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AUCSC
Appalachian Underground Corrosion Short Course

Induced AC Interference & Mitigation

Bryan Evans, Pond & Company

May 10, 2023

About the Speaker

Bryan Evans, E.I.T.
Pond & Company – Executive Vice President | Energy

B.S. Civil Engineering Technology

- Certifications
  - Cathodic Protection Specialist – No. 9754
  - Sr. Corrosion Technologist – No. 9754
  - Internal Corrosion Technologist – No. 9754
  - Coating Inspector Level 1 – No. 21458
  - API 570 Piping Inspector – No. 80649
- 25+ years of experience in corrosion control, cathodic protection, pipeline integrity and AC mitigation both as a design consultant & installation contractor.

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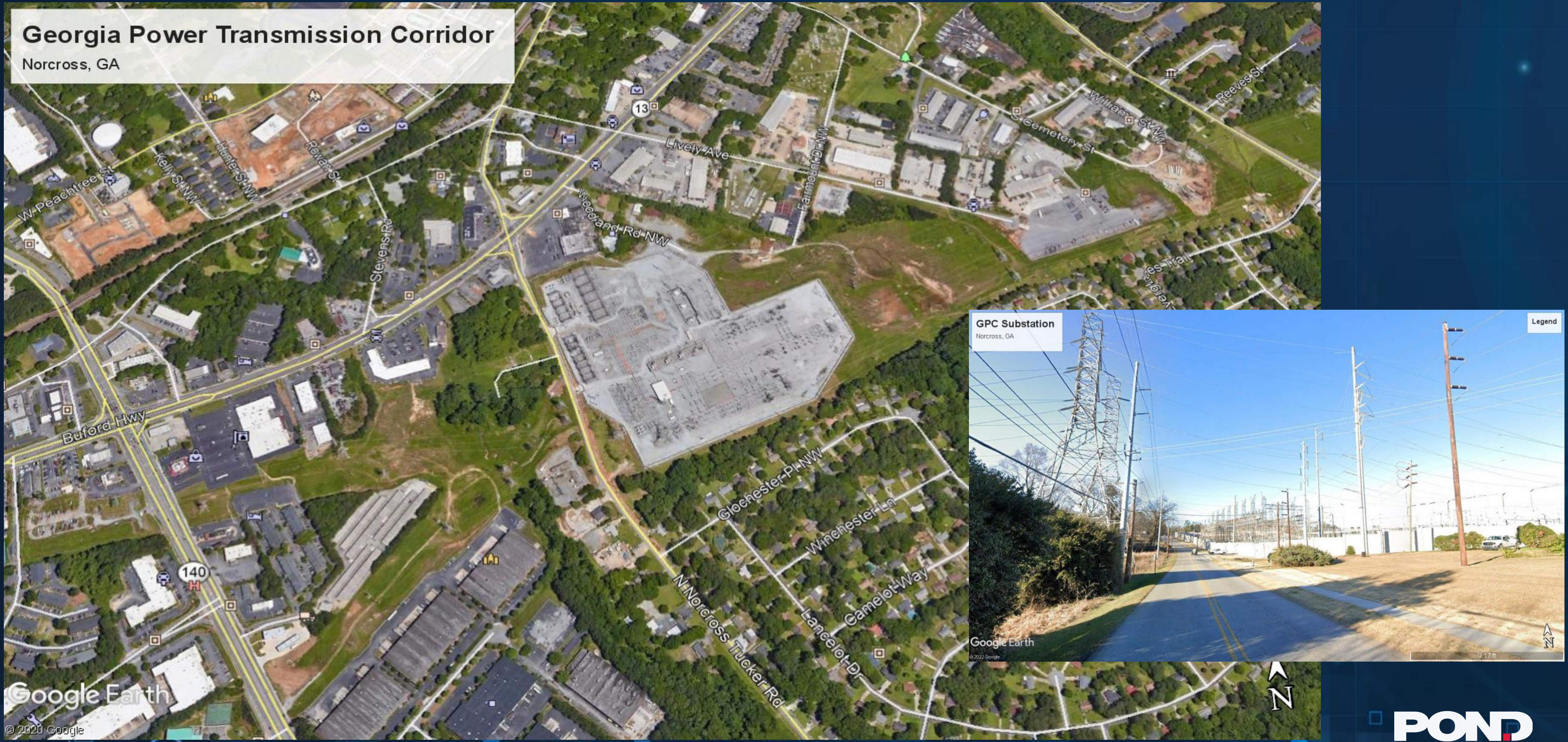
Agenda

- ❑ Why the Problem?
- ❑ Basic Power Transmission
- ❑ Induced AC ROW Safety
- ❑ Assessing the Problem
- ❑ AC Corrosion
- ❑ AC Interference Modeling
- ❑ AC Interference Mitigation & Testing
- ❑ Over Design Issues
- ❑ Case Studies

Why the Problem?

The Issue Congested - Shared Right of Ways



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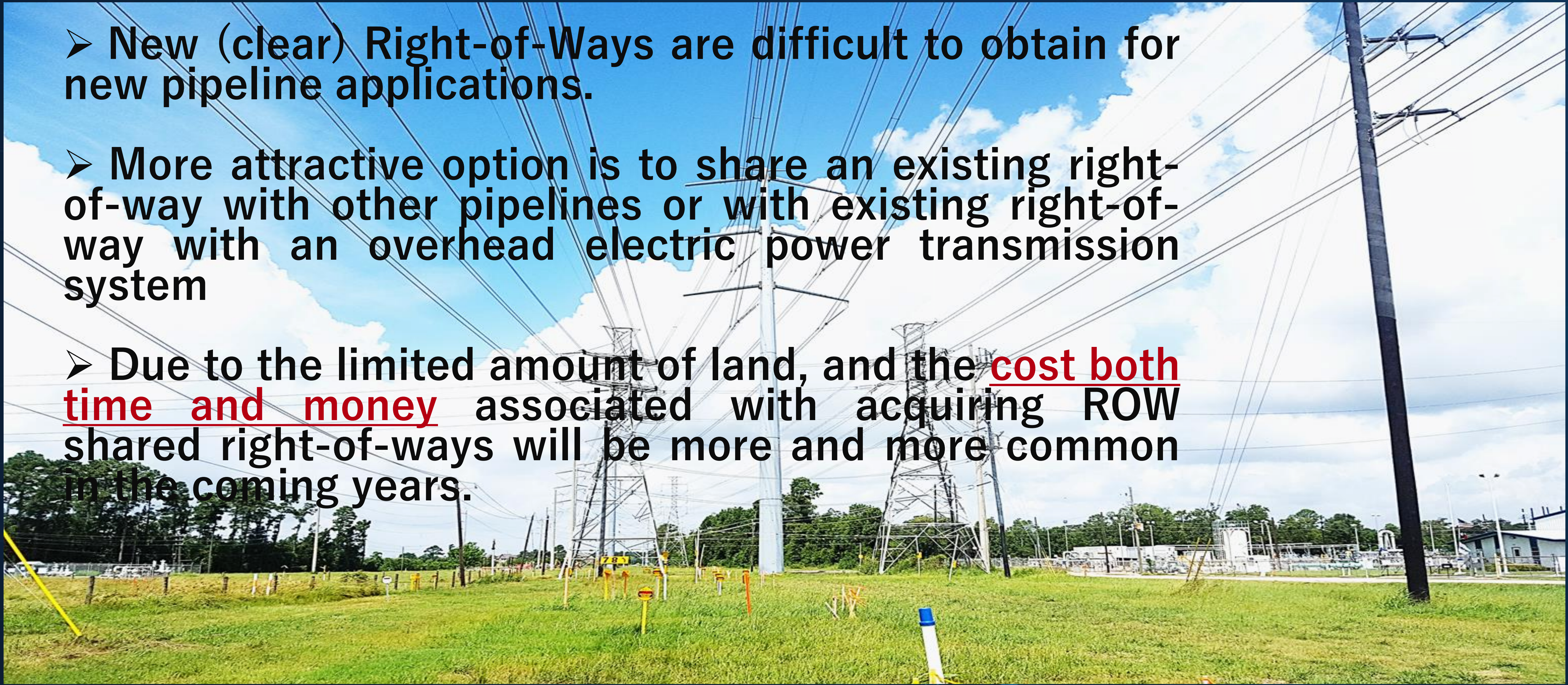
Shared Right of Ways

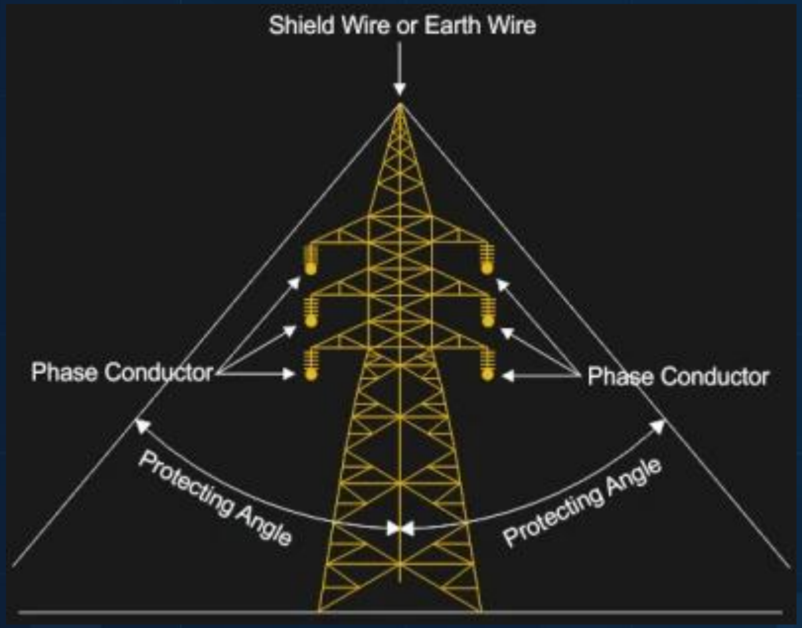


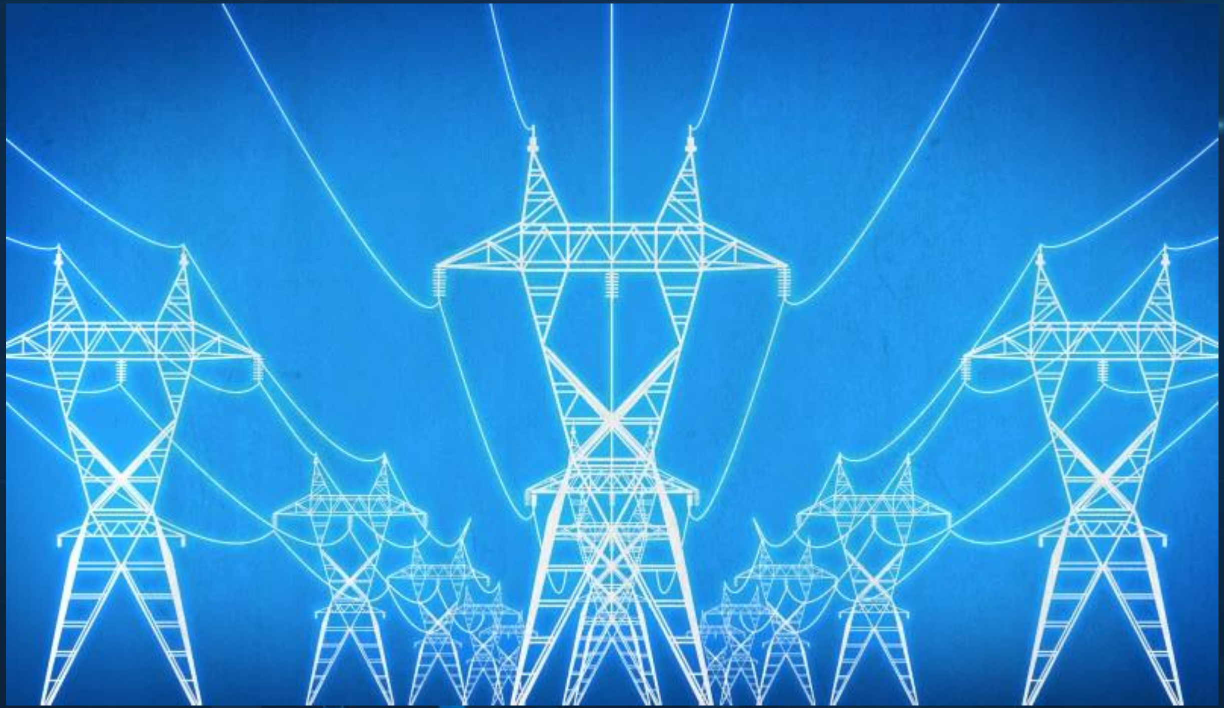
- New (clear) Right-of-Ways are difficult to obtain for new pipeline applications.
- More attractive option is to share an existing right-of-way with other pipelines or with existing right-of-way with an overhead electric power transmission system
- Due to the limited amount of land, and the cost both time and money associated with acquiring ROW shared right-of-ways will be more and more common in the coming years.

AC Interference

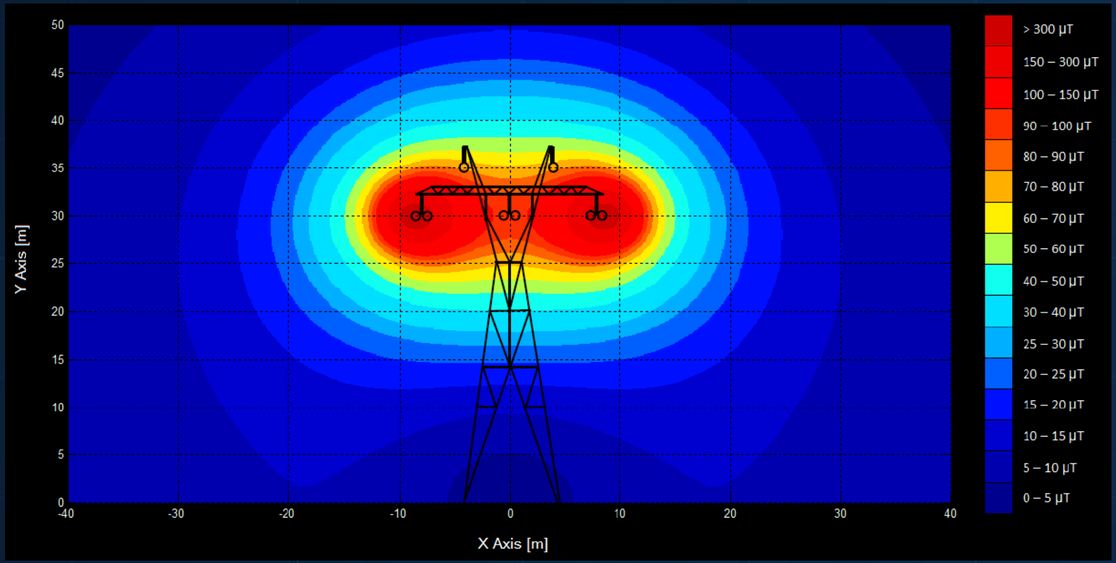
A pipeline can experience AC interference as a result of being in the proximity of any AC power line. However, the vast majority of interference problems are created by *three-phase (3φ) power transmission systems* and the *magnetic fields* they create.

A 3φ power transmission system consists of three energized conductors,. Each conductor has approximately the same voltage to ground, and each carries approximately the same amount of current.

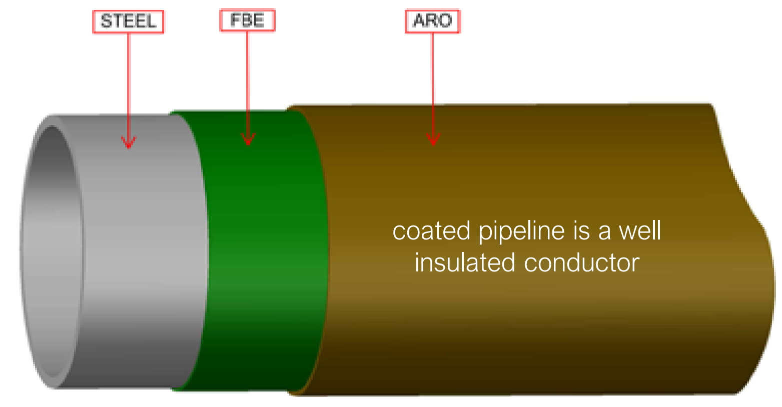




AC Interference | Why Does it Occur?



Electromagnetic Fields (EMF) High Voltage Power Lines

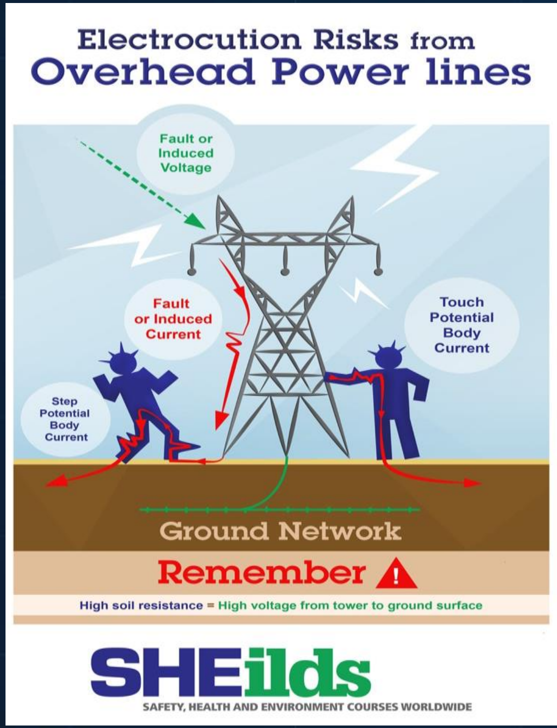


The **Right Hand Rule** simply shows how a current-carrying wire generates a magnetic field

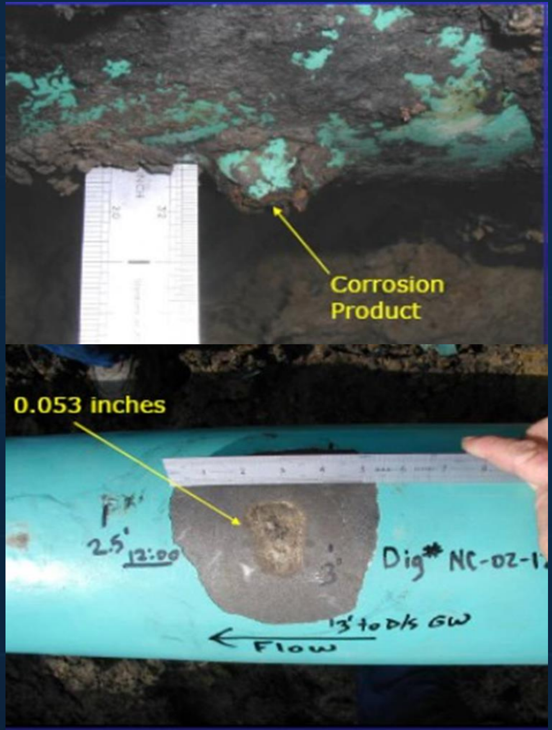
- point your thumb in the direction of the current and let your fingers assume a curved position, the magnetic field circling around the wires flows in the direction in which your four fingers point.
- Fleming's right hand rule (for generators). The appropriately-handed rule can be recalled by remembering that the letter "g" is in "right" and "generator"

Why is AC Interference A Problem?

