus on the factor or factors that most critically contribute to the corrosion risk. Keying in on the most critical variables, and accounting for the effect additional variables have over time provides the best path for ensuring a long-term solution. Focusing on the data and using an aggressive and comprehensive measurement/monitoring cadence provides visibility into the overall effectiveness of the AC mitigation efforts.

## References


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