Continuous Verification Monitoring at AC Mitigation Stations

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ABSTRACT

The introduction of high performance, fusion bond coatings provide pipeline structures with excellent isolative characteristics. These high performance coatings are of great benefit to the industry as they increase the efficiency and performance of the cathodic protection systems. However, when pipelines are collocated along high voltage AC power transmission lines, the high dielectric effect of fusion bond coatings may have a detrimental effect resulting in induced AC voltage. These induced voltages may create safety hazards to operating personnel and the general public and are known to cause corrosion at varying voltage levels and operating environments.

It is essential to design and install an adequate grounding system capable of lowering and maintaining induced AC voltage at safe operating levels, and ensuring that AC currents discharging to the soil at coating faults are not exceeding current densities known to cause corrosion. Due to the variables affecting induced AC voltage and AC current levels, and the potential safety concerns of exceeding permissible levels, continual verification of the effectiveness of the AC mitigation system is a necessary part of a complete AC mitigation solution.

Methods of tracking these levels through periodic measurements or data logging at test-point sites provide an incomplete picture with data retrieved after the fact rather than real time. Tests were done with remote monitoring equipment designed to capture induced AC voltage fluctuations in real-time and send immediate notification of out-of-range readings, as well as continually logging the readings in the internal memory for upload retrieval over the web at user defined intervals. The conclusion is this method of benchmarking and verification of AC mitigation performance provides superior information through the transmission of actionable alarm data and increased frequency of logged data retrieval. This method is designed to be a permanent, ongoing verification of mitigation system effectiveness as the influences contributing to AC induction on pipelines continually change.

Key words: Induced AC, AC Corrosion, AC Mitigation, AC Corrosion Current, Fusion Bond Coating, Remote Monitoring, Cathodic Protection

INTRODUCTION

This paper illustrates the issues involved in evaluating the risk of corrosion from induced AC voltage on buried pipelines, and the challenge of verifying the effectiveness of AC mitigation over time. The pipelines studied in this analysis were known to have induced AC from numerous crossings and shared right of ways with high-voltage overhead transmission lines. AC mitigation was deployed, reducing the voltage levels to below the NACE safe-touch recommendation of 15VAC. Voltage monitoring used at that time showed that the reduced AC voltage levels were still very erratic, and subject to wide fluctuation due to demand load changes, and ground faults on the power transmission system. Recently, the focus has shifted from the AC voltage level to the AC current density per meter squared. This was due to increasing concern in regards to the possibility of AC corrosion on the pipelines. A target level of <20 A/m² of AC current density was established to reduce the likelihood of AC corrosion. A system of continuous measurements of AC levels at test stations in the affected areas was devised in order to account for the fluctuations of the AC levels and to provide timely notification of out of normal range AC levels.

Induced AC voltages with respect to ground potentials develop as a result of capacitive, electromagnetic, or inductive affects (Gummow).[1] The magnitude of the induced voltage depends on many combined factors including: the voltage and current load generated on the power lines, tower dimensions, separation distance of the pipeline from the power lines, soil resistivity, coating conductivity, the distance the pipeline runs parallel with the power line and whether the power line is experiencing a fault or large transient surge associated with a switch on. Voltages may also be induced conductively where large currents flow in the ground as the result of a fault at a transmission tower, a lightning discharge, or where a severed power line comes in contact with the ground.

Seasonal changes affect the current demand on the power transmission lines changing the inductive effects on collocated pipelines. The failure of the AC grounding system on the pipeline could also cause significant changes in AC voltage levels on the line. As a result of this, induced voltage levels may fluctuate to the point that there is a threat to personnel safety. Additionally, the fluctuations raise concerns that AC corrosion currents could develop undetected.

The presence of induced AC voltages on the pipelines operated in this region has been known for years. AC mitigation systems on these pipelines have focused on the public safety criteria of reducing the voltage levels to below 15 volts. Once acceptable voltage levels were achieved, the typical ongoing monitoring of the operational integrity of mitigation systems consisted of periodic readings of the AC voltages at test stations. As corrosion attributed to AC discharge at coating faults was discovered on pipelines in this region, the focus of mitigation shifted to maintaining current density levels below the level at which corrosion is understood to occur. Prinz summarized a decade of laboratory work and field observations establishing what has become the generally accepted criteria in the industry for AC current density levels in regards to corrosion on steel structures (Table 1).[2]

Table 1
Expectation of AC induced corrosion at varying current densities.