Potential of Personnel Safety Issues (15 V_{AC})



Potential for AC Corrosion



Potential for Coating Damage

Potential for Pipeline Damage

Metal loss due to AC currents ~ *2.0 lbs/amp-year* *(~10% (21 lbs/amp-year) of DC current metal loss)* ; but the magnitude is potentially much higher. Especially, in ground fault conditions.

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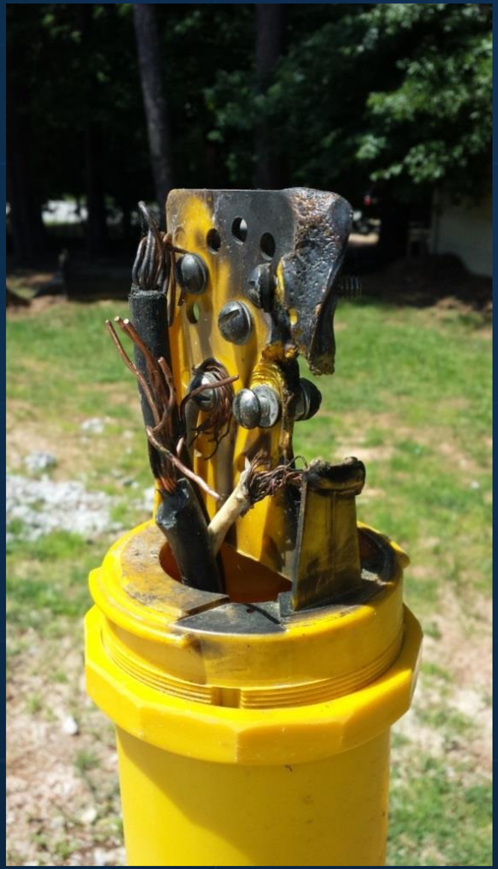
Primary Focus | Personnel Safety & Avoiding Pipeline Failures



Primary Focus | Personnel Safety & Avoiding Pipeline Failures

For natural gas alone, the Pipeline and Hazardous Materials Safety Administration (PHMSA), a United States Department of Transportation agency, has collected data on more than 3,200 accidents deemed serious or significant since 1987.

A "significant incident" results in any of the following consequences:

- ❑ Fatality or injury requiring in-patient hospitalization
- ❑ $50,000 or more in total costs, measured in 1984 dollars
- ❑ Liquid releases of five or more barrels (42 US gal/barrel)
- ❑ Releases resulting in an unintentional fire or explosion.

TWENTY-THREE (23) SUCH EVENTS IN 2019

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Code – 49 CFR 192 | Gas Transmission Pipeline

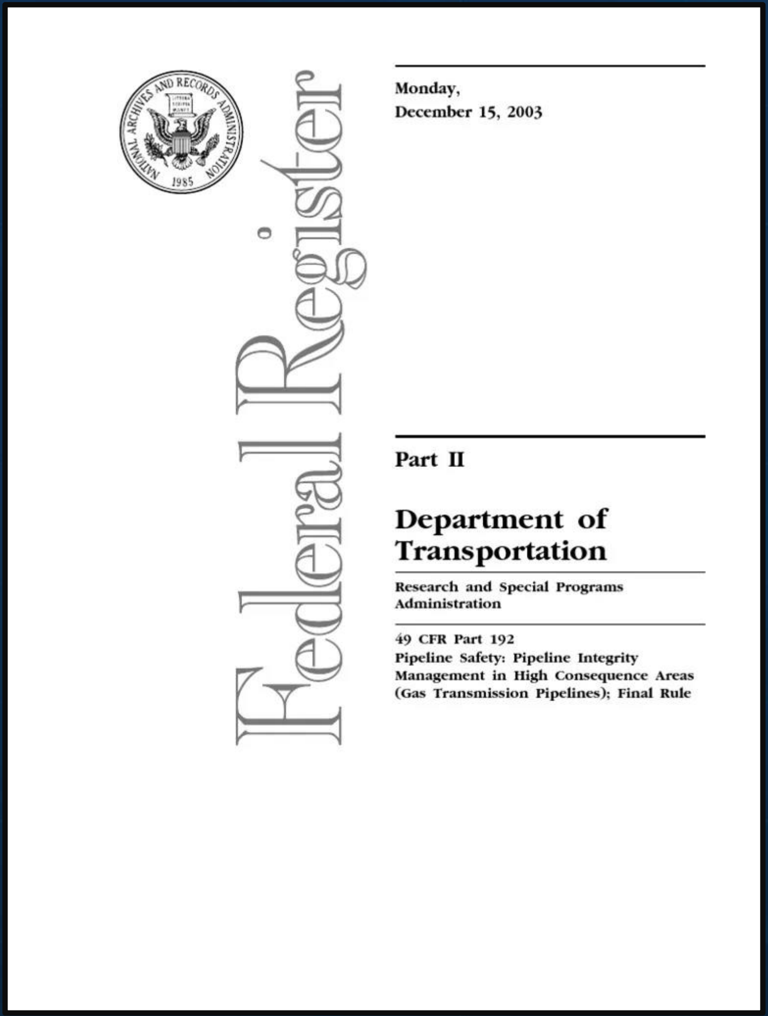
United States DOT – Pipeline Hazardous Material Safety Administration (PHMSA)

Where AC Interference effects falls within the Code:
§192.473 External Corrosion Control: Interference Currents.
(a) Each operator whose pipeline system is subjected to stray currents shall have in effect a continuing program to minimize the detrimental effects of such currents.

Very similar language in 49 CFR 195 part 195.577 for (Hazardous Liquid Pipelines)

NOTE SPECIAL PERMIT PIPELINES:
§192.328 Additional construction requirements for steel pipe using alternative maximum allowable operating pressure. Special Permit Lines >80% SMYS

(b) Interference currents.
(1) For a new pipeline segment, the construction must address the impacts of induced alternating current from parallel electric transmission lines and other known sources of potential interference with corrosion control.



Federal Register

Monday,
December 15, 2003

Part II

Department of Transportation

Research and Special Programs Administration

49 CFR Part 192
Pipeline Safety: Pipeline Integrity Management in High Consequence Areas (Gas Transmission Pipelines); Final Rule

Code – 49 CFR 192 | Gas Transmission Pipeline (On Shore)

PHMSA Mega Rule RIN2 Issued August 24, 2022

Corrosion Control: Interference Surveys § 192.473

PHMSA proposed to amend § 192.473 to require that operator's program include interference surveys to detect the presence of interference currents and take remedial actions within 6 months of completing the survey. Additionally, PHMSA proposed that operators perform periodic surveys whenever needed.

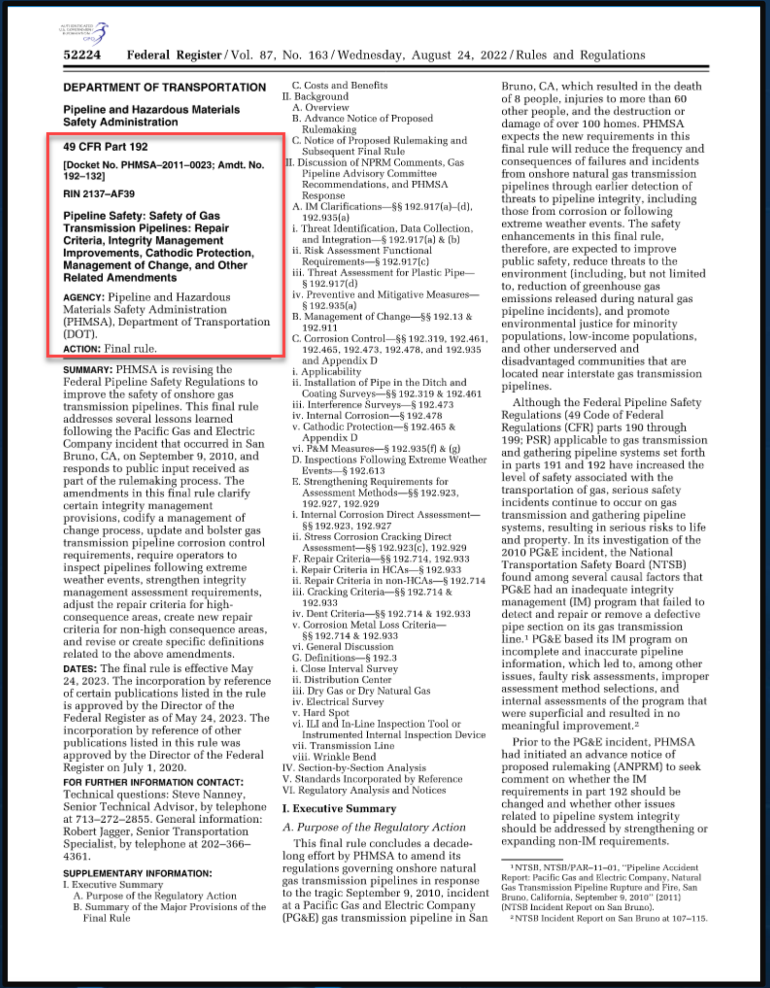
Interference currents can negate the effectiveness of CP systems. Section 192.473 currently prescribes general requirements to minimize the detrimental effects of interference currents. However, subpart I does not presently contain specific requirements to monitor and mitigate detrimental interference currents. Accordingly, this final rule adds a new paragraph (c) to require that onshore gas transmission operator corrosion control programs include interference surveys to detect the presence of interference currents when potential monitoring indicates a significant increase in stray current, or when new potential stray current sources are introduced. Sources of stray current can include co-located pipelines, structures, HVAC power lines, new or enlarged power substations, new pipelines, and other structures. They can also include additional generation, a voltage uprating, and additional lines. The rule also requires operators perform remedial actions no later than 15 months after completing the interference survey, with an allowance for permitting, to protect the pipeline segment from detrimental interference currents. These additional requirements do not apply to gas gathering pipelines or distribution mains.

Clarifications to 49 CFR 192 RIN2 Issued April 24, 2023

Technical Correction to Specify Unit Measure in 192.473(c)(3)

This correction was to specify that operators must take remedial action when surveys detect interference currents that meets or exceed 100 amps per meter squared alternating current (AC).

PHMSA could potentiallu issue a NPRM to modify 49 CFR 195 (Hazardous Liquid Pipelines) change to similar language in the coming 12-18 months.



52224 Federal Register / Vol. 87, No. 163 / Wednesday, August 24, 2022 / Rules and Regulations

DEPARTMENT OF TRANSPORTATION

Pipeline and Hazardous Materials Safety Administration

49 CFR Part 192

[Docket No. PHMSA–2011–0023; Amdt. No. 192–132]

RIN 2137–AF39

Pipeline Safety: Safety of Gas Transmission Pipelines: Repair Criteria, Integrity Management Improvements, Cathodic Protection, Management of Change, and Other Related Amendments

AGENCY: Pipeline and Hazardous Materials Safety Administration (PHMSA), Department of Transportation (DOT).

ACTION: Final rule.

SUMMARY: PHMSA is revising the Federal Pipeline Safety Regulations to improve the safety of onshore gas transmission pipelines. This final rule addresses several lessons learned following the Pacific Gas and Electric Company incident that occurred in San Bruno, CA, on September 9, 2010, and responds to public input received as part of the rulemaking process. The amendments in this final rule clarify certain integrity management provisions, codify a management of change process, update and bolster gas transmission pipeline corrosion control requirements, require operators to inspect pipelines following extreme weather events, strengthen integrity management assessment requirements, adjust the repair criteria for high-consequence areas, create new repair criteria for non-high consequence areas, and revise or create specific definitions related to the above amendments.

DATES: The final rule is effective May 24, 2023. The incorporation by reference of certain publications listed in the rule is approved by the Director of the Federal Register as of May 24, 2023. The incorporation by reference of other publications listed in this rule was approved by the Director of the Federal Register on July 1, 2020.

FOR FURTHER INFORMATION CONTACT: Technical questions: Steve Nanney, Senior Technical Advisor, by telephone at 713–272–2855. General information: Robert Jagger, Senior Transportation Specialist, by telephone at 202–366–4361.

SUPPLEMENTARY INFORMATION:

I. Executive Summary

A. Purpose of the Regulatory Action

This final rule concludes a decade-long effort by PHMSA to amend its regulations governing onshore natural gas transmission pipelines in response to the tragic September 9, 2010, incident at a Pacific Gas and Electric Company (PG&E) gas transmission pipeline in San Bruno, CA, which resulted in the death of 8 people, injuries to more than 60 other people, and the destruction or damage of over 100 homes. PHMSA expects the new requirements in this final rule will reduce the frequency and consequences of failures and incidents from onshore natural gas transmission pipelines through earlier detection of threats to pipeline integrity, including those from corrosion or following extreme weather events. The safety enhancements in this final rule, therefore, are expected to improve public safety, reduce threats to the environment (including, but not limited to, reduction of greenhouse gas emissions released during natural gas pipeline incidents), and promote environmental justice for minority populations, low-income populations, and other underserved and disadvantaged communities that are located near interstate gas transmission pipelines.

Although the Federal Pipeline Safety Regulations (49 Code of Federal Regulations (CFR) parts 190 through 199; PSR) applicable to gas transmission and gathering pipeline systems set forth in parts 191 and 192 have increased the level of safety associated with the transportation of gas, serious safety incidents continue to occur on gas transmission and gathering pipeline systems, resulting in serious risks to life and property. In its investigation of the 2010 PG&E incident, the National Transportation Safety Board (NTSB) found among several causal factors that PG&E had an inadequate integrity management (IM) program that failed to detect and repair or remove a defective pipe section on its gas transmission line.[1] PG&E based its IM program on incomplete and inaccurate pipeline information, which led to, among other issues, faulty risk assessments, improper assessment method selections, and internal assessments of the program that were superficial and resulted in no meaningful improvement.[2]

Prior to the PG&E incident, PHMSA had initiated an advance notice of proposed rulemaking (ANPRM) to seek comment on whether the IM requirements in part 192 should be changed and whether other issues related to pipeline system integrity should be addressed by strengthening or expanding non-IM requirements.

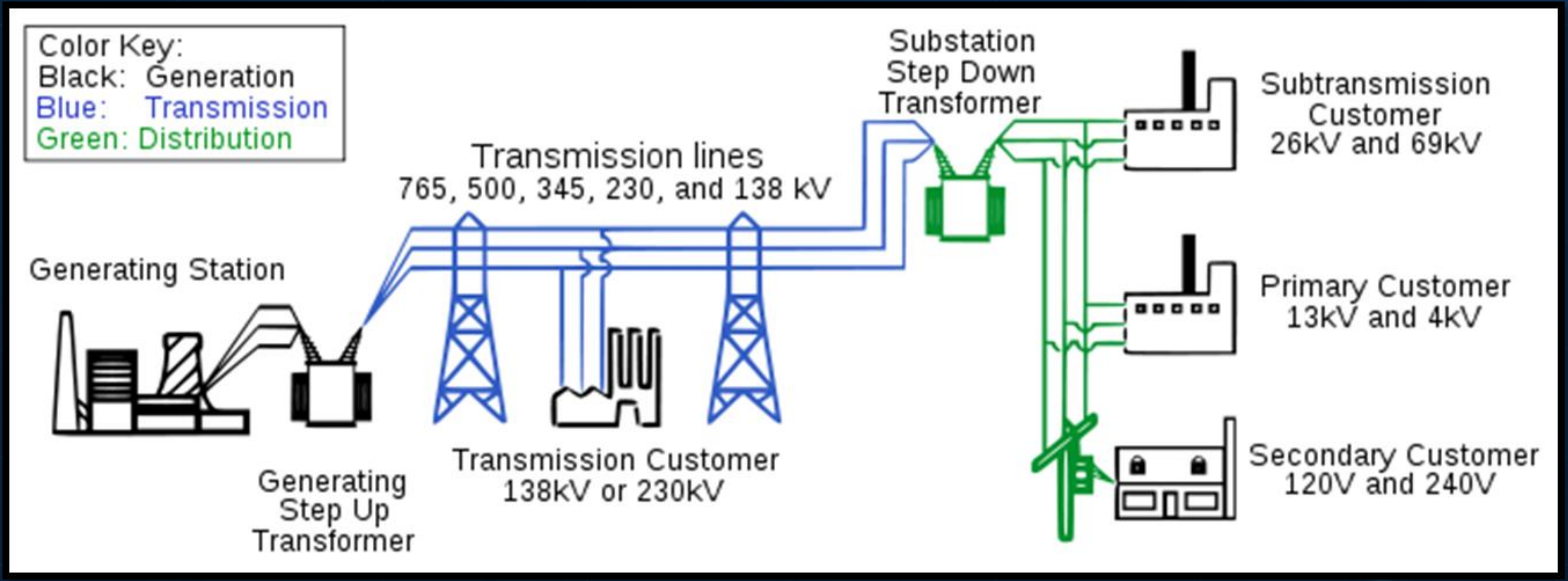
[1] NTSB, NTSB/PAR–11–01, "Pipeline Accident Report: Pacific Gas and Electric Company, Natural Gas Transmission Pipeline Rupture and Fire, San Bruno, California, September 9, 2010" (2011) (NTSB Incident Report on San Bruno).

[2] NTSB Incident Report on San Bruno at 107–115.

Basic Power Transmission

Alternating Current – Power Grid System

A system of high tension cables by which electrical power is distributed throughout a region



Power travels from the power plant to your house through a system called the **power distribution grid**.

