

**AC POWER INTERACTIONS WITH PIPELINES –
The “Usual Suspect,” The Ugly Geology, and, Finally, The Weird:
Faulty AC Power Conditioning Capacitors Interacting with Well-Coated Pipeline**

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ABSTRACT

This presentation describes the influence of local soils, geology, and even shallow ground water in AC power induction on well-coated steel pipelines. It evaluates medium-voltage AC (MVAC) power lines causing pipeline interactions, in addition to the high-voltage AC (HVAC) power lines usually suspected. It discusses influence from complicated MVAC (and possibly pipeline) geometries. Finally, it describes the use of AC power distribution capacitors used for power conditioning, and a highly unusual interaction identified, between a well-coated steel pipeline and a faulty capacitor.

Key Words

High-Voltage AC, HVAC, Medium-Voltage AC Power, MVAC, AC Distribution, Induction, Induced AC, Power Capacitor, Phase, Voltage, Artificial Lift, Motors, Rotating Equipment, Soil Resistivity, Shallow Geology, Ground Water

INTRODUCTION

In 2018 and 2019, our staff studied AC power system interactions with three different and newer, well-coated steel pipelines, all located in a common area in West Texas, USA. The interactions varied considerably, showing how soil and shallow geology attributes, complicated geometric patterns of power lines versus pipeline(s), and the types and sizes of power systems and various devices used on such AC power systems all contribute to induced-AC power loading to pipelines.

Such AC power loads create risks both from personnel safety and AC-induced corrosion standpoints. Field measurements and on-the-ground observations are crucial to understand such complexities, and then to choose the appropriate modeling approaches and software/expertise, mitigation designs, and then installation and commissioning of AC mitigation systems.

The three cases all lie within a 15-mile (24.1-kilometer) radius in Martin County, West Texas. This is an area with limited population. It does, though, have heavy agricultural production,

some of which uses irrigation by ground water from water wells, and tremendous crude oil production, natural gas production, compression, and pipelining operations. There are many different facilities present related to energy production, storage and transportation, with thousands of AC power services and motors in use. In August 2019, Martin County, Texas was the third-largest crude-producing county in Texas by volume.¹

Yet another set of major electricity uses involve salt-water disposal (SWD) wells and facilities. Many such facilities are found in Martin County, all of which use large-power “rotating equipment” frequently made up of 480-volt, three-phase AC electric motors and pumps.

FIELD OBSERVATIONS AND MEASUREMENTS

Case #1, The “Usual Suspect” – a new 10-inch-diameter (25.4-centimeter) pipeline was laid in 2018 along 345,000-volt AC (or 345-kV) lines and 138-kV power lines, but changes in topography from higher ground to low drainage areas, soils and moisture contents, geology and chemistry have caused different expression of AC power interaction along 12 miles (19.5 kilometers) or more of pipeline right-of-way length.



Figure 1: Map and AC Power Line Layout for 10-inch Pipeline, Case 1

Five data loggers were set at different locations, with a portable copper/copper sulfate reference cell buried in soils at each location. For five weeks in November-December 2019, DC “structure-to-soil” (S/S) voltages, AC S/S voltages, and ambient temperature were collected at one-minute intervals. Data obtained is shown in graph below, with significant variations in AC S/S voltages at each data logger over this period of time:

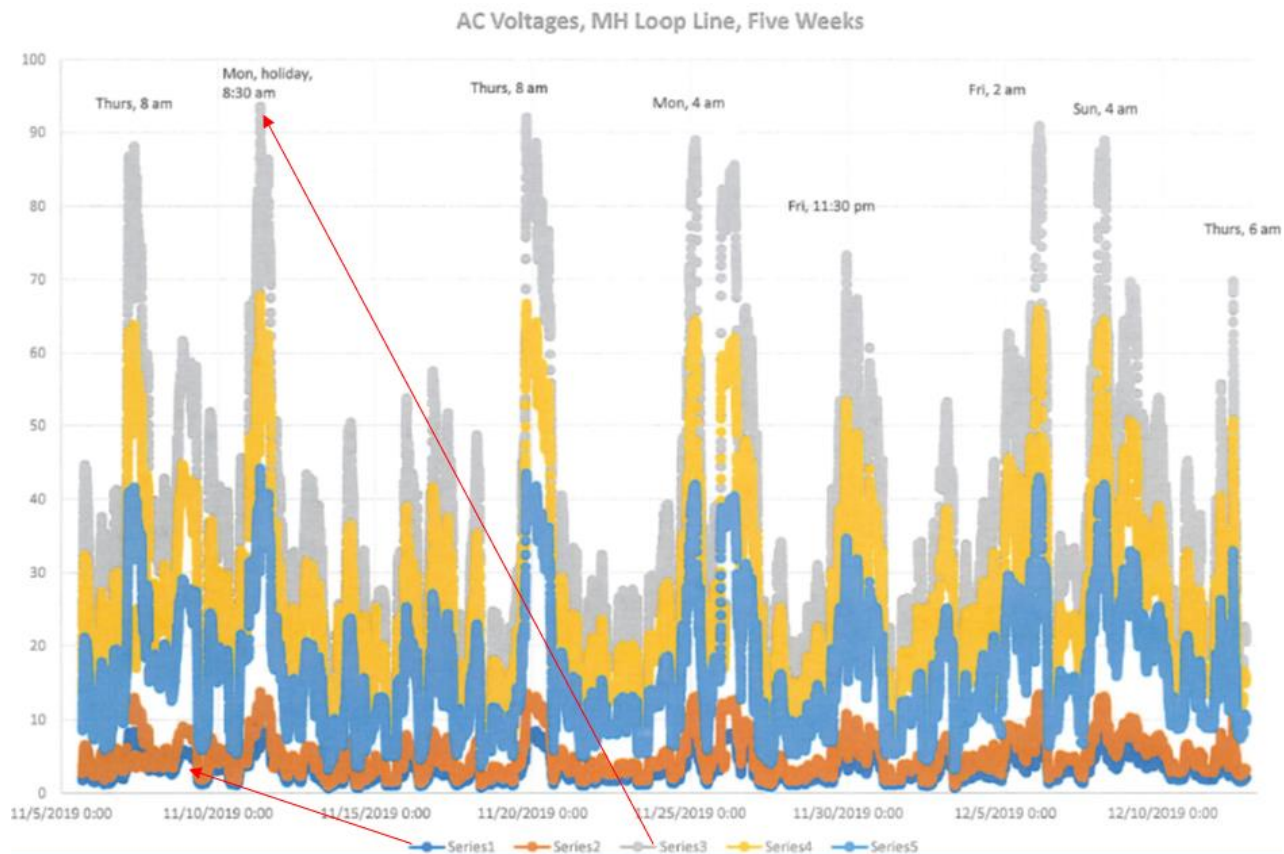


Figure 2: Graph of AC Voltages Measured at Five Data Logger Locations, Case 1

The east end of this 345-kV alignment, with Data Logger (DL) #1 (darker blue at bottom of graph, and “Series1” in legend) has salty soils in drainage area with the intermittent creek called Sulphur Spring Draw, and much lower AC voltages measured, structure to soil. This is likely an AC current discharge area, with very low soil resistivity found (at 2.0 ohm-meters), and wet ground on a frequent basis in the Draw topography. DL #2 in brown-orange color also had relatively low AC voltages, and lay not more than a quarter mile (400 meters) west of the same Sulphur Spring Draw discharge area.

At west end of 345-kV alignment, the power lines (red line in map above, Figure 1) come up from south, then turn east to come into dead parallel with the 10-inch Crude Line. DL #3 was positioned there (follow arrow from legend “Series3” to gray-colored data set). This 345-kV high line interconnects the El Paso, Texas market with the Dallas-Fort Worth market, and must have widely varying loads on it. These loads do not show the usual weekday early morning and evening residential peak loads, but rather have some erratic (by “clock” and “calendar” evaluations) highs and lows for induced AC voltages.

The 138-kV power line is probably carrying a large regional load. DL #4, of goldenrod color, showed second-highest voltages on average. Its variations, though, track the 345-kV line load changes to a great degree. As a further observation, induction from both power lines onto the pipeline was/is very significant a few miles further west of the 345-kV turnout away from pipeline. Power on the 345-kV HVAC line might easily be five to 20 times larger a load, on average, compared to the power on the 138-kV line. No information was obtained from the regional power distribution entity, and that is an ongoing research need.

There are two major risks to this pipeline, in relation to the induction and buildup of AC power on the pipe metal. Safety is the first factor. If AC voltages are present at 15 V or greater (this is judged to be the maximum “safety” voltage in NFPA⁽¹⁾ industry standard), then mitigation of AC induction must be done just to protect the safety of workers and the public, at every possible “touch” point, or where a surface soil voltage fault gradient might cause a “step potential” hazard.²

The second major risk to the pipeline is that of AC-induced corrosion. The published equation by NACE⁽²⁾ for determining “risk” of AC corrosion on well-coated pipelines is as follows:³

- Assume a holiday in otherwise competent fusion-bonded epoxy (FBE), or possibly other coating at girth welds, of one centimeter in approximately circular diameter, or of a surface area of about one square centimeter (assumed to be the worst-case holiday size for maximum AC current density to occur, and stated as 0.0113-meter holiday diameter);
- Measure or otherwise estimate the average soil resistivity along the subject pipeline, for portions of line that show strong AC interaction;
- Assume that AC-induced corrosion is aggravated by low soil resistivities, including what may be high soluble ion concentrations, and by the presence of good-quality fusion-bonded epoxy (FBE) or similar coating on the pipeline.