AC current densities <20A/m²	No AC induced corrosion occurs
AC current densities >20A/m² and <100A/m²	AC induced corrosion is unpredictable
AC current densities >100A/m²	AC induced corrosion to be expected

The same studies showed corrosion rates are highest at holidays with a surface area between 1cm² and 3cm². These criteria were used in establishing mitigation target levels on the pipelines used in this field study.

FIELD STUDY

The field study was done in two phases on separate pipelines. The sites selected for the first phase of the study were on a newly constructed fusion bond coated, 20-inch (50.8cm) diameter pipeline located in Northern Illinois. The pipeline is collocated with overhead high voltage transmission lines in two separate locations. The first collocation runs approximately four miles from MP 146 to MP 150, second collocation from MP 155 to MP 167. The pipeline is parallel with one double delta circuit configuration at 345kV. The overhead circuits induce voltages in excess of the NACE safety criterion of 15 volts during steady state operation fluctuating between 40 and 77 volts (Figure 1). The test sites were located at MP 159 and MP 163 where the highest AC values were measured.

Figure 1: AC transmission lines on the pipeline right of way.

Pipeline construction was completed 3-months prior to the installation of the impressed current cathodic protection systems, and the AC mitigation systems were in the design phase. During this time a coating inspection survey was conducted using an alternating current voltage gradient (ACVG survey). Coating anomaly digs were done at several locations based on the severity of the test results. The first excavation at MP 162 was prioritized and a total of nine coating faults were found, each contained pits ranging in depth from .025 to .085 inches (.635mm – 2.159mm) and from .025 to .500 inches (.635mm – 1.27mm) in diameter (Figures 2 and 3). The corrosion products as well as the coating surrounding the smaller diameter anomalies were burnt in appearance, the larger anomalies did not display this burnt condition but did have deeper pitting. Additional excavations were conducted and pitting was discovered at each location.

Figure 2: Small coating fault displaying evidence of burnt coating

Figure 3: Larger diameter fault showing deeper pitting.

By means of computer modeling and simulations, the electromagnetic interference environment existing at the pipeline was quantified. Both inductive and conductive coupling to the pipeline were considered in the model. It was found that excessive pipe potentials were induced for both steady state (normal) and transmission line fault operational scenarios. A pipeline mitigation plan was developed consisting of segmented horizontal buried copper conductors, bonded to the pipe thru steady state DC decoupling devices, installed within the collocations located at sites registering high AC voltage potentials. Monitoring equipment was included at two of the locations where decoupling devices were installed.

The monitoring systems were equipped to measure induced AC voltage potential, AC corrosion current, DC pipe to soil potential, DC pipe to soil off potential, and native potential using a dual coupon test station design. All values were read at one minute intervals and stored on 2GB SD memory cards in the monitor devices. The monitor systems were equipped with GSM cellular communication capability and readings were transmitted to the web interface every three hours. Stored data from the devices could be retrieved by downloading the stored readings from the SD cards directly into a computer or by retrieving the logged data through the web interface. The monitors were set to transmit immediate notification of any alarm level readings. The alarm levels for induced AC voltage were set at 15 volts and the alarms for AC current density were set at $20A/m^2$ as measured at $1cm^2$ surface area coupon holidays. The monitor equipment and mitigation systems were installed in integrated enclosures at dual coupon test station locations on the pipeline (Figures 4 and 5). These mitigation systems reduced the steady state pipe voltages to less than 10 volts for normal peak loading of the transmission line circuits.

Figure 4: AC mitigation facility with monitor system.

Figure 5: Mitigation facility installed on right of way.

The first ten AC mitigation facilities were installed on this pipeline between milepost 146.34 and milepost 166.38 in May of 2010. Monitoring equipment was installed in June of 2010 at the mitigation facility locations at milepost 159.24 and milepost 163.53. These two locations registered the highest induced AC voltages on the pipeline. Measurements taken prior to the installation of the mitigation systems showed induced AC voltage >64VAC at milepost 163.53 and >25VAC at milepost 159.24. AC current measurements were >140A/m² at milepost 163.53 and >80A/m² at milepost 159.24. The graphs below, displaying data measurements at the test locations, are generated from the monitor system web interface. The data in the graphs confirmed reduction of induced AC voltage to acceptable levels at these two locations following the installation of the first ten systems (Figures 6 and 7).

Figure 6: Mitigated induced AC voltage on mainline #1 at milepost 159.24

Figure 7: Mitigated induced AC voltage on mainline #1 at milepost 163.53

The measurements of AC corrosion current at these two sites for the same period were in the range of 23A/m² to 45A/m² (Figures 8 and 9). Though reduced significantly from the pre-mitigation measurements, the current levels were still excessive. It is significant that excessive AC corrosion current was present with induced AC voltage levels below 5 volts. Measuring induced AC voltage potentials alone in order to gauge the effectiveness of the AC mitigation system would not present an accurate picture regarding AC corrosion current levels at these locations.