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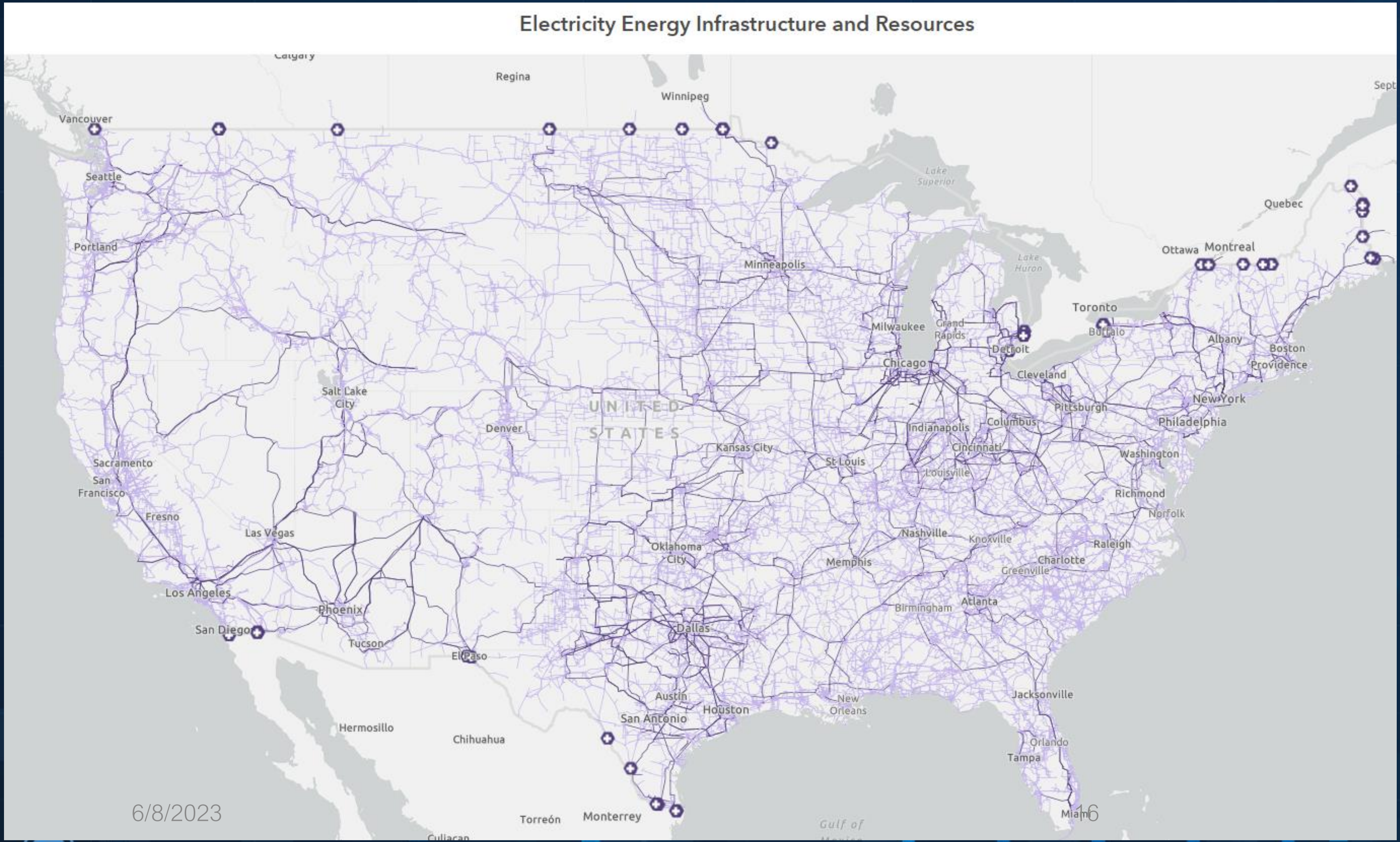
United States Power Transmission Grid



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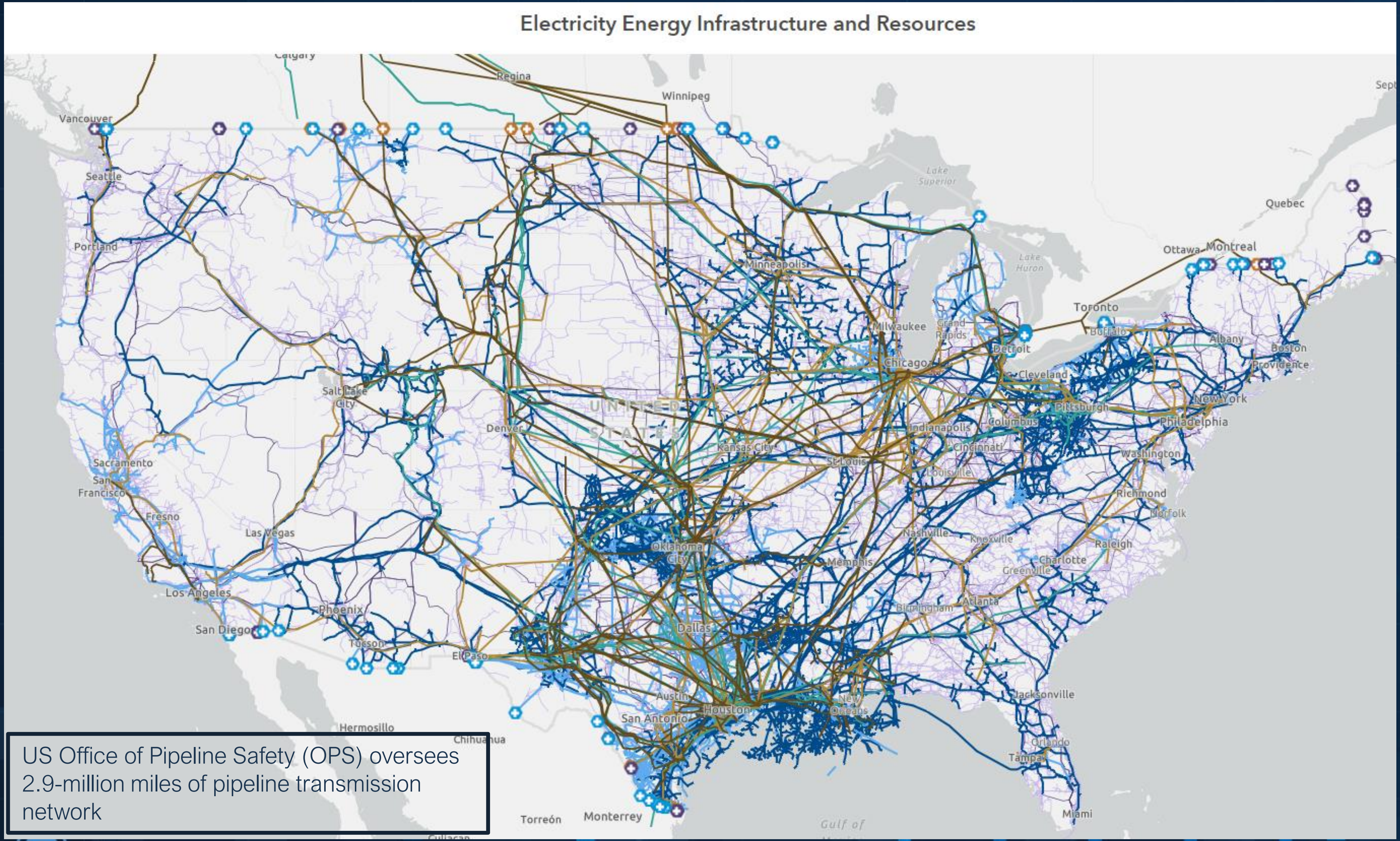
With US Pipeline Grid Overlaid



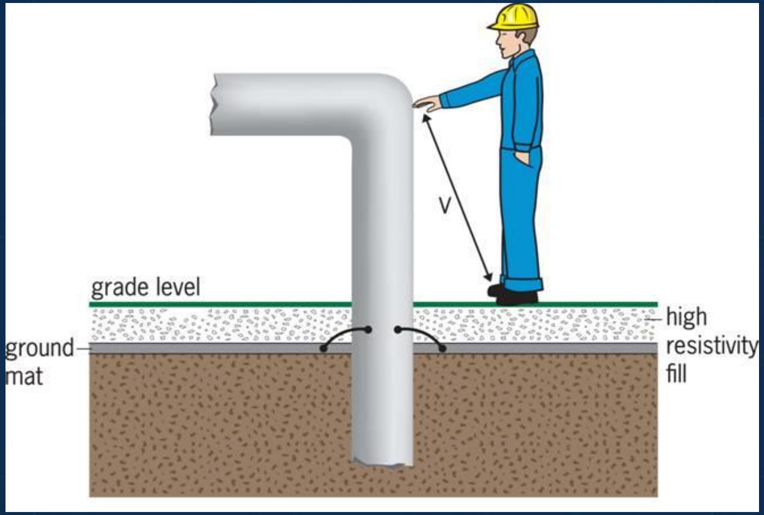
US Office of Pipeline Safety (OPS) oversees 2.9-million miles of pipeline transmission network

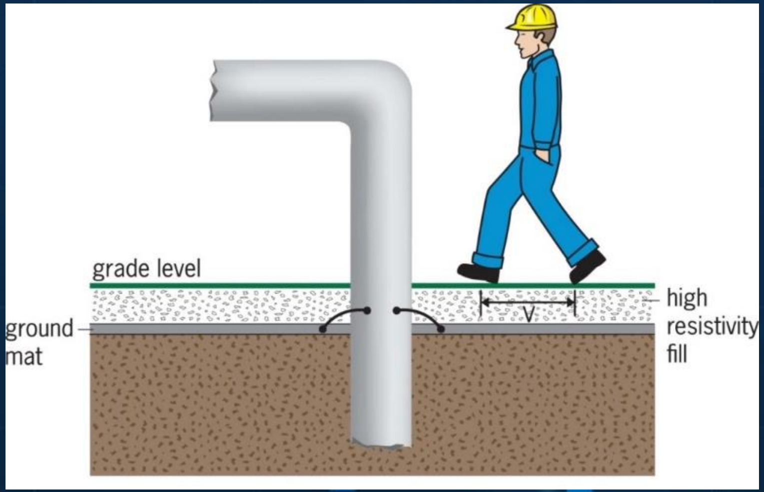
Induced AC Right-of-Way Safety

Personnel Safety

Safety – Touch & Step Potentials

- General Public
- Company Personnel
- Livestock & Other Animals





Potential of Personnel Safety Issues (15 V_{AC})

From AMPP SP0177-2019: Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

Table 3
Human Resistance to Electrical Current[12]

Dry skin	100,000 to 600,000 ohms
Wet skin	1,000 ohms
Internal body—hand to foot	400 to 600 ohms
Ear to ear	about 100 ohms

AC Interference – Safety Concerns

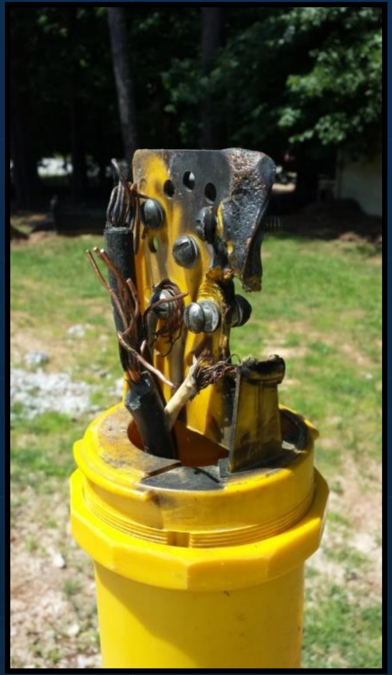
Maintaining personnel safety should be considered at all times including :

1. Construction phase:
   - Temporary grounding connections (bonds)
   - Ground Rods
   - Bare pipe casing
   - Grounding straps on vehicles/equipment
2. Typical Operation & Maintenance:
   - AC Mitigation Measures
   - Employee PPE

AC Interference – Safety Concerns

Safety –Touch Potentials

THIS IS THE MOST COMMONLY KNOWN ISSUE RELATED TO AC INTERFERENCE. NACE ESTABLISHED $15V_{AC}$ VOLTAGE POTENTIAL LIMIT VERSUS A COPPER-COPPER SULFATE REFERENCE ELECTRODE FOR PERSONNEL SAFETY.



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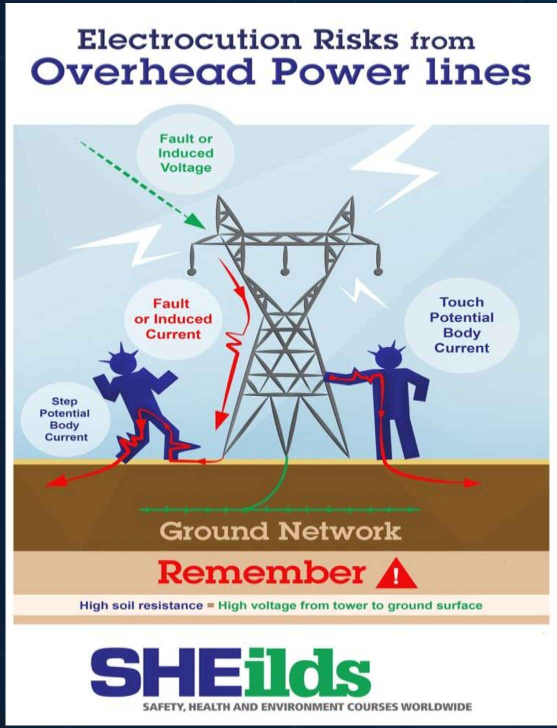
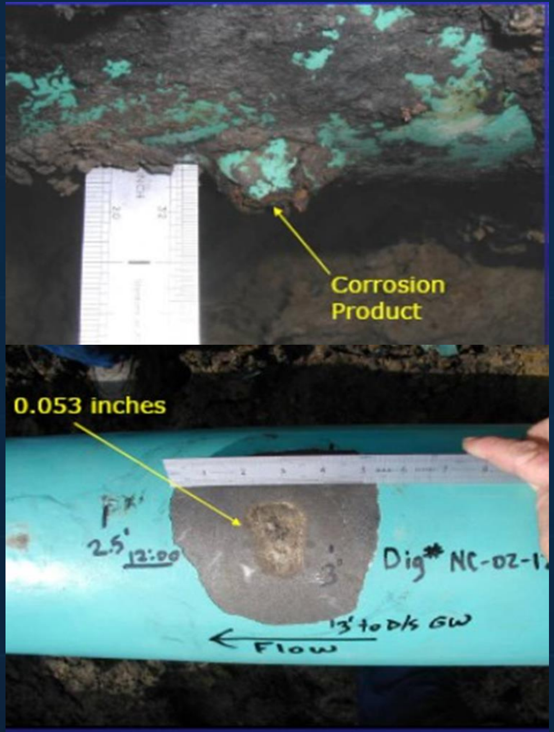
Assessing the AC Interference Problem?

Why is AC Interference A Problem?

Potential of Personnel Safety Issues (15 V_{AC})



Potential for AC Corrosion



Potential for Coating Damage

Potential for Pipeline Damage

Metal loss due to AC currents ~ *2.0 lbs/amp-year (~10% (21 lbs/amp-year) of DC current metal loss)* ; but the magnitude is potentially much higher. Especially, in ground fault conditions.

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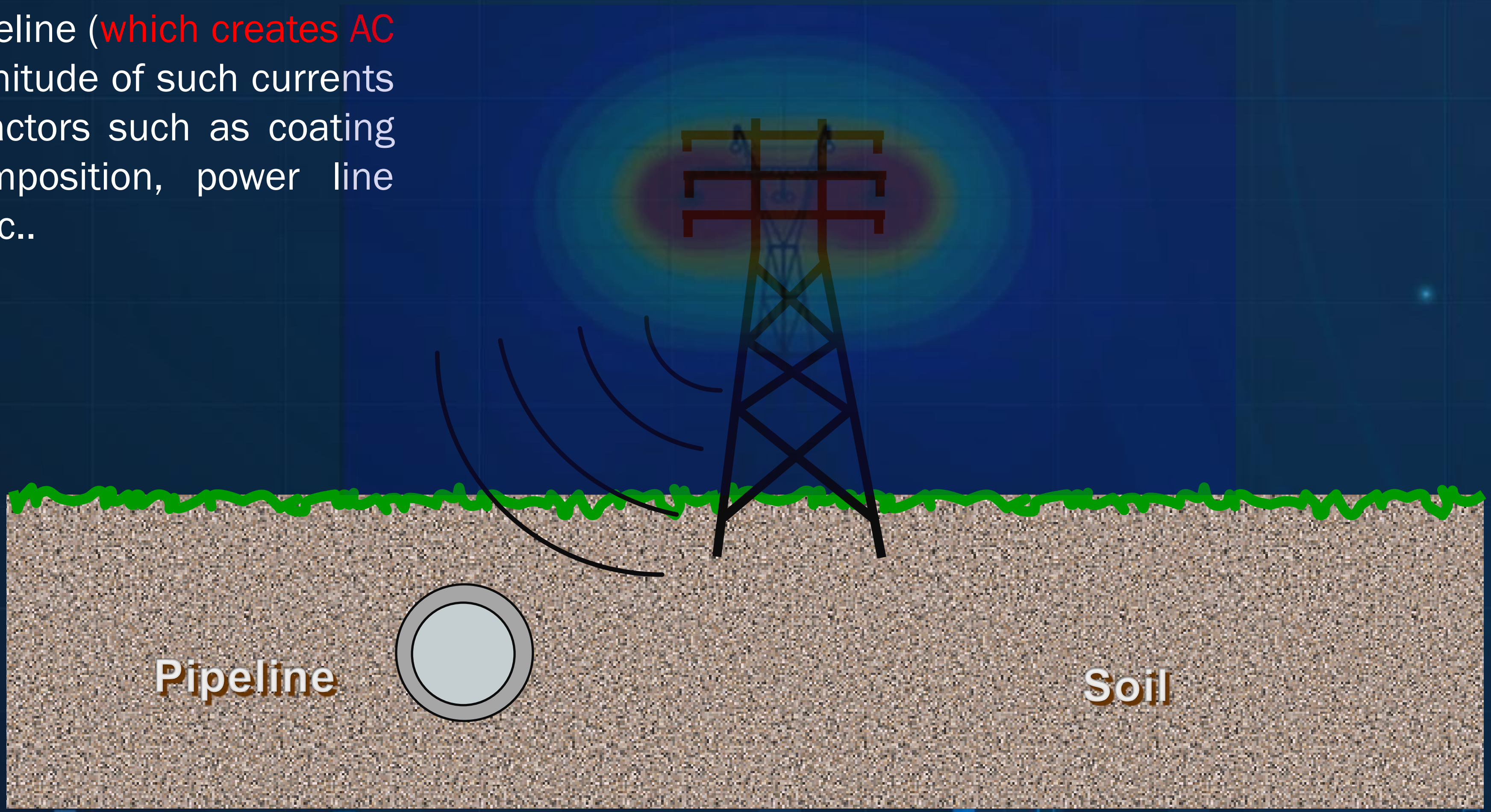
AC Interference

The magnetic field generated by the overhead power lines induces an AC voltage onto the pipeline (which creates AC currents). The magnitude of such currents depend on many factors such as coating condition, soil composition, power line voltage, distance, etc..



