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Mitigating Induced AC and AC Corrosion on a South Texas Pipeline

Introduction
AC voltage can appear on cathodically protected pipelines adjacent to electric power distribution or transmission circuits. This paper discusses the phenomena, as well as mitigation goals, products, and grounding systems designed for effective reduction of induced AC voltage. Mitigation of such voltage is increasingly important as pipelines are frequently located in common rights-of-way with high voltage circuits.

Case Overview
Two (2) south Texas pipelines shared a corridor with 69kV, 138kV, and 345kV transmission circuits. The pipelines were adversely affected by the various circuits, raising the induced AC touch potentials and AC current densities well beyond acceptable levels during steady-state conditions, as well as unsafe touch and step potentials during fault conditions. ARK Engineering & Technical Services, Inc., located in Braintree, MA, was instrumental in the modeling and design of the AC mitigation system to correct this situation. The identified AC issues were resolved through field analysis, modeling, AC mitigation system design, installation, and subsequent testing.

Electrical Hazards and Effects
AC interference effects can cause safety concerns and pipeline integrity issues that must be considered and addressed. Some of these issues can include electrical shock (to the public and company personnel), accelerated corrosion, arcing to nearby grounded structures and across isolation joints, and steel and coating damage.

Human health hazards can occur during both steady-state and fault conditions.

Steady-state hazards include unsafe touch voltage, while AC fault conditions can raise these touch values excessively, as well as introduce step voltage risks.

Touch voltage is the potential difference between a person's body, contacting a metallic structure, and their feet on the surface of the soil.

Step voltage occurs when gradients in the soil during AC fault conditions are high enough to establish an unsafe voltage difference between a person's two feet. These high AC potentials must be addressed during an AC interference investigation.

While steady-state induction effects would not typically damage equipment or isolation systems, AC faults are capable of causing arcing via the high voltage and current available from a transmission circuit. Faults that are not properly mitigated can result in coating and steel damage, and can result in the failure of isolation joints and electronic systems on the pipeline.

National Association of Corrosion Engineers (NACE) provides voltage limit guidance per Standard Practice SP0177 and recommends that users address induced voltages that exceed 15 Volts.

Induction Phenomena
Alternating magnetic fields associated with the normal operation of three-phase power circuits are the cause of AC induction on pipelines. Load current on each phase conductor has an associated magnetic field, which interacts with nearby metallic structures, such as pipelines. Variables such as load current, phase orientation, phase distance to the pipeline, coating quality, and soil resistivity, among others, all contribute to the overall net induction effect on the pipeline.

Steady-state induction linearly relates to steady-state load current, and pipeline touch voltage measurements, recorded at test stations and above grade structures, are measured under steady-state conditions. Such readings are then compared to the NACE criteria to determine if AC mitigation is necessary. Users could reach erroneous conclusions if not considering several other factors, addressed below.

The AC induction phenomena that produces a steady-state voltage measureable on a pipeline is the same mechanism in effect when an AC fault event occurs, however the electromagnetic forces and resulting AC current are drastically higher, producing values far in excess of the NACE criteria. Fault conditions therefore must be examined, even when steady-state voltage measurements yield only modest values below the NACE criteria. A second issue involves the varying nature of circuit load currents, which affect pipeline voltage readings taken at different times of the day. Therefore, datalogging over an extended period captures the varying inductive AC voltage conditions. Finally, seasonal soil resistivity changes will also affect the resulting pipeline voltage due to induction effects.

Mitigation Methods
The general technique for mitigating induced AC voltage is to

connect the pipeline at appropriate locations to a suitably low impedance grounding system in order to collapse the voltage to a safe level, as determined by modeling and analysis.

Typical AC mitigation grounding locations include:

- Where the pipeline enters, exits, or changes position within a right-of-way with an electric circuit
- Where there are changes in pipeline coating characteristics, such as a well-coated to a poorly-coated pipeline
- Where circuit phases are transposed
- At isolation joints in or near the area of influence

Horizontal AC mitigation grounding systems typically consist of linear bare copper cable or zinc ribbon, buried to the side of the pipeline. Grounding must be accomplished without negatively affecting cathodic protection (CP) systems used for corrosion management. This is accomplished by installing and connecting decoupling devices between the AC grounding system and the pipeline/structure. Decoupling devices (or decouplers) block direct current (DC) from CP systems while conducting induced AC to the grounding system, thus reducing the AC interference effects. Decouplers are also rated for various levels of AC fault current and lightning surge current, as these are expected field conditions. Induction modeling and analysis determines the expected fault current values that can affect the pipeline, and can be used to select the decoupler rating.

Case Study Conditions
This case involved two parallel pipelines, 4" and 18" diameter, both approximately 30 miles (48.3 km) long. These lines had fusion bonded epoxy (FBE) coating and were parallel with numerous overhead 3 phase AC transmission circuits. For modeling purposes 2,000A was used as an assumed worst case load current condition, as utility data was not available. The two pipelines were being adversely affected by the induced AC effects during normal electric circuit operation (steady-state conditions), and the client was also concerned about high AC step/touch potentials and coating stress during possible fault conditions. Due to the complexity of designing effective AC mitigation systems, the pipeline operator enlisted the services of ARK Engineering and Technical Services, Inc. to analyze, model and design the AC mitigation system.

ARK Engineering and Technical Services, Inc. is a full service engineering firm providing AC interference modeling, AC mitigation services, and cathodic protection and design services.