Figure 8: Mitigated AC current on mainline #1 at milepost 159.24

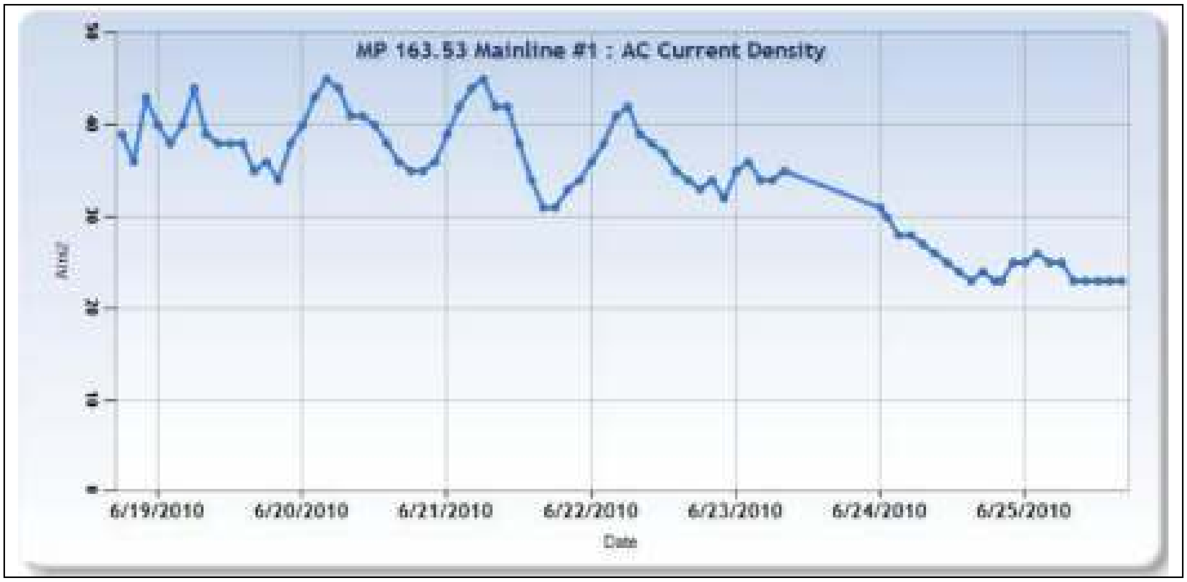

Figure 9: Mitigated AC current on mainline #1 at milepost 163.53

Additional mitigation facilities were installed at milepost 160.92 and milepost 161.60 in this corridor in July of 2010, reducing the AC corrosion current at milepost 159.24 below the >20A/m² maximum acceptable level (Figure 10). The current level at milepost 163.53 remained very close to the 20A/m² range, occasionally spiking above the acceptable threshold (Figure 11). The current level at this location continued to drop in the days following the installation of the last two systems. This gradual change was likely due to the increased ground contact as the backfill settled around the grounding rods at the new installations. The induced AC voltage levels and the AC corrosion current levels have remained within the acceptable range since the installation of the mitigation systems. Alarm limits were set at 15 volts and 20A/m² to provide immediate notification of out of range readings due to changes in the overhead transmission line loads, soil resistivity, mitigation system failure, or other variables affecting induced AC voltage levels.

Figure 10: Mitigated AC current on mainline #1 at milepost 159.24. Installation of additional mitigation devices occurred on 7/20/2010.