AC Interference – (3) Issues

1. **Electrostatic (Capacitive) Coupling**

   Affects aboveground structures only

   - such as a pipeline during construction, above ground test station, a car, or pipe stored near ditch

2. **Electromagnetic (Inductive) Coupling**

   Affects structures above or below ground

   Structure acts as secondary coil

   - Most important component, steady state conditions, causes AC corrosion of steel as well as personnel hazard potential

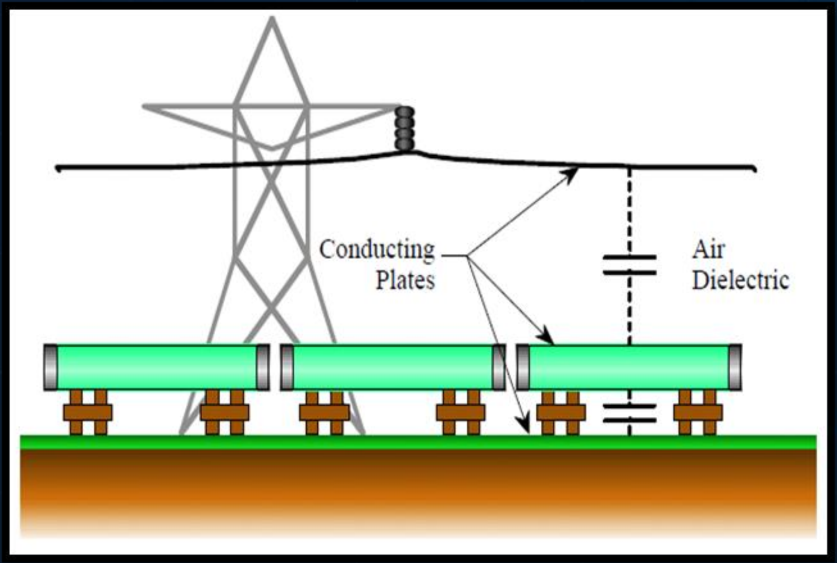
3. **Conductive (Resistive) Coupling**

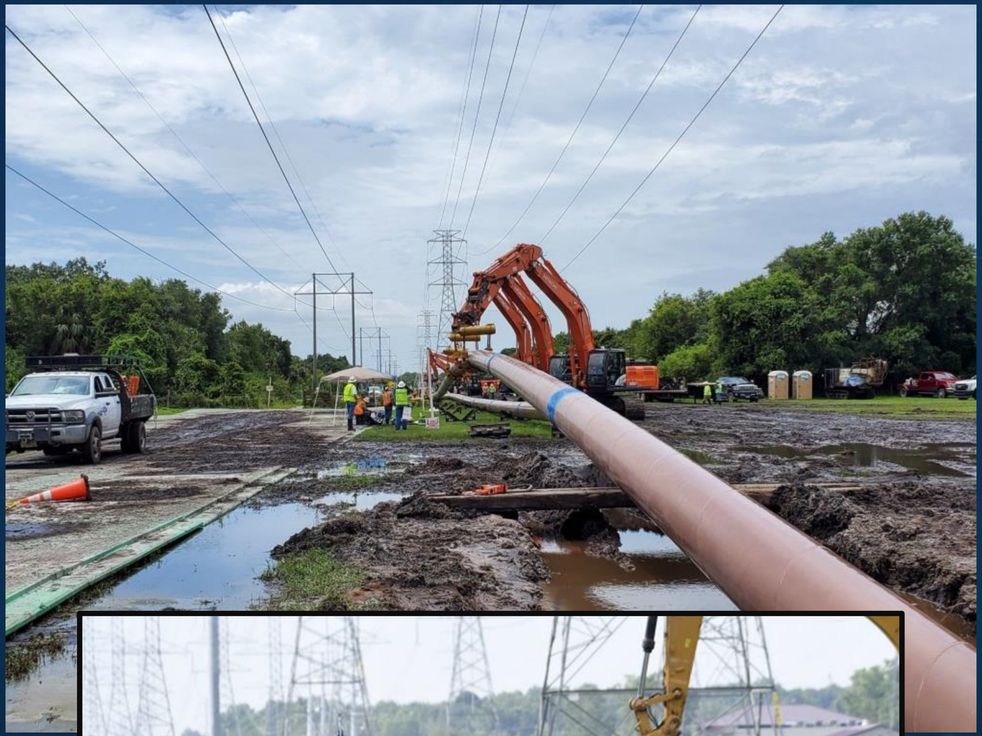
   Affects only buried structures (during line faults)

   - Rare emergency/safety related occurrences, high magnitude conditions, coating stress, pipeline damage, personnel safety.

AC Interference | Capacitive Coupling

Caused by accumulation of electro-static voltage resulting in a capacitance coupling (buildup) between the power line and the pipeline.

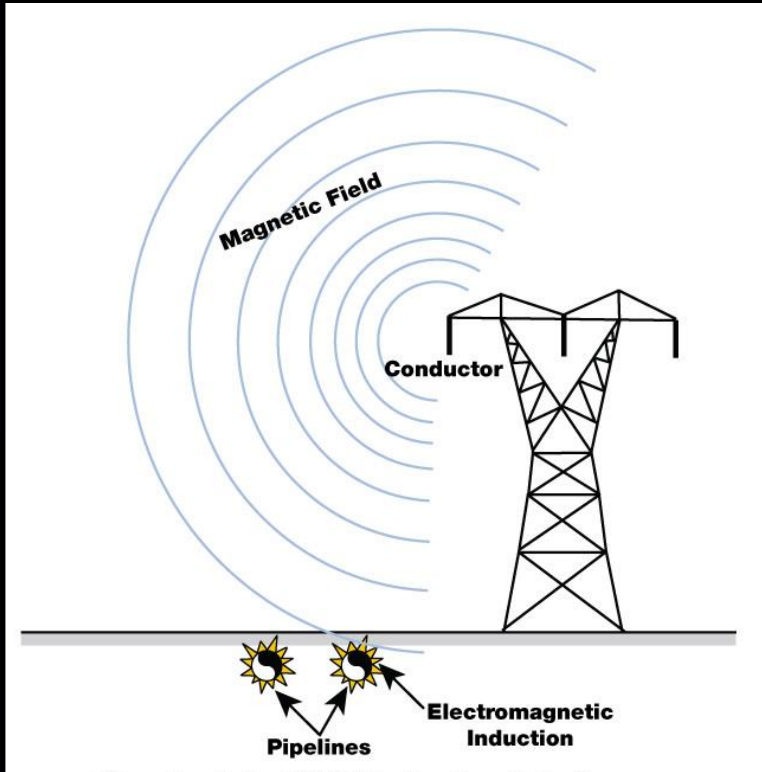




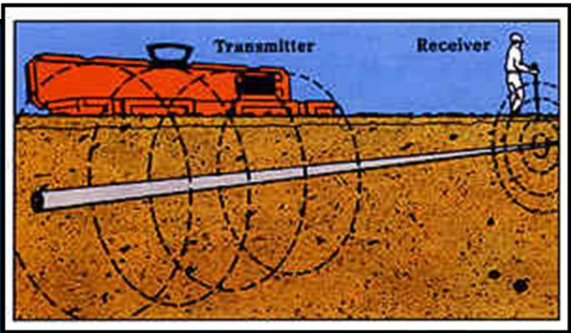
AC Interference | Inductive Coupling

Caused by current flow in steady state operations of the transmission power line which creates an electromagnetic field surrounding the paralleling pipeline. **Most Common Concern.**

- Occurs during normal operating conditions of the power line.
- Magnitude can reach 100’s of volts and presenting shock hazards.
- Pipelines within 1000 lf of a HVAC power line should be investigated in particular, if they share a common ROW in parallel.
- Can create operational issues with SCADA/MOVs and can cause AC Corrosion



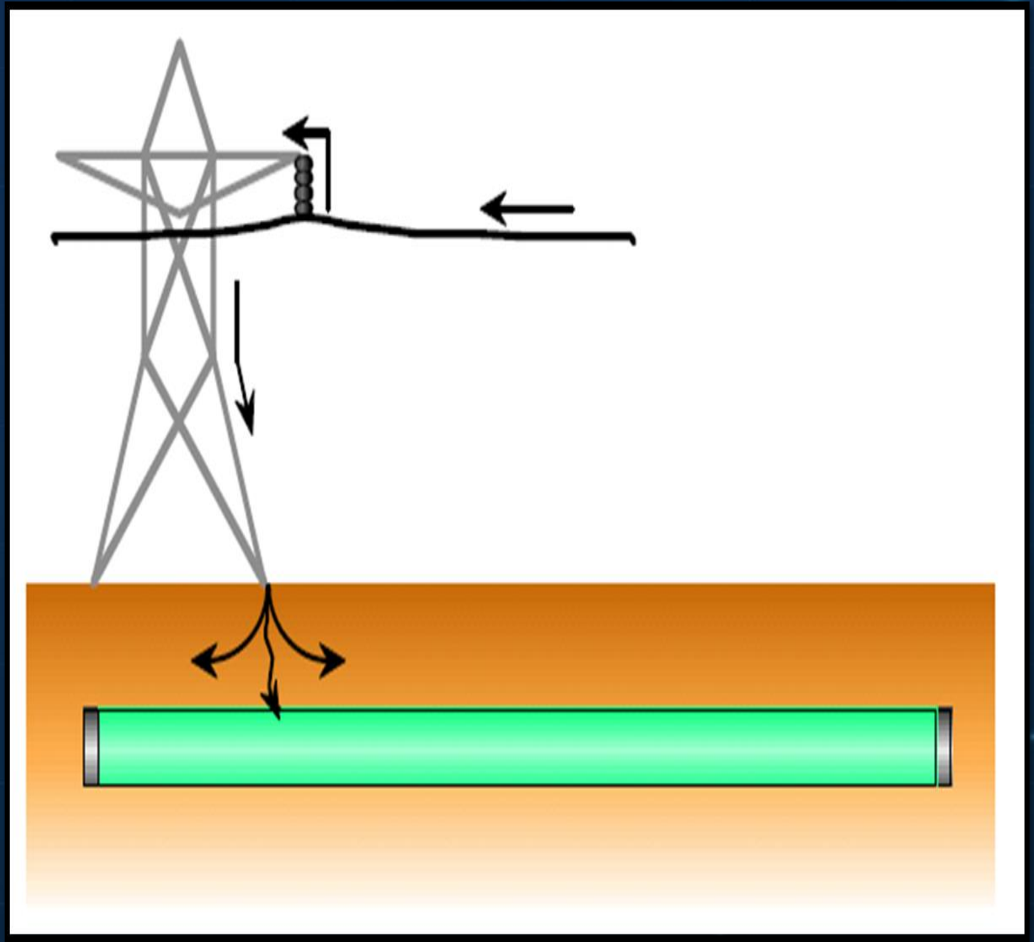
Steady state HVAC Inductive Interference



AC Interference | Resistive Coupling

Direct contact between a live component of the power line and an exposed metallic structure. Occur during ground fault conditions or during lightning strikes.

- ❑ Not common.
- ❑ Short duration (breakers will trip). Typically, 0.1 seconds or less on high voltage systems.
- ❑ Potentials can exceed 15,000 volts.
- ❑ Pipeline ruptures have occurred due to these fault conditions. Can cause melting or cracking of the pipe wall.
- ❑ Coating stress for voltage in excess 5,000 volts for newer, high strength, dielectric coatings, i.e. Fusion Bonded Epoxy (FBE).
- ❑ Metal loss due to AC currents *~ 2.0 lbs./amp-year (~10% of DC metal loss)* ; but the magnitude is potentially much higher. Especially, in ground fault conditions.



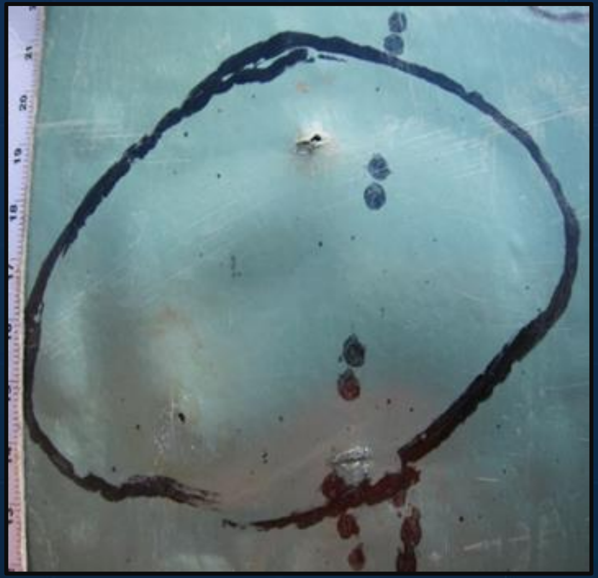
AC Interference | Resistive Coupling

CAUSES OF POWERLINE FAULT CONDITIONS

- On high voltage powerlines faults are most likely to occur as the result of lightning, which can ionize the air in the vicinity of an insulator.
- High winds
- Failure of the powerline structures or insulators.
- Accidental contact between powerlines and other structures (cranes, construction equipment, etc.).

AC Interference – Resistive Coupling

Fault current is transferred through the pipeline through the pipeline coating. The better the coating quality (i.e. fewer holidays) and the higher the coatings dielectric strength (breakdown voltage) the lower the current transfer to the pipeline.



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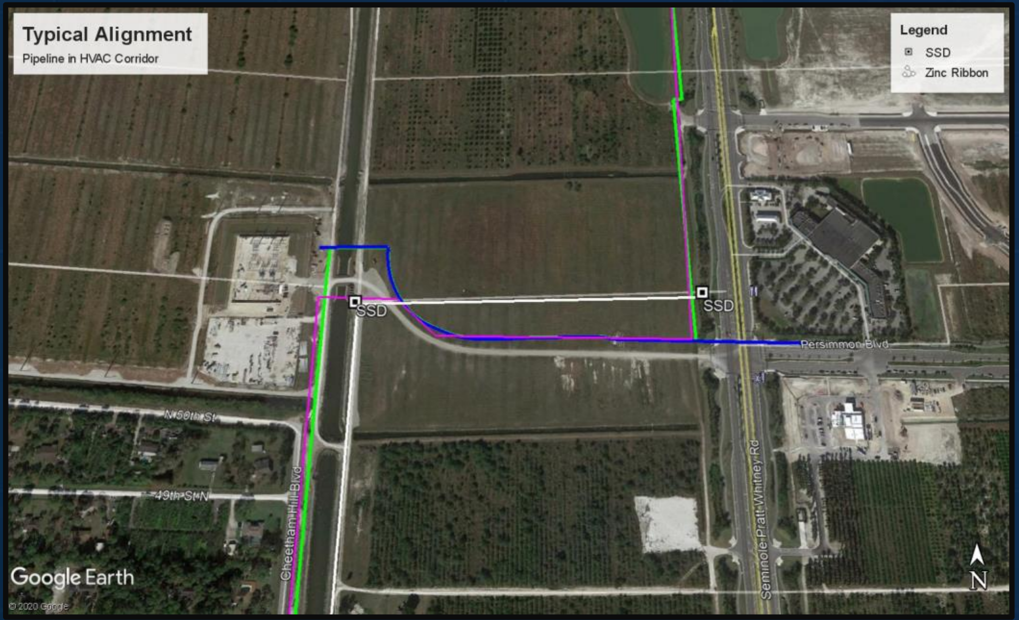
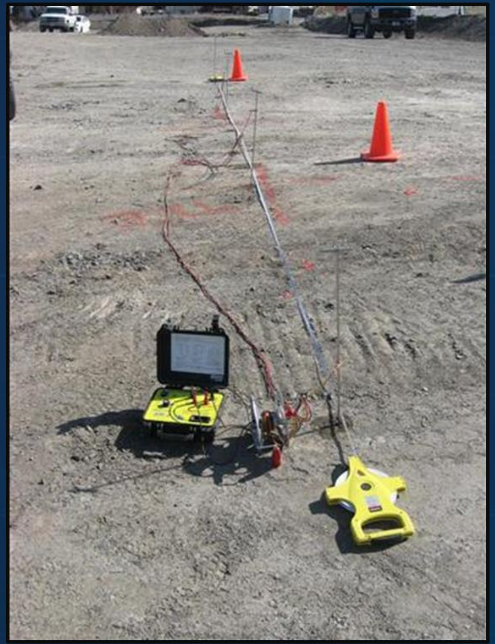
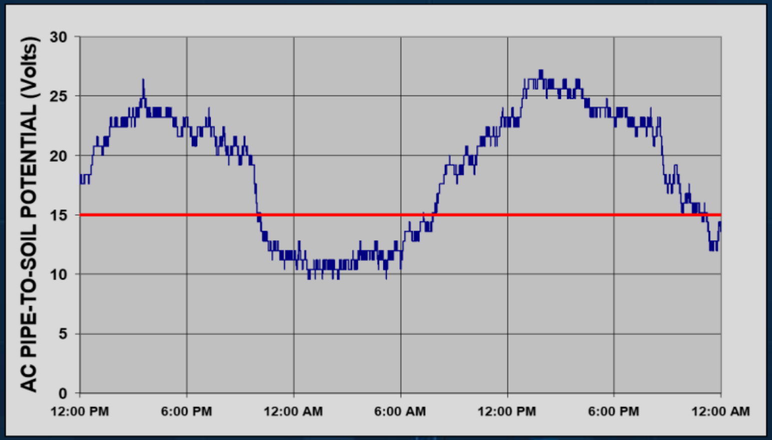
Factors Influencing - AC Interference on Pipeline

- Pipeline coating type & quality.
- Soil Resistivity.
- Tower Geometry | Separation distance and orientation between power line and pipeline
- Power line operating characteristics.
- Magnitude of steady state current in power line.
- Magnitude and duration of fault currents.
- Tower grounding characteristics.







AC CORROSION

AC Corrosion Current Density

Based on recent studies of AC corrosion related failures, the following guideline was developed:

- AC induced corrosion does not occur at AC current densities **less than 20 A/m^2 (~ 1.86 A/ft^2).**
- AC corrosion is unpredictable for AC current densities between 20 to 100 A/m^2 (~ 1.86 A/ft^2 to 9.3 A/ft^2).
- AC corrosion typically occurs at AC current densities **greater than 100 A/m^2** (~9.3 A/ft^2).

Highest corrosion rates occur at very small coating defects with surface areas between 1 and 3 cm^2 (0.16 in^2 – 0.47 in^2)

Surface Area of a US Dime = 2.54 cm^2

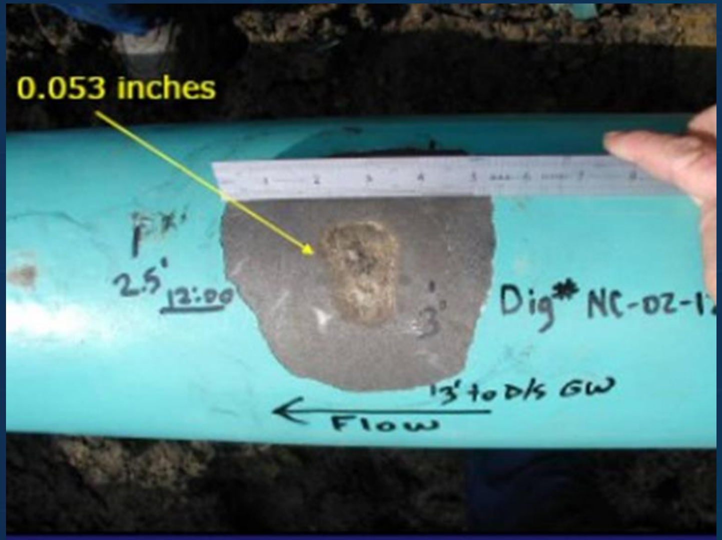
SP21424-2018 AC Corrosion Criteria:

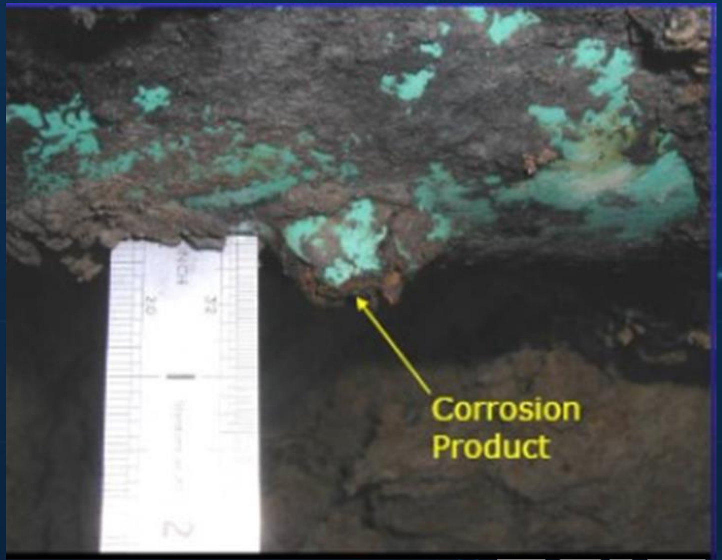
New studies cite 30 A/m^2 as lower end of "Unpredictable" range for new pipelines, with the possible exception of an intermediate AC current density of 50 A/m^2 limit at HDDs used by the vast majority of pipeline operators.