The equation is:
$$I_{ac} = 8 * V_{ac} / (\rho * \pi * \text{diam}) \quad (1)^4$$

Where I_{ac} = the current density related to AC power induced on pipeline

V_{ac} = AC voltage on pipeline

ρ = soil resistivity in ohm-meters

π = the constant 3.14159 . . .

Diam = approximate circular diameter of holiday in coating, in meters

Results of calculations are interpreted as follows:

1. For I_{ac} less than 30 amps per square meter (A/sq m) as a time-weighted average and when DC current density exceeds one A/sq m, the risk of AC-induced corrosion is low;
2. For I_{ac} greater than 100 A/sq m and DC current density is less than one A/sq m, the risk of AC-induced corrosion is significant.

Soil resistivities were quantified by Wenner Four-Pin field testing near each data logger location, and compared with information provided by the USDA NRCS⁽³⁾ on-line “Web Soil Survey” database across this 12-mile portion of the pipeline alignment.⁵

In the table below, data logger results are shown including highest AC voltage measured, soil resistivity measurement at approximate pipe depth nearest each data logger position, the AC current density calculated from highest AC voltage, and then a ratio of the highest current density divided by the 30 A/sq m threshold of general AC corrosion concern. Farther right, an estimate of the “High Average” of AC voltage is given, at 70 percent of the

⁽¹⁾ National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts, USA 02169-7471

⁽²⁾ NACE International, 15835 Park Ten Place, Houston, Texas, USA 77084

⁽³⁾ United States Department of Agriculture Natural Resources Conservation Service, 1400 Independence Avenue SW, Washington, DC, USA 20250

highest voltage, followed by the AC current density calculated using that “High Average” voltage, and the ratio of “high average current density” to the 30 A/sq m threshold of concern.

	DL #	High VAC	Rho, ohm-m	High lac	lac/30 Ratio	"High Ave" VAC	"High Ave" lac	High Ave lac/30 Ratio
Location, East to West:								
E of Drainage w/Salt	1	11	2	1,239	62.0	8	901	45.07
Valve Pen N of 846	2	20	56	80	4.0	10.7	43	2.15
AC PI at 137 and FM 846	3	93	90	233	11.6	63.5	159	7.95
1.0 mi E of 829, CR 3101	4	72	68.5	237	11.8	51.2	168	8.42
ME-12 Xing W of 829	5	45	90	113	5.6	31.9	80	3.99

Figure 3: Table of Calculations for Critical Parameters at Five Data Logger Locations, Case 1

A mitigation need or design should not be based on the highest instantaneous voltage numbers. Rather, a “weighted average” approach is used, calculating the “High Ave” voltages by considering all data points over time. These typically fall in the range of 50 to about 70 percent of the highest instantaneous AC voltages found. Note, too, that there was no cathodic protection applied yet to this new pipeline, during the AC measurement work described. When CP is added, AC-induced corrosion rates will likely increase.

There were significant “swings” in the AC voltages apparently related to either high-load or “nearly no load” conditions on the 345-kilovolt (kV) power line. It is likely that the 138-kV power line carries loads that are generally higher over time, whereas the variability on the 345-kV line is pronounced. Future field work will include performance of “Longitudinal Electric Field” (LEF) strength measurements under each phase wire, and measurement of “electromagnetic field” (EMF) at designated points under the high line sets.

Measurements taken at DL Sites 3, 4 and 5 all indicate a concern for personnel safety as well as moderate to very high risk of AC-induced corrosion. While the numbers at sites 1 and 2 do not appear as high, on a voltage basis, soil resistivities in this area are exceptionally low due to naturally occurring salts and elevated moisture contents in local soils. Because the soils are more electrically conductive, the built-up AC power on the pipeline is “leaking off” through small holidays in coating to the earth. At each of these locations, AC-induced corrosion is likely taking place. It is then a question of the size of each holiday and the amount of AC current leaving, as to the severity of AC corrosion at such defects. The comparison of AC current densities to the 30 A/sq m threshold gives a sense of the likelihood that formal mitigation is needed. At the valve pen north of FM 846, DL #2 location, with a comparison factor of only two, mitigation might be avoided. When extensive mitigation called for across the Sulfur Spring Draw “likely AC discharge area” is installed and working, the induced AC load at the DL #2 area might be reduced sufficiently that no local mitigation is needed in that part of the corridor. But much more field work is called for before such decisions are made.

Another very important consideration is measurement of induced AC voltages at test points outside the “in parallel” run of pipeline and power lines. The worst-case power induction onto the pipeline is often not where the power lines and pipeline are in direct parallel but rather when the geometry of pipeline to power line changes. It is likely, therefore, that the point “DL3” is one of the worst interaction areas through the 12-mile (19.5-kilometer)