Project Goals

1. Reduce steady-state AC touch potentials on the pipeline to less than the 15V NACE criteria.
2. Reduce the AC touch and step voltages near the pipeline during fault conditions to levels below those specified by ANSI/IEEE 80, to protect the public and pipeline personnel.
3. Reduce fault-induced coating stress voltages to less than 5,000 Volts, to protect the pipeline coating system from damage – a value consistent with industry practices, and per the client's project requirements.
4. Reduce the AC density through coating holidays (defects in the coating) on the pipeline to less than $20A/m^2$ to prevent AC corrosion effects, per industry practice and the client's goals. Typical industry practices are to limit AC current densities as follows:

   a. With AC current densities less than $20A/m^2$ there is a lower likelihood of AC induced corrosion.

   b. AC corrosion has a moderate likelihood of occurrence for AC current densities between 20 – $100A/m^2$.

   c. AC corrosion has a higher likelihood of occurrence for AC current densities greater than $100A/m^2$.

Figure 1: Example of AC corrosion

Modeling the AC Mitigation Solution
The pipe-to-soil AC voltages recorded during annual surveys in 2013 and 2014 indicated that induced AC pipeline potentials exceeded the limits of 15Vrms, outlined in NACE SP0177. Since induced voltage varies based on a number of factors, modeling was needed to examine all steady-state and fault conditions on these pipeline segments. One immediate concern from the modeling was possible future fault conditions exceeding the ANSI/IEEE 80 touch and step voltage criteria. Modeling was performed at all valve sites and other above ground facilities. The analysis determined that the step and touch voltages were below the safe limits and additional AC mitigation was not required at these sites.

The maximum steady-state induced potentials on the pipelines, based on worst case electric circuit conditions, were computed to be 481 Volts and 610 Volts. These worst case conditions indicated that AC mitigation was necessary. Additional modeling and analysis associated with this AC mitigation system design determined that these peak AC interference locations could be reduced to less than 5 Volts.

The modeling and analysis computed the maximum AC current densities on these pipelines. This analysis determined that the AC density values could well exceed acceptable criteria during worst case conditions on the electric circuits. AC mitigation methods could reduce the density values to less than the project design limit of 20 A/m^2 .

Table 1 shows modeled AC density values for steady-state conditions.

Pipeline	Mitigation Status	Pipeline Station Number	Maximum Current Density (A/m^2)	Design Limit (A/m^2)
4”	Without AC Mitigation	668+20	255	20
4”	With AC Mitigation	668+20	19.00	20
18”	Without AC Mitigation	754+60	178	20
18”	With AC Mitigation	754+60	16.73	20

Table 1: Modeled AC density for specified conditions

Installation Design

The proposed AC mitigation system design, (installed in 2016), consisted of approximately 68,630 feet of zinc ribbon grounding conductor, installed horizontally, in various segments along the two (2) pipelines.

Figure 2: Typical installation of zinc mitigation system

In addition, a total of 214 zinc ground rods, 10 feet long, spaced at 10 foot intervals, were installed at 13 locations along the pipelines.

Seventy-five (75) Dairyland model PCR-10KA decouplers were connected between the pipeline and the zinc grounding conductor, isolating the zinc grounding system from the pipeline. Pedestals were used to house the PCR units along the pipeline right-of-way.

Solid state decouplers are designed to provide a continuous path for AC current to flow, while blocking the flow of DC current under normal operating conditions. Decouplers provide protection to the public, personnel, and isolation systems while not compromising the cathodic protection system. Dairyland’s solid state decouplers were specifically recommended by ARK Engineering, due to their demonstrated reliability and durability.

“ARK Engineering included the Dairyland Electrical Industries solid state decoupler (PCR-10KA) in our design, to reduce the AC interference effects on the pipeline, by acting as an AC current drain path from the pipeline to the zinc ribbon horizontal grounding conductor while blocking the DC current used for cathodic protection from leaving the pipeline at these locations,” explains Robert Allen, Founder and President of ARK Engineering.

Figure 3: Dairyland PCR in MTP-36 pedestal (with cover removed) on AC mitigation project along high voltage AC right-of-way

Figure 4: Plowing application of linear zinc mitigation system

Solid state decouplers automatically switch to the conduction mode during AC fault conditions, lightning strikes and device failures. This mode permits AC and DC current to flow. Dairyland decouplers are designed reset to the AC closed/DC open operating mode after each event.

Testing After System Installation

Measurements were recorded after installation of the AC mitigation system and again during the 2017 annual corrosion control survey to verify the operation of the AC mitigation system and correlate this field data with the modeling results. This field data included AC measurements along with the typical cathodic protection system testing.

All recorded measurements were determined to be significantly below the project's design limit and safety limit. Reference Table 2.

Pipeline	Mitigation Status	Pipeline Station Number	Maximum Induced Potential (V)	Design Limit (V)
4”	Modeled peak condition without mitigation	668+20	481	15
4”	Measured, with mitigation	668+20	1.86	15
18”	Modeled peak condition without mitigation	754+60	610	15
18”	Measured, with mitigation	754+60	2.36	15

Table 2: Field measurements verifying effective voltage mitigation

AC Mitigation Study Conclusions

AC mitigation systems were designed to effectively reduce the induced AC interference effects and AC density levels on these pipelines to less than the transmission company's design limits.

Computer modeling and analysis, using peak load currents on electric transmission circuits, can accurately predict induced AC potentials, AC touch and step voltages, coating stress voltages under fault conditions, and pipeline AC current densities. AC mitigation modeling should be completed by a reputable engineering firm with the requisite expertise regarding AC interference and AC corrosion effects and experience and knowledge of appropriate AC mitigation designs for the particular environment and location.

Dairyland decouplers were key in meeting the design targets, while preventing CP current exchange with the AC mitigation grounding system.

“Our client is very satisfied with the design and performance of this AC mitigation system,” Allen concludes. “We attribute a lot of this satisfaction to the decision to specify and use the Dairyland Electrical Industries' products as the interface equipment between the pipeline and the AC mitigation systems.”

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