AC Corrosion

Characteristics of AC corrosion:

1. Typically located in areas of low soil resistivity.
2. Typically located at coating defects.
3. Hard dome shaped cluster of soil and corrosion products.
4. Typically results in rounded shaped pits.
5. Typically pit size larger than coating defect.





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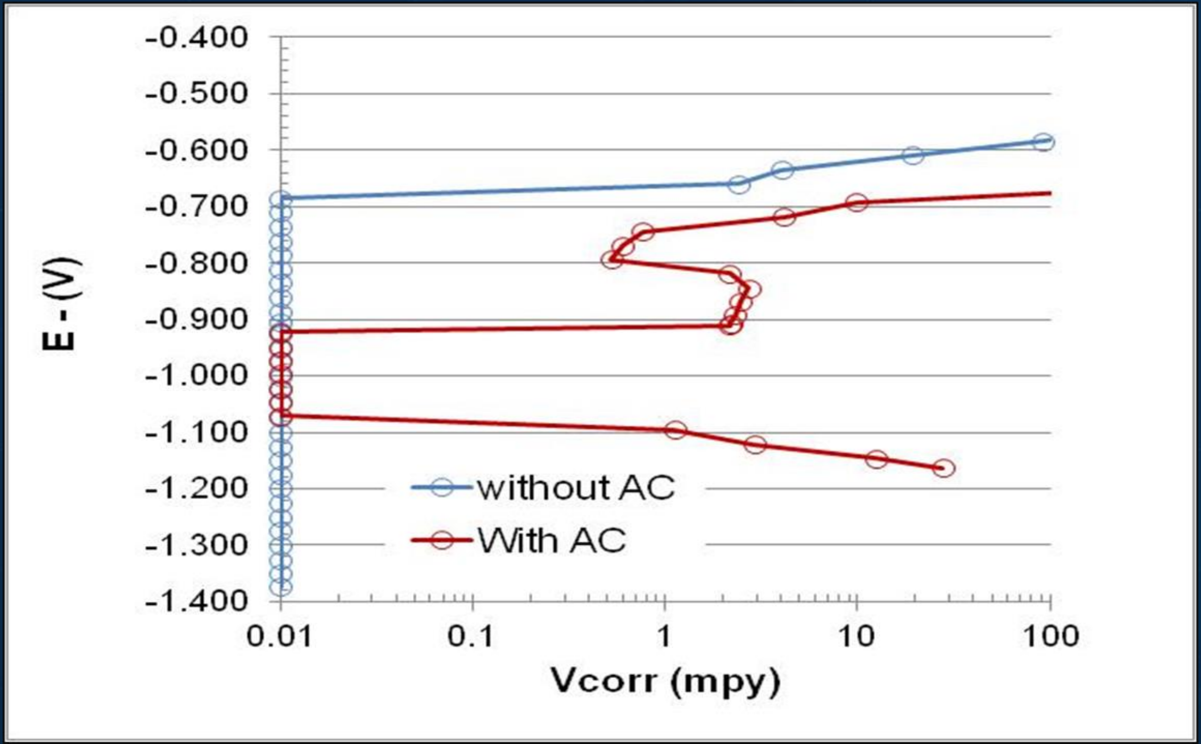
AC Corrosion

Recent studies related to AC have concluded the following:

1. AC does not have any significant effect on the polarization or depolarization of cathodically protected steel.

2. It has been found that excessive amounts of CP can actually increase AC corrosion rates. This has been attributed to the lowering of the electrolyte resistivity immediately adjacent to the site of the holiday, which coincides with the high pH resulting from increased levels of CP.



CP can reduce AC corrosion impact…

but too much CP can make things much much worse!

AC Induced Current Density Calculation

Likelihood of AC corrosion can be determined by approximating the AC current density using Ohm's Law where:

$$i_{ac} = \frac{8V_{ac}}{\rho \pi d}$$

i = AC current density (A/m^2)

V_{AC} = AC voltage of the pipeline (V)

ρ = soil resistivity (at holiday, not bulk soil) (Ω-m)

d = diameter of a circular holiday having an area equal to that of the actual holiday (m)

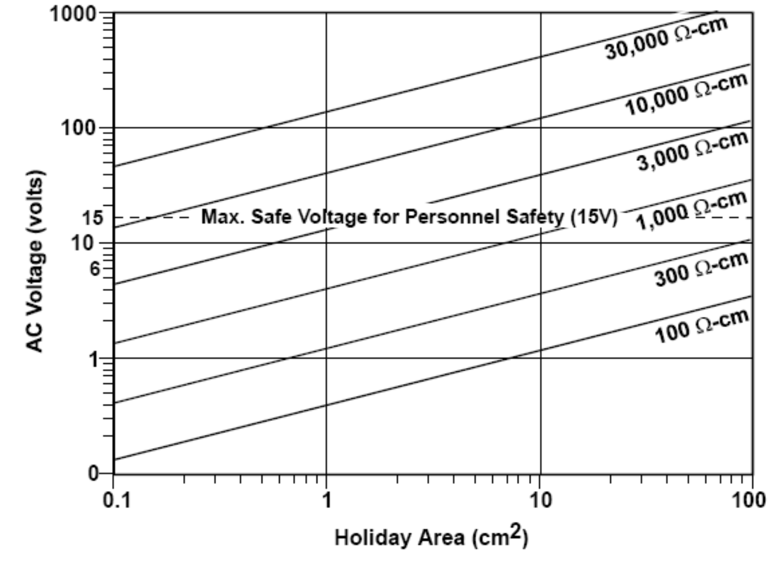


Figure 3-55: AC Voltage Required to Produce 100 A/m^2 Current Density for a Variety of Holiday Sizes and Soil Resistivities

How Much AC Voltage is Too Much?

Assumptions:

- Soil resistivity is low: 1,000 Ω-cm (10 Ω-m)
- Worst case coating holiday: 1 cm^2 = diameter 0.011 m

Voltage needed to reach 20 A/m^2	*Voltage needed to reach 100 A/m^2*
$V_{ac} = \frac{i_{ac}(\rho \pi d)}{8} = \frac{20(10)(\pi)(0.011)}{8}$	$V_{ac} = \frac{i_{ac}(\rho \pi d)}{8} = \frac{100(10)(\pi)(0.011)}{8}$
$V_{ac} = 0.864\ V_{ac}$	$V_{ac} = 4.32\ V_{ac}$

- With the given parameters:
- AC corrosion could be possible with as little as 0.864 V_{ac}.
- AC corrosion will be likely with as little as 4.32 V_{ac}.

POND

How Much AC Voltage is Too Much?

Assumptions:

- Soil resistivity is low: 35,000 Ω-cm (350 Ω-m)
- Worst case coating holiday: 1 cm^2 = diameter 0.011 m

Voltage needed to reach 20 A/m²	*Voltage needed to reach 100 A/m²*
$V_{ac} = \frac{i_{ac}(\rho \pi d)}{8} = \frac{20(350)(\pi)(0.011)}{8}$	$V_{ac} = \frac{i_{ac}(\rho \pi d)}{8} = \frac{100(350)(\pi)(0.011)}{8}$
$V_{ac} = 30.24\ V_{ac}$	$V_{ac} = 151.20\ V_{ac}$

POND

AC Interference – Pipeline Integrity Concerns

Pipeline Integrity / Asset Protection

- AC Corrosion
- Equipment Reliability
- Coating Damage
- Mechanical Integrity Pipe Wall Loss
- Potentials Impact on CP Effectiveness & Monitoring

POND

Review - Key Points:

Most important things to remember related to AC Voltages:

- 15-volt AC Limitation for Protection of Personnel
- Voltages of 1000 volts - 3000 volts Causes Coating Damage
- > 5000 volts Can Cause Pipe Structural Damage
- AC does not have any significant effect on the polarization or depolarization of cathodically protected steel
- AC corrosion typically occurs at AC current densities greater than 100 A/m^2 (~9.3 A/ft^2).
- Highest corrosion rates occur at coating defects with surface areas between 1 and 3 cm^2 (0.16 in^2 – 0.47 in^2)

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AC Interference Modeling

AC Interference | Computer Modeling

Several organizations and companies have developed software to model complex Right-of-Way conditions related to Induced AC voltages. This is the most efficient means to effectively evaluate "What If Scenarios" during the design phase. The modeling involves very complex mathematical formulae to analyze the various scenarios.

The range from affordable to very expensive (~ $40,000/license), and all have Pro's and Con's. Some industry available models are as follows:

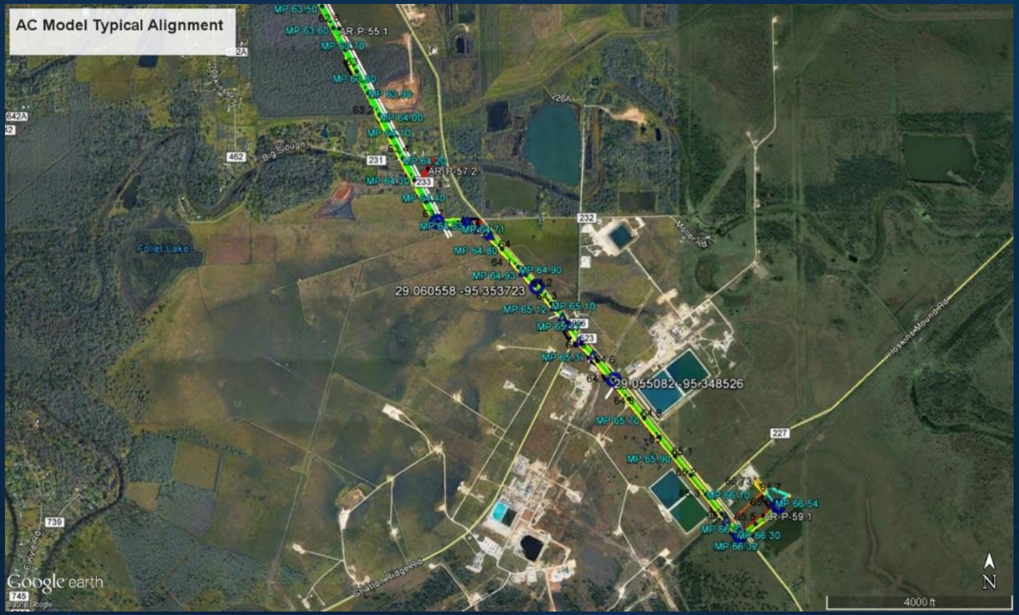
- Safe Engineering Services & Technologies (SES)
    - CDEGS
    - Safe ROW
- PRCI AC Mitigation Tool Box
- Technical Toolboxes – AC Mitigation PowerTool (ACPT)
- Elsyca IRIS
- OTHERS

RULE OF THUMB COSTS FOR FIELD DATA COLLECTION, MODELING AND DESIGN FEES FOR AC MITIGATION

RANGE FROM $2,000 TO $4,000 /mile on up

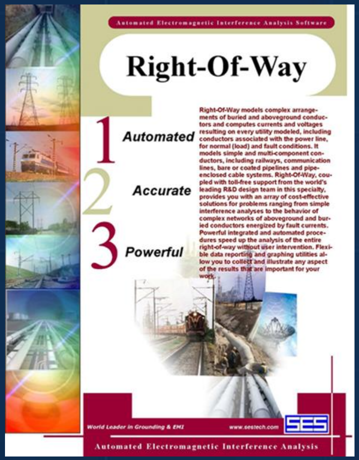
For computer modeling only, $1,000 to $1,500 on up depending on complexity of the HVPL corridor.

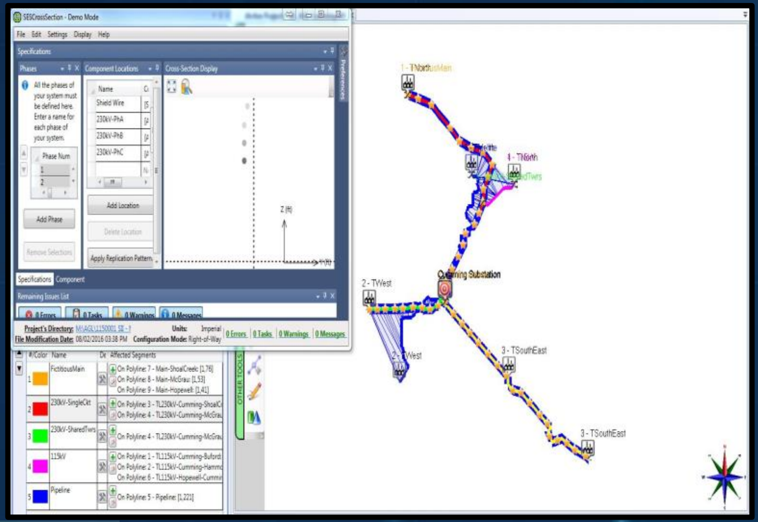
GARBAGE IN = GARBAGE OUT

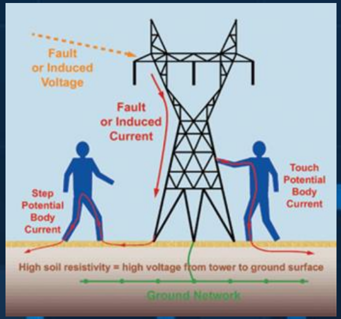


AC Interference – Computer Modeling

- Typical AC Conditions Modeled:
  - Steady State Induced AC Levels Power Line Load Operating Conditions (Steady State, Peak or Emergency Loads)
  - Pipe Potentials Under Line Phase-to-Ground Fault
  - AC Corrosion
  - Arcing Distance
- 15-volt Limitation for Protection of Personnel
  - Step Potentials
  - Touch Potentials
- Tower Ground Faults
  - 1000 volts - 3000 volts Causes Coating Stress (Damage)
  - >5000 volts Can Cause Pipe Structural Damage







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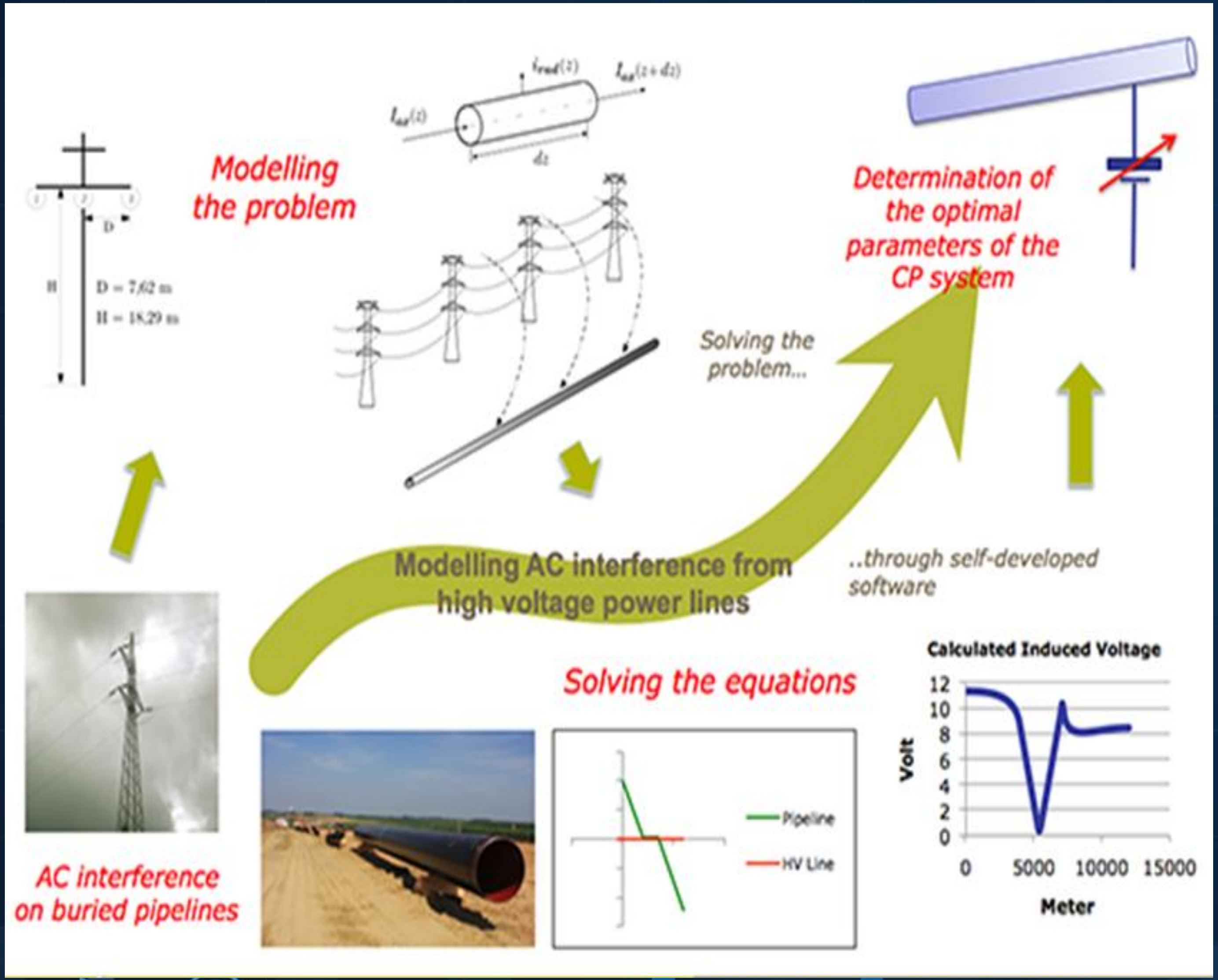
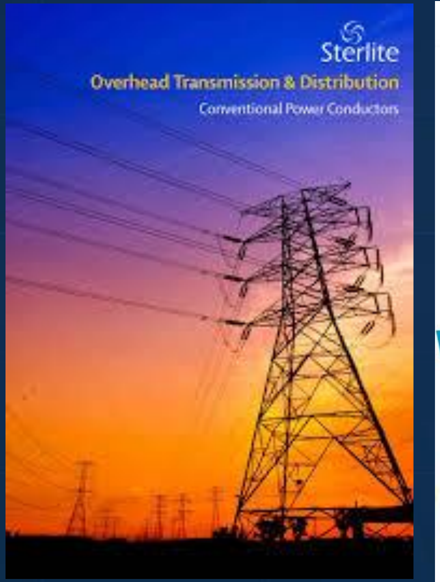
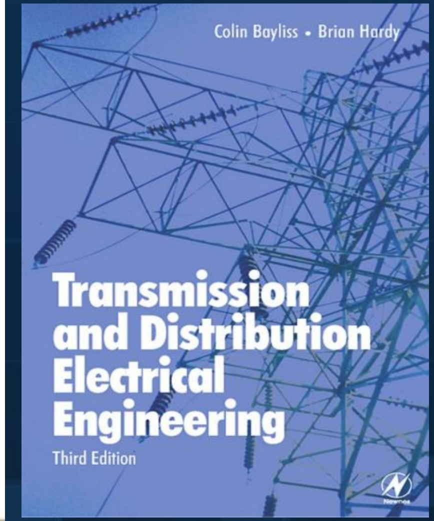
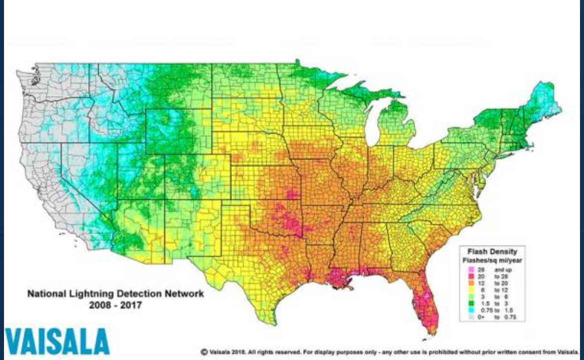
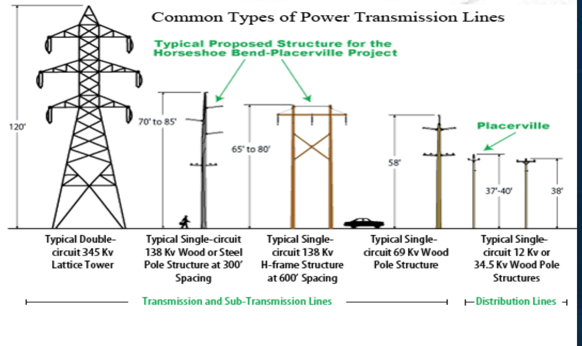
AC Interference | Use Available Resources











AC Interference | Data Necessary

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AC MITIGATION INVESTIGATION

For any AC Mitigation investigation and subsequent modeling, the following data will be required:

TYPICAL AC POWER TRANSMISSION DATA REQUIRED

- Tower geometry, configuration & GPS location
  - Tower grounding (ground resistance) details
  - HVPL conductor vertical heights
  - HVPL conductor horizontal separation distances
  - Shield wire data (ground height and separation distance)
  - HVPL sag height between towers
  - HVPL phase location / conductor arrangement with respect to pipe centerline
  - HVPL conductor type, size & rating for all phase and shield wires
- Locations of any phase transpositions
- Current loading under different conditions namely:
  - Steady State (Average)
  - Peak Load
  - Emergency conditions (for power line with multiple circuits)
- Fault information i.e. Duration, magnitude, etc.
- Power line-to-ground fault current at each end of the collocation, number of collocations, parallel runs, as well as at the midpoint. In other words, near the substation, halfway, etc. These are just approximate figures.
- Fault current split in the faulted conductor (i.e. - the current being fed from any of the directions). This will provide an indication of feedback conditions that may exist at a fault site.