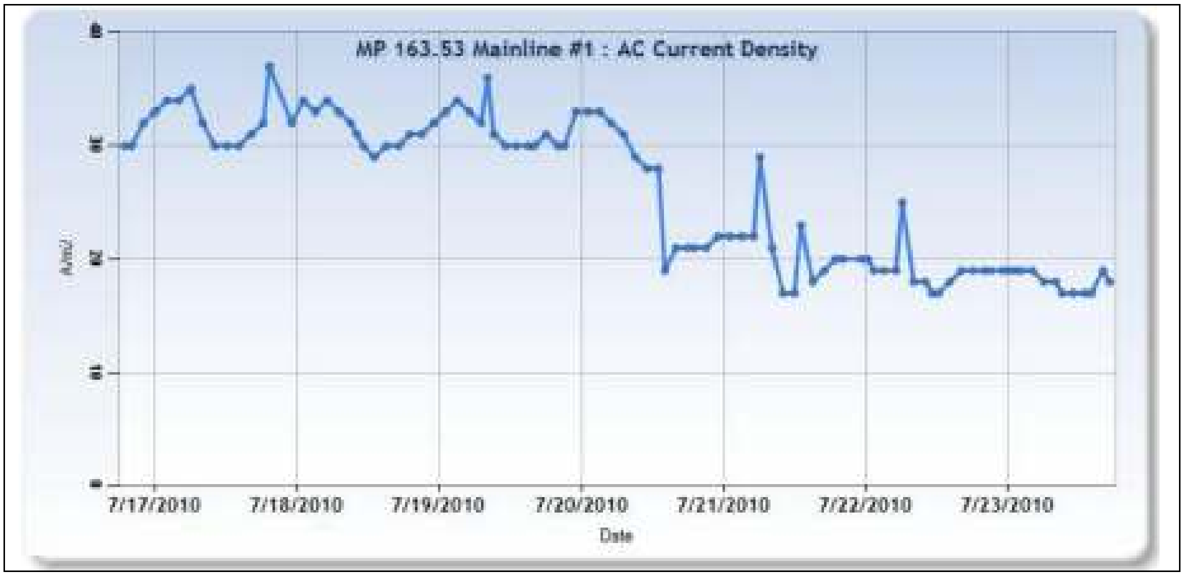

Figure 11: Mitigated AC current on mainline #1 at milepost 163.53. Installation of additional mitigation devices occurred on 7/20/2010.

Mitigation Failure Event Simulation

The second phase of the field study was testing the alarm and notification capabilities of the monitor equipment in the event of significant changes in values or failure of the AC mitigation system. The site selected for this test was on a fusion bond coated 30-inch (76.2cm) diameter pipeline in suburban Chicago. This pipeline is collocated with two 345 kV overhead lines for a span in excess of twenty miles. AC mitigation for the section monitored consisted of a horizontal buried copper conductor, bonded to the pipe thru a steady state DC decoupling device, installed at milepost 452.82. Induced AC voltage at the location prior to the installation of the mitigation system fluctuated between 12 volts and 25 volts, frequently exceeding the 15 volt safety level. AC corrosion current at the location fluctuated between 30A/m² and 75A/m², continually above the target of 20A/m². Monitoring equipment was installed with the mitigation system, as at the locations in the first phase of the field study. The mitigated AC voltage levels recorded continually registered <5 volts and the AC corrosion current level registered <5A/m², both well under the maximum acceptable values. On September 20, 2010 the AC mitigation system at this location was disconnected in order to simulate a mitigation system failure. Recorded values were transmitted from the site hourly during this event.

When the system was disconnected, the induced AC voltage and the AC corrosion current levels both went into the alarm range and notifications of the alarm readings were sent to the technicians administering the pipeline. The mitigation system was reconnected on the afternoon of September 22, 2010, at which time al values returned to the normal, mitigated range. The graphs in Figures 12, 13, and 14, display induced AC voltage, AC corrosion current, and DC pipe to soil values recorded during this test. The induced AC voltage and the AC corrosion current fluctuated cyclically throughout the system failure, reflecting cyclical changes in the load levels on the overhead lines corresponding with the time of day. Peak loads on the electric power transmission system in the afternoon and early evening hours corresponded with increased induced voltage measurements on the pipeline, and lower demand loads over night and in the early morning hours corresponded with lower induced voltage levels.

The voltage measurement in particular is significant, as many of the values recorded during this event were below the safe touch limit, but were not indicative of the voltage level occurring throughout the system failure test. In addition, the AC corrosion current levels registered at the low points of induced AC voltage were significantly above the <20A/m² acceptable value. If verification of the mitigation system was done using periodic measurements of induced AC voltage rather than continual monitoring of the voltage and the current, the conditions produced in this test may not be recognized as a significant event. The DC pipe to soil potential registered no significant change during this test. DC pipe to soil potential is the most commonly measured test point value, but in this test it did not provide any indication of AC mitigation system failure.