PIPELINE DATA

- Physical attributes of the pipeline
  - Pipeline alignment sheets
  - Pipeline installation date
  - Pipeline length, diameter & wall thickness
  - Operational history i.e. (ILI anomalies, direct assessment findings)
  - Coating type, thickness and coating conductance
  - Detailed depth of cover and centerline GPS location in areas of collocation with the overhead HVPL AC lines
  - Pipeline crossing locations with the HVPL's
  - Location of above-grade appurtenances
    - Valves
    - Casings

    - Pig Launchers/Receivers
    - CP Test Stations
  - Location of foreign pipelines (crossings or parallel in same ROW)
- Existing cathodic protection ground bed data
  - Ground bed location & configuration
  - Output data

FIELD DATA

- GPS at key features
- Photos of key features
- HVPL tower location and geometry data if not provided by others
- Accurate soil resistivity (ASTM G-57 – Wenner 4-pin) data at various layers along the collocation. Minimum one (1) per mile at additional readings at any obvious resistivity changes. (Typical pin spacings 2.5', 5', 10', 15', 20', 25', 50' & 100')
- Field measured Longitudinal Electric Field (LEF) data at each soil resistivity location
- Representative 24 hour LEF data collection at key locations
- AC & DC potential measurements at existing test stations (if possible)
- Measurement of AC current density at AC coupon test stations (if possible)

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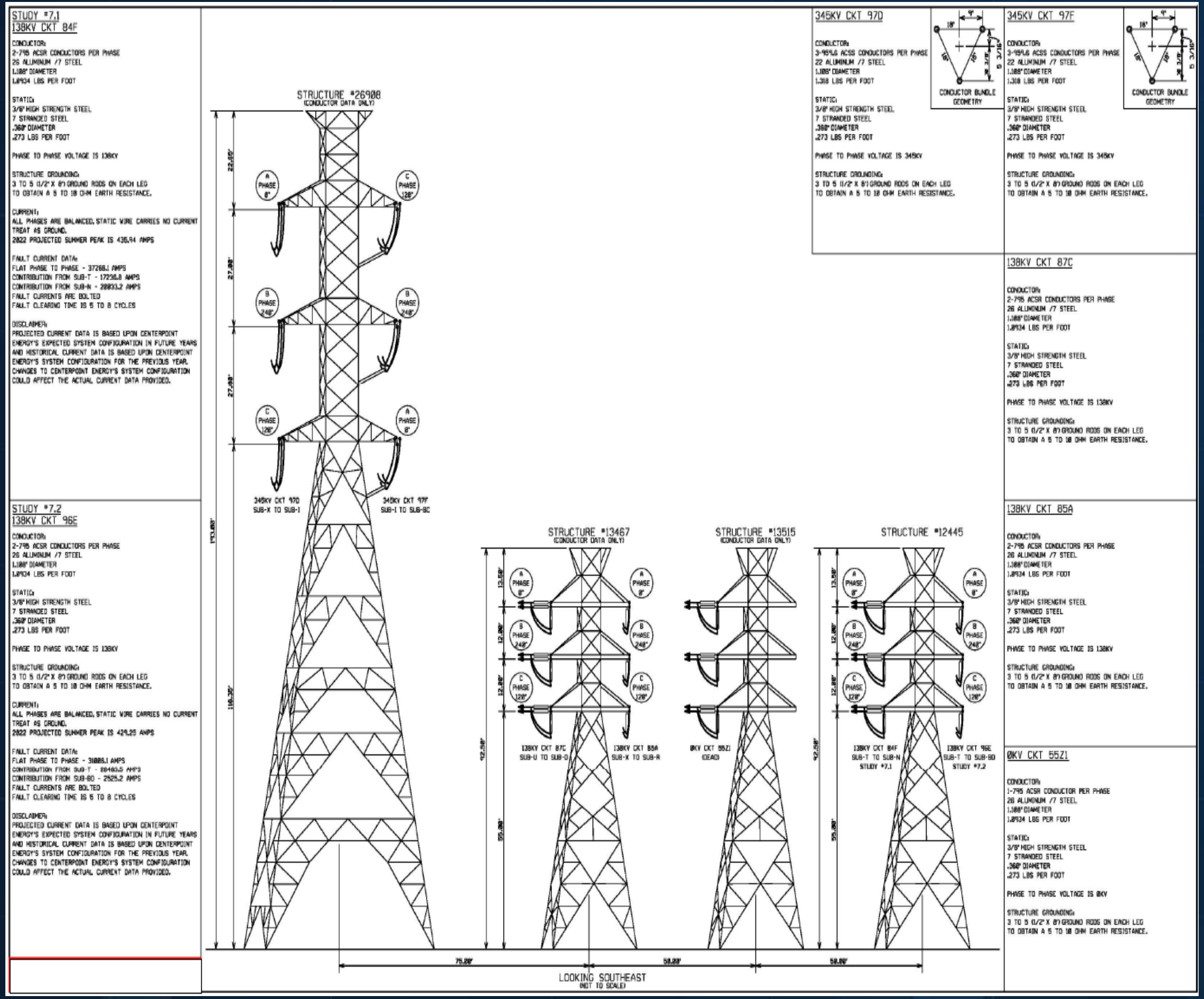
AC Interference | Typical Power Company Data



AC Interference | Typical Power Company Data

FAULT CURRENT

Exposure level: Unless the pipeline has a direct, metallic connection to a power line grounding system (which is not recommended), the fault current is kept to moderate levels under most conditions due to the resistance offered by the pipeline coating and soil, and the limitations of the inductive coupling effect that produces this voltage.

AC Fault Current (amperes-rms) 50/60Hz

Model	1 cycle	3 cycles	10 cycles	30 cycles
1.2kA	2,100	1,600	1,400	1,200
2.0kA	5,300	4,500	3,700	2,000
3.7kA	6,500	5,000	4,200	3,700
5.0kA	8,800	6,800	5,700	5,000

Figure 2: AC Fault Current ratings for the Dairyland SSD

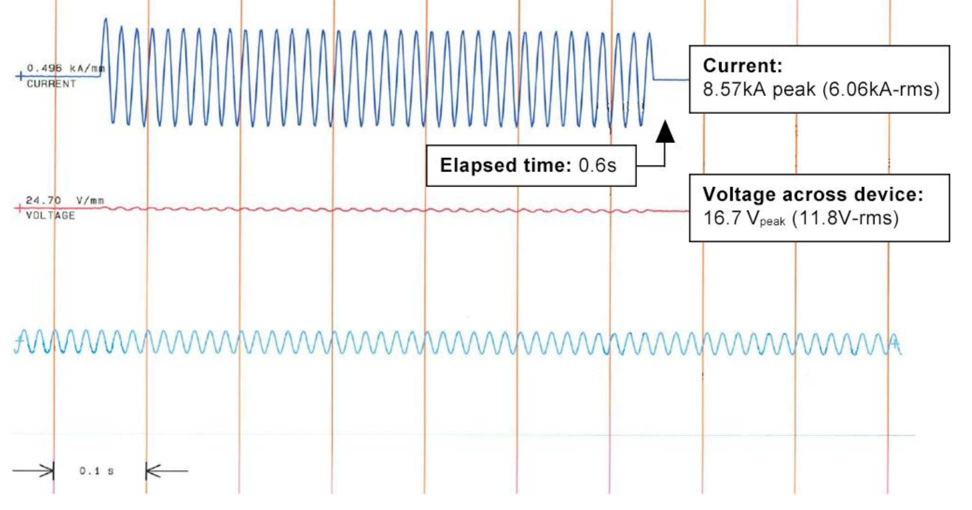
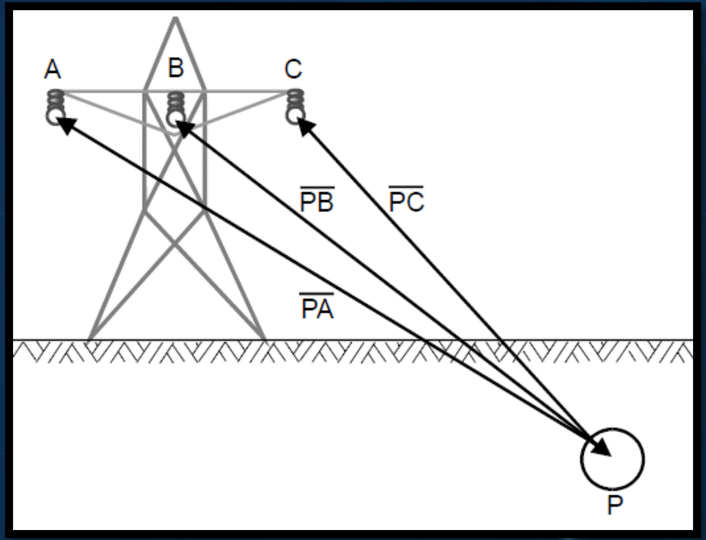


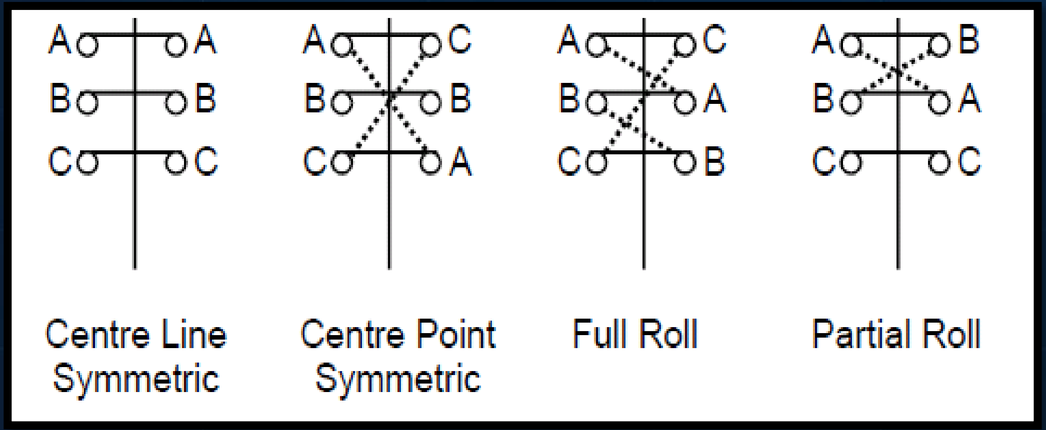
Figure 1: AC Fault Test of a Dairyland SSD-2/2-5.0-100

HVAC Tower Configurations:

In the "Single Horizontal Circuit" example shown, Phase C has the most effect on the pipe line and Phase A the least. The greater the separation distance the less effect by that Phase. Figure to Right



Effect of Phase Conductor Separation



Phase Arrangements for Double Vertical Circuit

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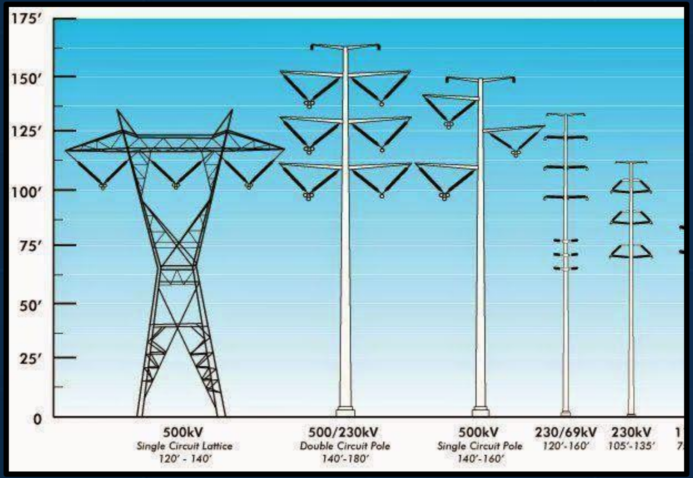
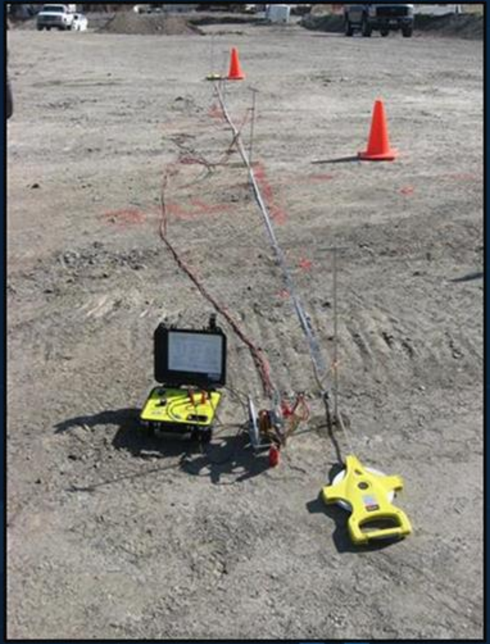
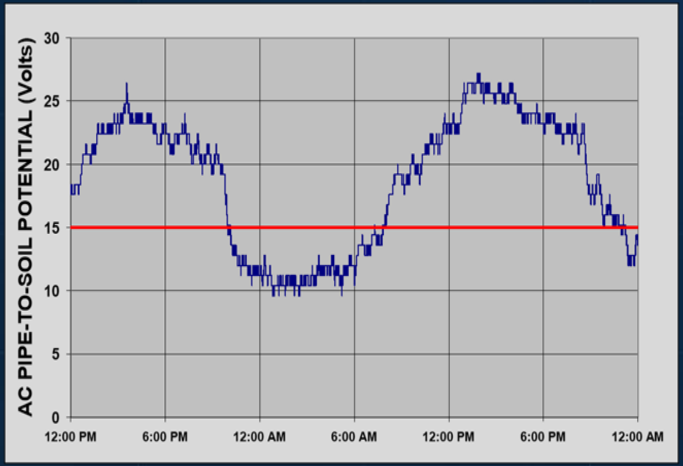
AC Interference – Data Necessary for Modeling







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Pipeline Electrical Characteristics:

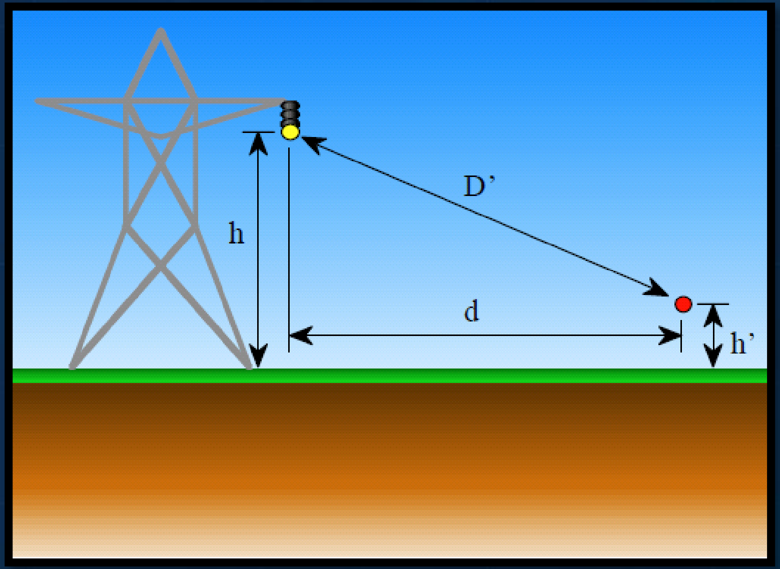
Longitudinal Electric Field (LEF):

One of the most difficult steps in the calculation of induced voltages is in the determination of the magnitude and phase angle of the LEF to which section of the pipeline is exposed. Then, the pipeline must sectionalized where each section exhibits uniform characteristics for analysis:

The LEF resulting from a $I\phi$ flowing in a powerline conductor is a function of the mutual impedance Z_M between the pipeline and the powerline.

$$E = I_\phi \cdot Z_M \qquad [3\text{-}54]$$

Z_M , Mutual Impedance Between 2 Parallel Conductors



Pipeline-Powerline Geometry for Calculation of LEF

$$Z_M = j \cdot f \cdot \mu_0 \cdot \ln \frac{\sqrt{\left(h - h' + 2\sqrt{\rho / j2\pi f \mu_0}\right)^2 + d^2}}{\sqrt{(h + h')^2 + d^2}}$$

where:

- f = frequency (Hz)
- μ_0 = permeability of free space = 1.26×10^{-6} H/m
- ρ = soil resistivity (Ω-m)
- j = complex operator

and where: h, h', d, and D define the pipeline-powerline geometry

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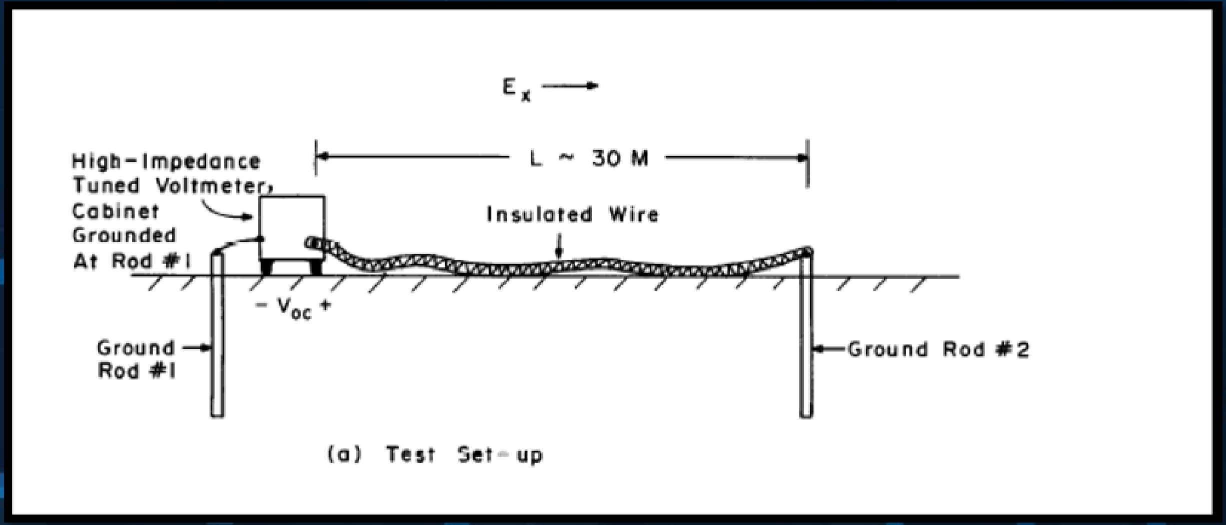
Field Simulation of Longitudinal Electric Field (LEF):



INGAA Study – AC Modeling

- INGAA Foundation Study (http://www.ingaa.org) – "Criteria for Pipelines Co-Existing with Electric Power Lines"
- Study Performed by Det Norske Veritas (U.S.A.) Inc. (DNV GL)
- Project commenced May 2014; Final Report issued October 2015
- Provides guidelines for risk analysis based on five criteria
- A major conclusion of the study encourages sharing of TL data to foster closer coordination between pipeline operators and transmission line companies

INGAA FOUNDATION

Available on INGAA Foundation web site at:
http://www.ingaa.org/Foundation/Foundation-Reports/24712.aspx

The INGAA Foundation, Inc.

Criteria for Pipelines Co-Existing with Electric Power Lines

Prepared For:
The INGAA Foundation

Prepared By:
DNV GL

October 2015

The INGAA Foundation
FINAL Report No. 2015-04

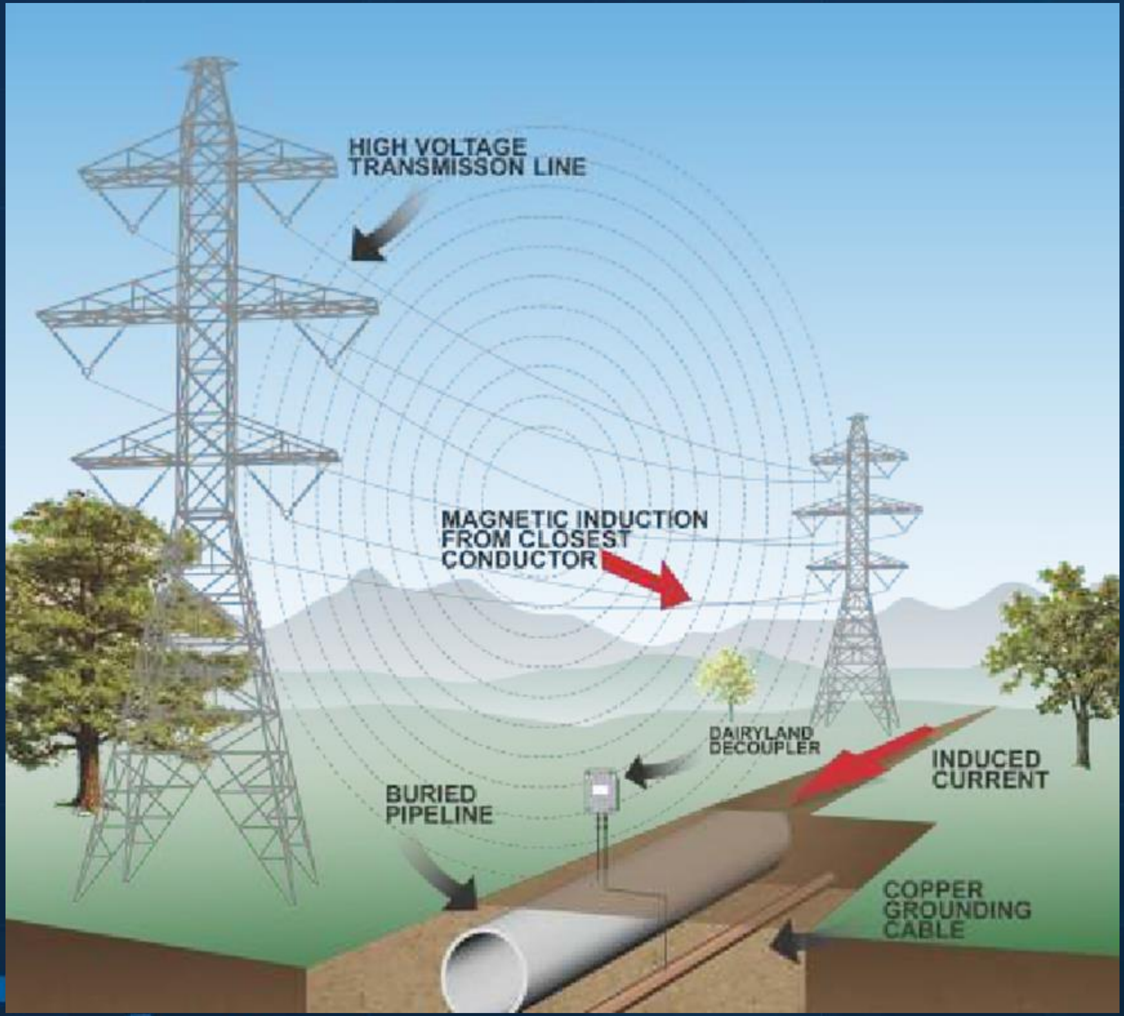
Reason for the INGAA Study

Predicting ac interference on pipelines is a complex problem, with multiple interacting variables affecting the influence and consequences.

Detailed computer modeling generally requires extensive data collection, field work, and subject-matter expertise. $$, ⏱

The quality and accuracy of the computer modeling results are directly related to the quality of the data and assumptions utilized to perform the modeling.

The report provides basic guidelines for a risk-based decision-making process to help prioritize regions for detailed modeling or to exclude regions from modeling to improve the efficiency of addressing induced ac issues.



INGAA Summary of (5) Key Variable Severity Rankings

Separation Distance - D (Feet)	Severity Ranking of HVAC Interference
D < 100	High
100 < D < 500	Medium
500 < D < 1,000	Low
1,000 < D ≤ 2,500	Very Low

Collocation/Crossing Angle - θ (°)	**Relative Severity**
θ < 30	**High**
30 < θ < 60	**Medium**
θ > 60	**Low**

Collocation Length: L (feet)	Relative Severity
L > 5,000	High
1,000 < L < 5,000	Medium
L < 1,000	Low

HVAC Current - I (amps)	Relative Severity of HVAC Interference
I ≥ 1,000	Very High
500< I > 1,000	High
250 < I < 500	Medium-High
100< I < 250	Medium
I < 100	Low

Soil Resistivity - ρ (ohm-cm)	**Relative Severity of HVAC Corrosion**
ρ < 2,500	**Very High**
2,500 < ρ < 10,000	**High**
10,000 < ρ < 30,000	**Medium**
ρ > 30,000	**Low**

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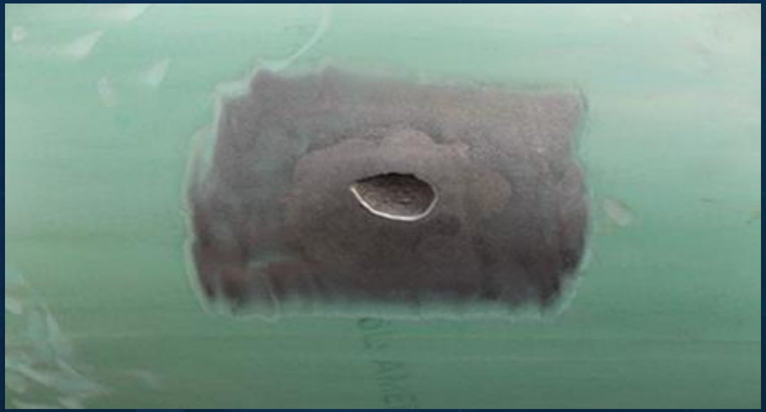
Induced AC | Key Points

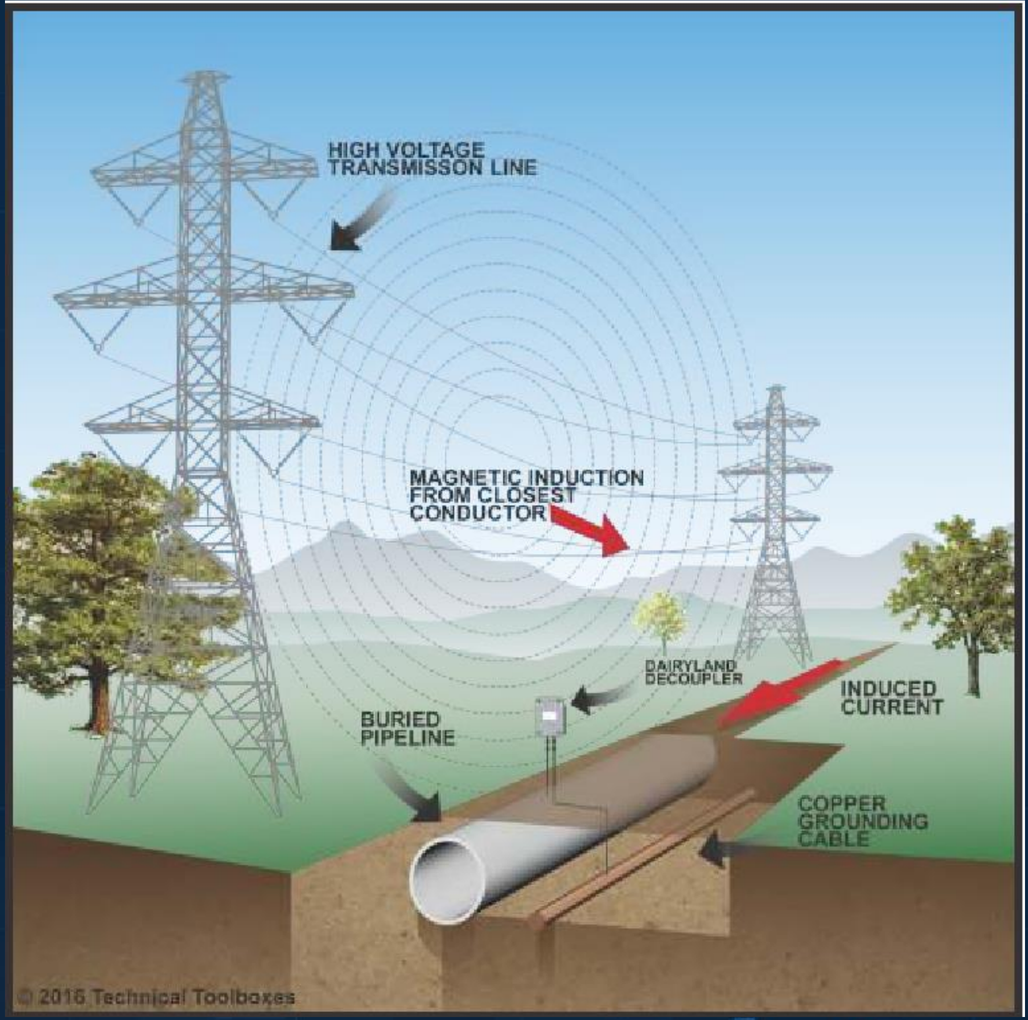
Most important things to remember related to AC Voltages:

- 15 volt Limitation for Protection of Personnel
- Voltages of 1000 volts - 3000 volts Causes Coating Damage.
- >5000 volts Can Cause Pipe Structural Damage
- AC corrosion typically occurs at AC current densities greater than 100 A/m^2 (~9.3 A/ft^2). Typically in locations with low soil resistance.
- Highest corrosion rates occur at coating defects with surface areas between 1 and 3 cm^2 (0.16 in^2 – 0.47 in^2). Very small coating defects.
- AC corrosion typically has pimple like blisters and have very round corrosion pit morphology.

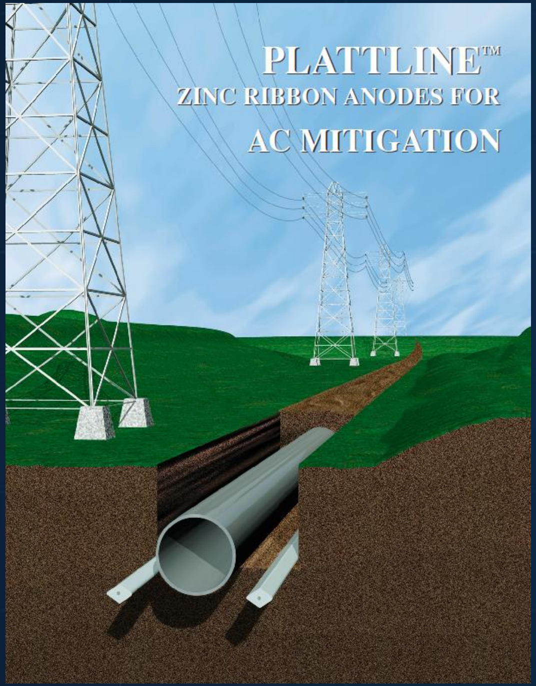


AC Interference Mitigation & Testing

Induced AC Mitigation – In One Picture



Typical AC Mitigation Grounding Components



Specification Chart	Super	Plus	Standard	Small
Product Size	Super	Plus	Standard	Small
Cross Section: Inches Millimeters	1" x 1-1/4" 25.4 x 31.75	5/8" x 7/8" 15.88 x 22.22	1/2" x 9/16" 12.7 x 14.28	11/32" x 13/32" 8.73 x 10.32
Weight/Foot, Pounds [1] Weight/Kg., Meters	2.4 3.570	1.2 1.785	0.6 .8925	0.25 .372
Diameter of wire core [2] Inches Millimeters	0.185 4.70	0.135 3.43	0.130 [3] 3.30	0.115 2.92
Standard Coil Length [4] Feet Meters	100 $^{+10}_{-0}$ 30.5 $^{+3}_{-0}$	200 $^{+20}_{-0}$ 61 $^{+6.1}_{-0}$	500 $^{+30}_{-0}$ 152 $^{+9}_{-0}$	1000 $^{+50}_{-0}$ 305 $^{+15}_{-0}$
Standard Coil I.D. Inches Centimeters	36 91.44	36 91.44	12 30.5	12 30.5
Packaging	Steel-banded random-wound open coils	Steel-banded random-wound open coils	Wood Reels	Wood Reels

Sizing an Equipment Grounding Conductor	
Overcurrent Device Rating	Copper Conductor
15A	14 AWG
20A	12 AWG
25A to 60A	10 AWG
70A to 100A	8 AWG
110A to 200A	6 AWG
225A to 300A	4 AWG
350A to 400A	3 AWG
450A to 500A	2 AWG
600A	1 AWG
700A to 800A	1/0 AWG
1,000A	2/0 AWG
1,200A	3/0 AWG

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Other Typical AC Mitigation Components

DAIRYLAND ELECTRICAL INDUSTRIES

ISOLATE. GROUND. PROTECT.

The Isolation Switch

Installation and Operating Instructions - SSD

Installed in a 36" Fiberglass Pedestal

These instructions ONLY apply to Isolation Switch model SW-50-SSD when it is being installed along with an SSD decoupler with standard terminal arrangement (with –R suffix in model number) in a Dairyland model MTP-36. If installation is inside the discontinued model MTP-42, please use the alternate installation instructions found on www.dairyland.com. Pedestals can be identified by the dimensions of their opening where the MTP-36 has a 9"x14" opening and the MTP-42 has a 6"x6" opening.

WARNING:
When Isolation Switches are used in ac voltage mitigation applications, if multiple or all decouplers are disconnected, the pipeline voltage may rise to an unsafe level (i.e., above the 15Vac that NACE standards consider safe). Therefore, safety precautions should be implemented by the user when decouplers are isolated from the pipeline, particularly at pipeline contact points. Dairyland will provide suggested procedures for installing and operating the Isolation Switch, but the user must be responsible for and approve the procedures to be used by its workers when initially installing the Isolation Switch in a field retrofit installation and when operating the Isolation Switch to disconnect or reconnect a decoupler because Dairyland cannot be familiar with each users safety guidelines.

WARNING:
Isolation Switches are not to be installed in a defined hazardous location, but rather in an "ordinary" location.

CAUTION:
When a SSD is being used to provide ac grounding for an item of electrical equipment, an Isolation Switch should not be installed because per electric codes such equipment must always be solidly AC grounded.

INTRODUCTION

The SSD is available with two different terminal configurations as illustrated. The SSD version of the Isolation Switch can be installed on either model. These instructions only pertain to the SSD model on the right with the –R suffix in the model number.

The SSD version of the Isolation Switch is illustrated below showing toggle switch and link positions when a decoupler is connected versus disconnected from the cathodically protected structure.

SSD Isolation Switch: SW-50-SSD Decoupler Connected

SSD Isolation Switch: SW-50-SSD Decoupler Disconnected

For worker safety during installation, it was recommended in Dairyland's Isolation Switch ordering information that the user obtain certain equipment; namely a pair of electrically insulated gloves, a shorting cable approximately 3 ft in length with insu-

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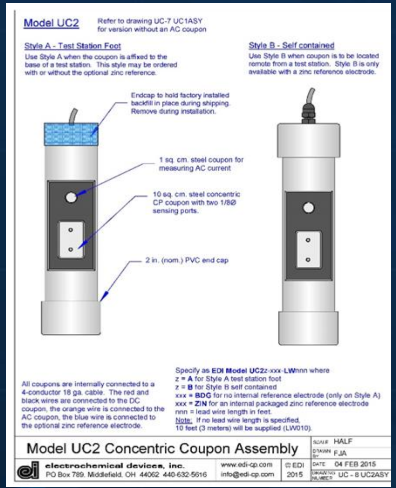
Rev. 4/15



Model UC2 — Refer to drawing UC-7 UC1ASY for version without an AC coupon

Style A - Test Station Foot

Use Style A when the coupon is affixed to the base of a test station. This style may be ordered with or without the optional zinc reference.

Style B - Self contained

Use Style B when coupon is to be located remote from a test station. Style B is only available with a zinc reference electrode.

Endcap to hold factory installed backfill in place during shipping. Remove during installation.

1 sq. cm. steel coupon for measuring AC current

10 sq. cm. steel concentric CP coupon with two 1/8Ø sensing ports.