Figure 12: Induced AC voltage level changes associated with disconnection of the AC mitigation system at Mainline #2, milepost 452.82

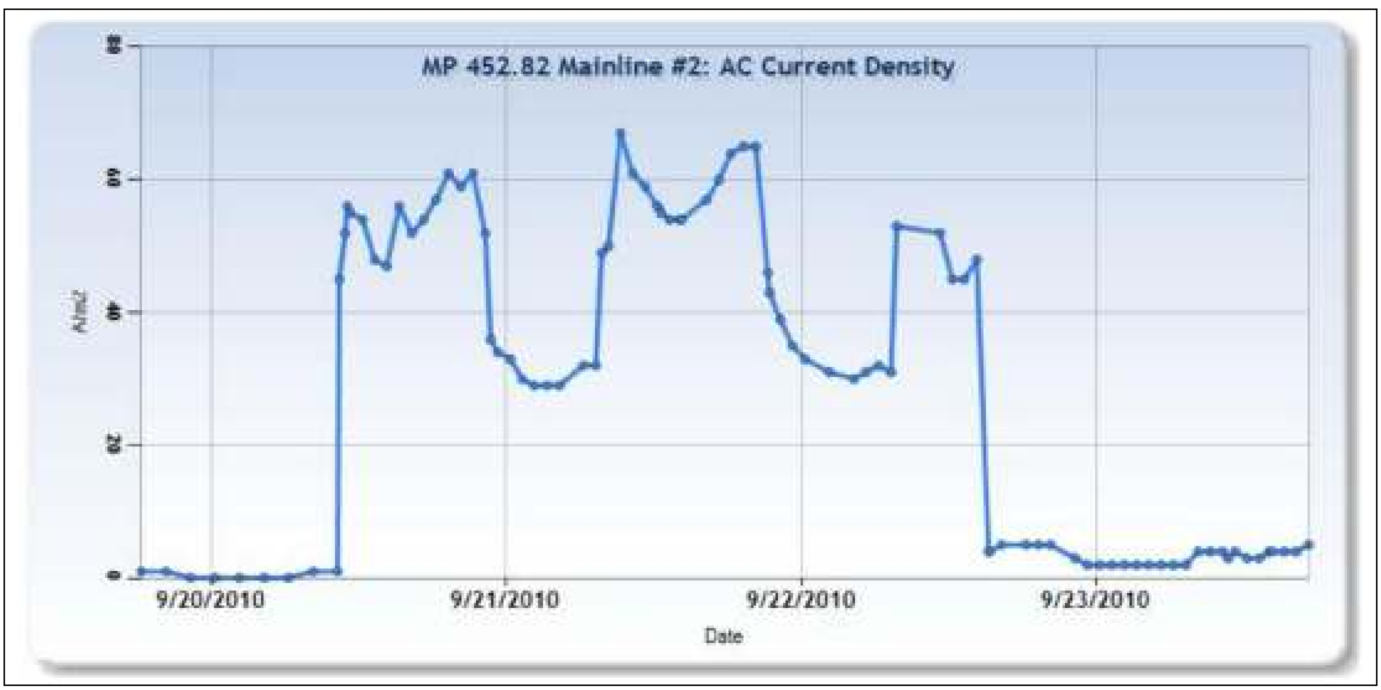

Figure 13: AC corrosion current level changes associated with disconnection of the AC mitigation system at Mainline #2, milepost 452.82

Figure 14: DC pipe to soil potential measurements associated with disconnection of the AC mitigation system at Mainline #2, milepost 452.82

CONCLUSIONS

The 15 volt safe touch standard is the historical benchmark for gauging the effectiveness of AC mitigation systems. Using this measurement alone does not assure the AC corrosion current is also reduced to levels below which corrosion from AC current discharge may occur. A wide range of variables affect the AC voltage and current levels on pipelines collocated with high voltage transmission lines. This combined with the possibility of undetected failure of AC mitigation systems present significant challenges to the pipeline operator. Public safety and pipeline integrity are directly impacted by the effectiveness of AC mitigation systems. Induced voltage potentials in excess of the safe touch level will produce significant shock hazards, possibly over long sections of pipeline right of way. A field study of AC corrosion by Floyd showed excessive AC corrosion current levels to be responsible for very rapid corrosion on new pipelines resulting in multiple leaks even when induced AC voltage potentials were at acceptable levels. [3]

Commonly monitored test point parameters provide no information regarding the performance of the AC mitigation system. Periodic measurement of induced AC voltage potential and AC corrosion current density may provide an inaccurate indication of actual values do to the cyclical fluctuations of induced voltage potentials.

Continual monitoring of induced AC voltage potential and AC corrosion current density in this field study provided an accurate view of AC mitigation system effectiveness. Immediate notification of out of normal range values provided the pipeline operator with the necessary information to respond quickly to system anomalies. The perpetual data record allows the operator to review and graph data over time. Data trends are easily produced and proactive responses to changes can be planned and instituted. Continual monitoring of both induced AC voltage potentials and AC corrosion current density should be included as part of any comprehensive, effective AC mitigation system design.

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