2 in. (nom.) PVC end cap

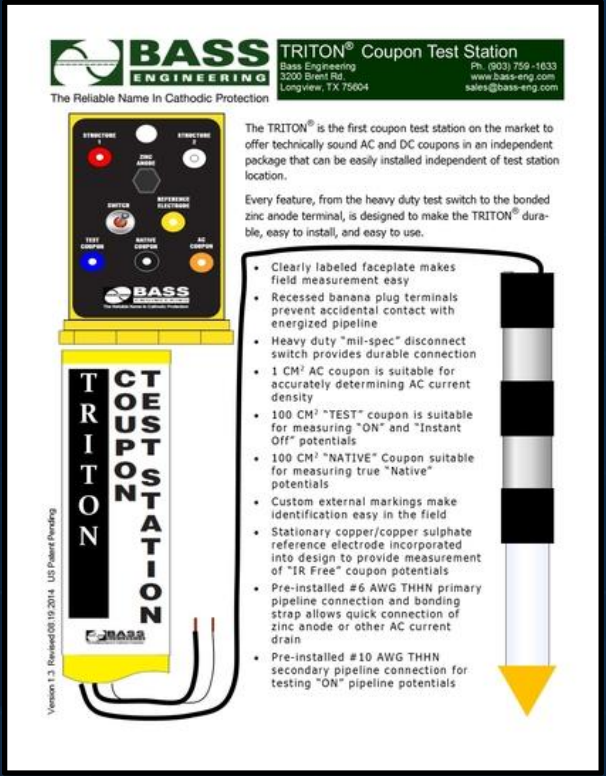
All coupons are internally connected to a 4-conductor 18 ga. cable. The red and black wires are connected to the DC coupon, the orange wire is connected to the AC coupon, the blue wire is connected to the optional zinc reference electrode.

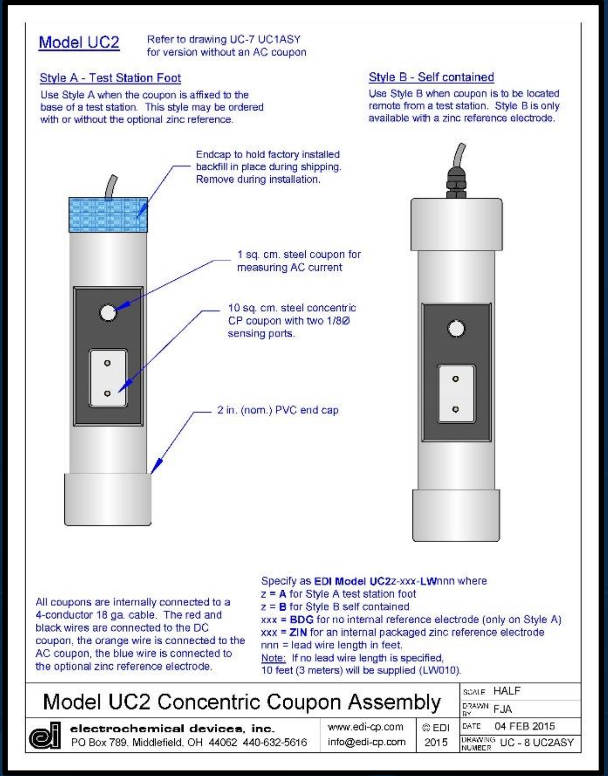
Specify as **EDI Model UC2**z-xxx-**LW**nnn where
z = **A** for Style A test station foot
z = **B** for Style B self contained
xxx = **BDG** for no internal reference electrode (only on Style A)
xxx = **ZIN** for an internal packaged zinc reference electrode
nnn = lead wire length in feet.
Note: If no lead wire length is specified, 10 feet (3 meters) will be supplied (LW010).

Model UC2 Concentric Coupon Assembly		SCALE HALF
		DRAWN BY FJA
electrochemical devices, inc. PO Box 789, Middlefield, OH 44062 440-632-5616	www.edi-cp.com info@edi-cp.com	© EDI 2015 · DATE 04 FEB 2015 · DRAWING NUMBER UC - 8 UC2ASY

AC & DC Coupon Test Stations

Coupon test stations are invaluable for system testing. Some typical industry available models are as follows:





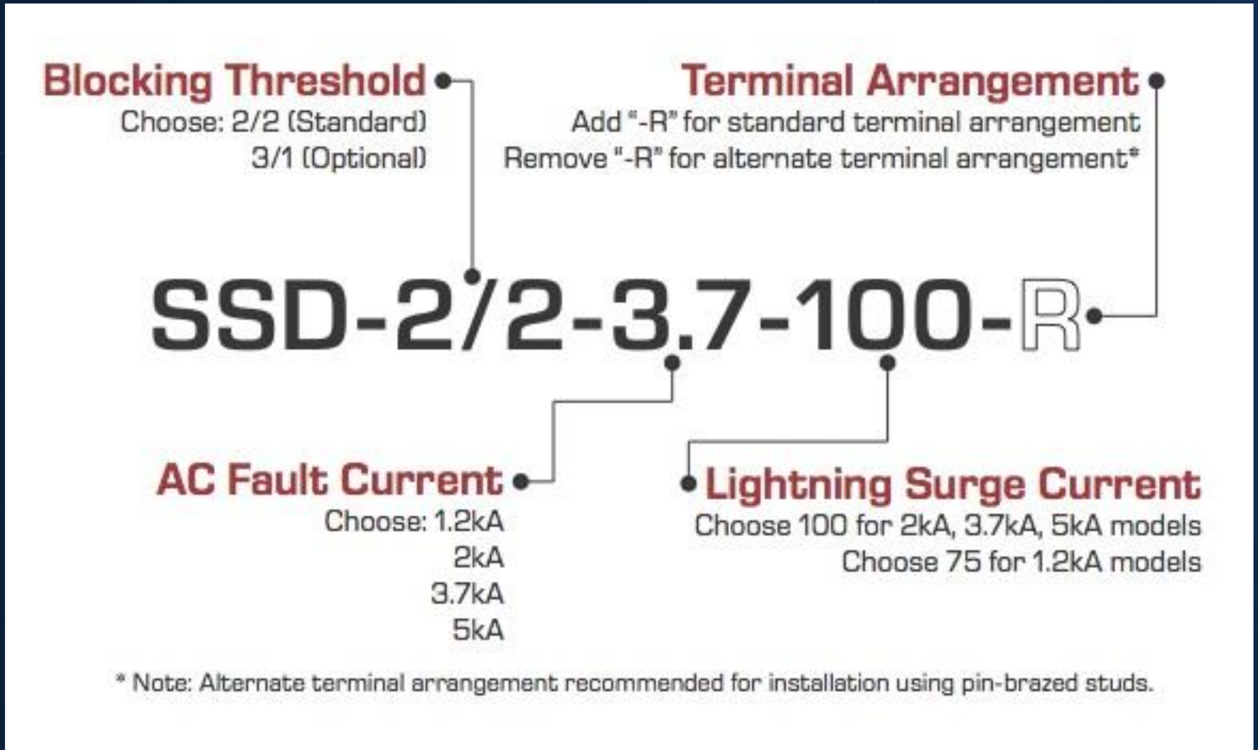
What is a Decoupler?

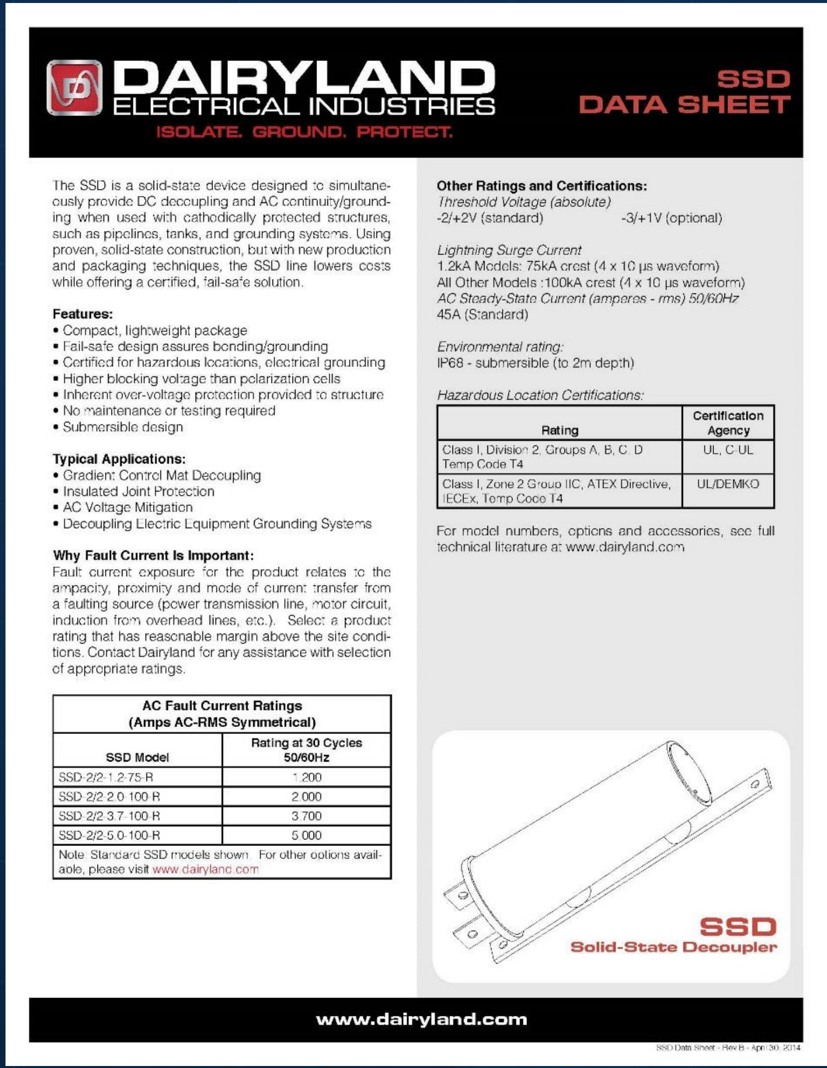
- Device with very low impedance to AC but blocks DC up to a predetermined voltage level, typically 2 to 3 volts
- Typical AC impedance: 10 milliohms
- Typical DC resistance: Megaohms
- Solid-state construction, two terminal device
- Connects between pipeline and ground, or other structure:
  - Virtually the same as direct bonding for AC, but
  - DC isolates the grounding system from the pipeline CP system

http://www.dairyland.com/knowledge-base-article/33-getting-started/68-video-training-decoupler-101-updated

POND

Dairyland SSD Ratings





DAIRYLAND ELECTRICAL INDUSTRIES

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SSD DATA SHEET

The SSD is a solid-state device designed to simultaneously provide DC decoupling and AC continuity/grounding when used with cathodically protected structures, such as pipelines, tanks, and grounding systems. Using proven, solid-state construction, but with new production and packaging techniques, the SSD line lowers costs while offering a certified, fail-safe solution.

Features:
- Compact, lightweight package
- Fail-safe design assures bonding/grounding
- Certified for hazardous locations, electrical grounding
- Higher blocking voltage than polarization cells
- Inherent over-voltage protection provided to structure
- No maintenance or testing required
- Submersible design

Typical Applications:
- Gradient Control Mat Decoupling
- Insulated Joint Protection
- AC Voltage Mitigation
- Decoupling Electric Equipment Grounding Systems

Why Fault Current Is Important:
Fault current exposure for the product relates to the ampacity, proximity and mode of current transfer from a faulting source (power transmission line, motor circuit, induction from overhead lines, etc.). Select a product rating that has reasonable margin above the site conditions. Contact Dairyland for any assistance with selection of appropriate ratings.

AC Fault Current Ratings (Amps AC-RMS Symmetrical)	
SSD Model	Rating at 30 Cycles 50/60Hz
SSD-2/2-1.2-75-R	1,200
SSD-2/2-2.0-100-R	2,000
SSD-2/2-3.7-100-R	3,700
SSD-2/2-5.0-100-R	5,000
Note: Standard SSD models shown. For other options available, please visit www.dairyland.com	

Other Ratings and Certifications:
Threshold Voltage (absolute)
-2/+2V (standard) -3/+1V (optional)

Lightning Surge Current
1.2kA Models: 75kA crest (4 x 10 µs waveform)
All Other Models :100kA crest (4 x 10 µs waveform)
AC Steady-State Current (amperes - rms) 50/60Hz
45A (Standard)

Environmental rating:
IP68 - submersible (to 2m depth)

Hazardous Location Certifications:

Rating	Certification Agency
Class I, Division 2, Groups A, B, C, D Temp Code T4	UL, C-UL
Class I, Zone 2 Group IIC, ATEX Directive, IECEx, Temp Code T4	UL/DEMKO

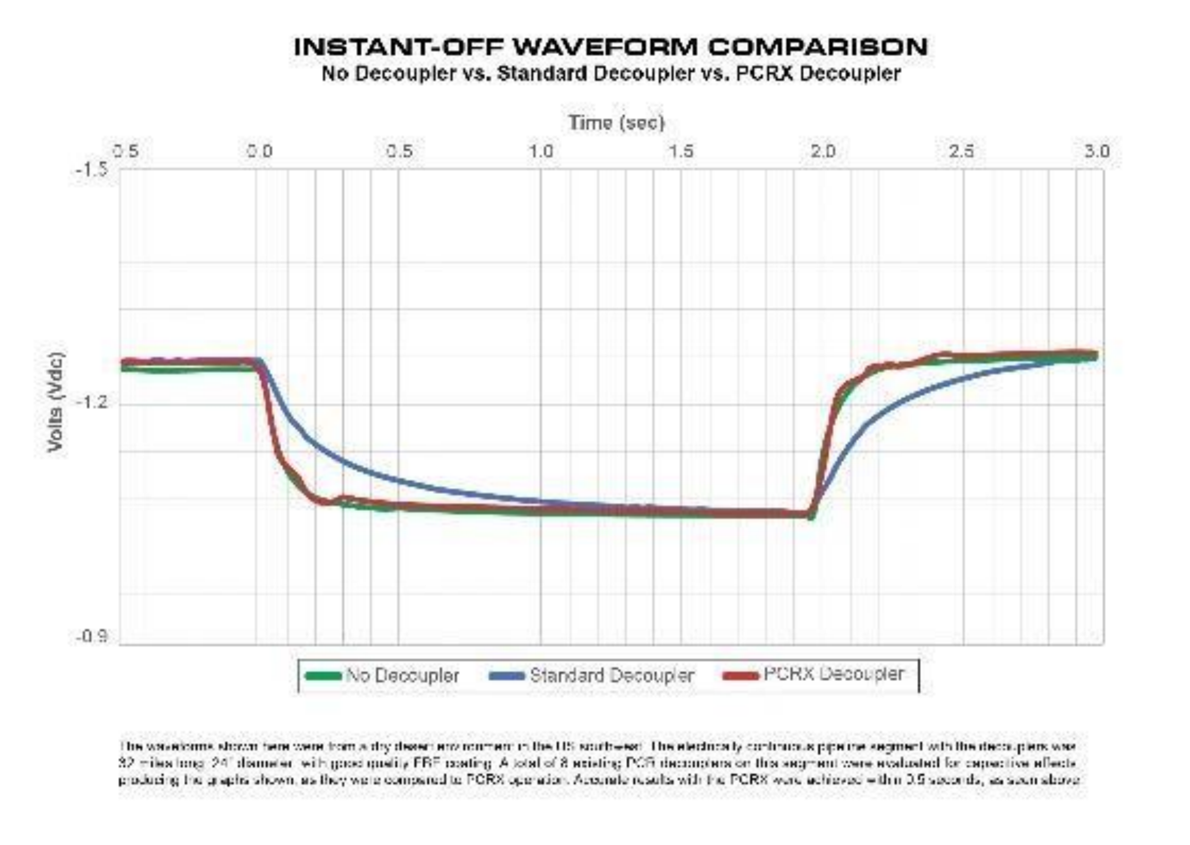
For model numbers, options and accessories, see full technical literature at www.dairyland.com

SSD
Solid-State Decoupler

www.dairyland.com

SSD Data Sheet - Rev B - April 30, 2014

Dairyland PCRX



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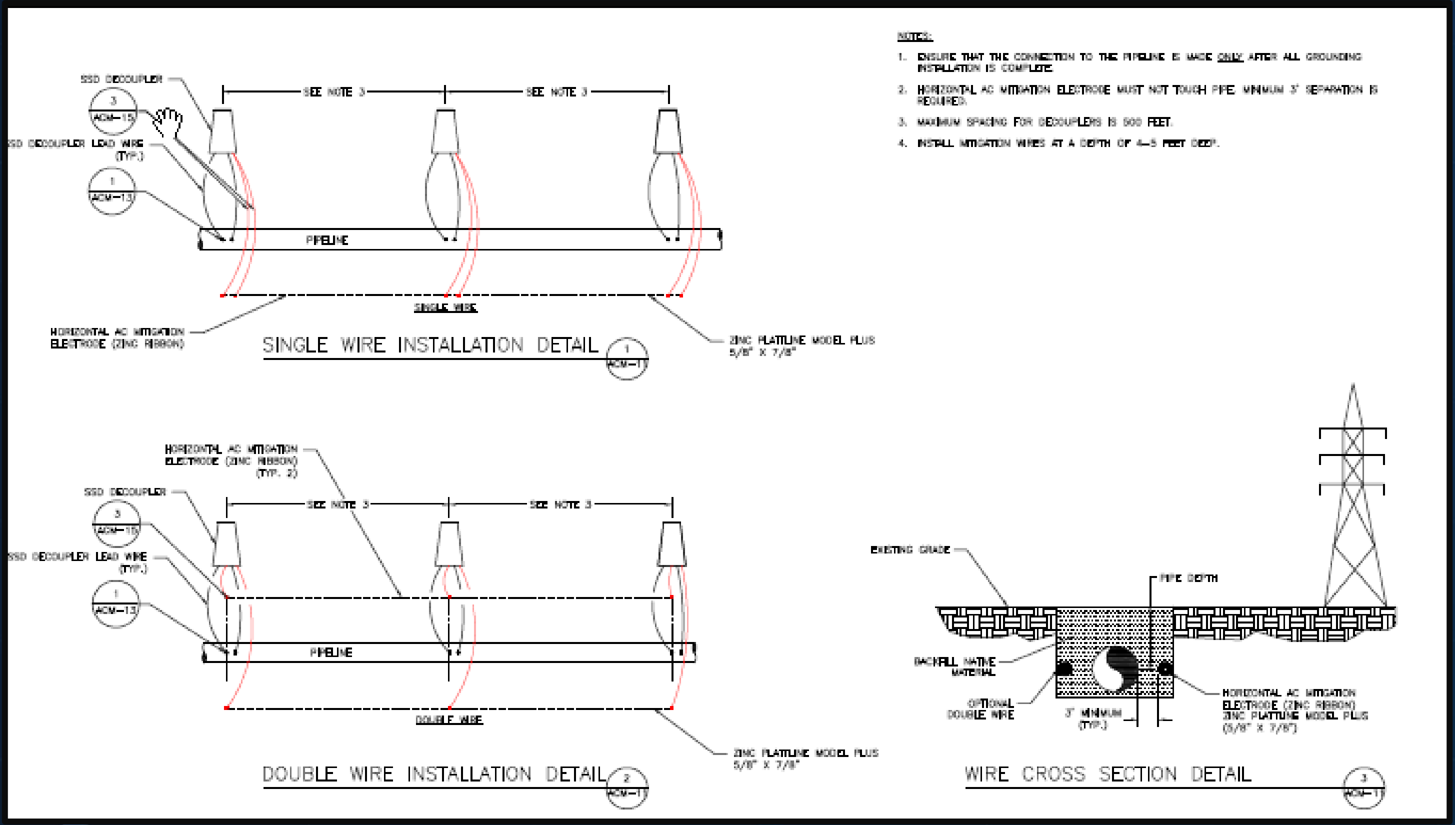
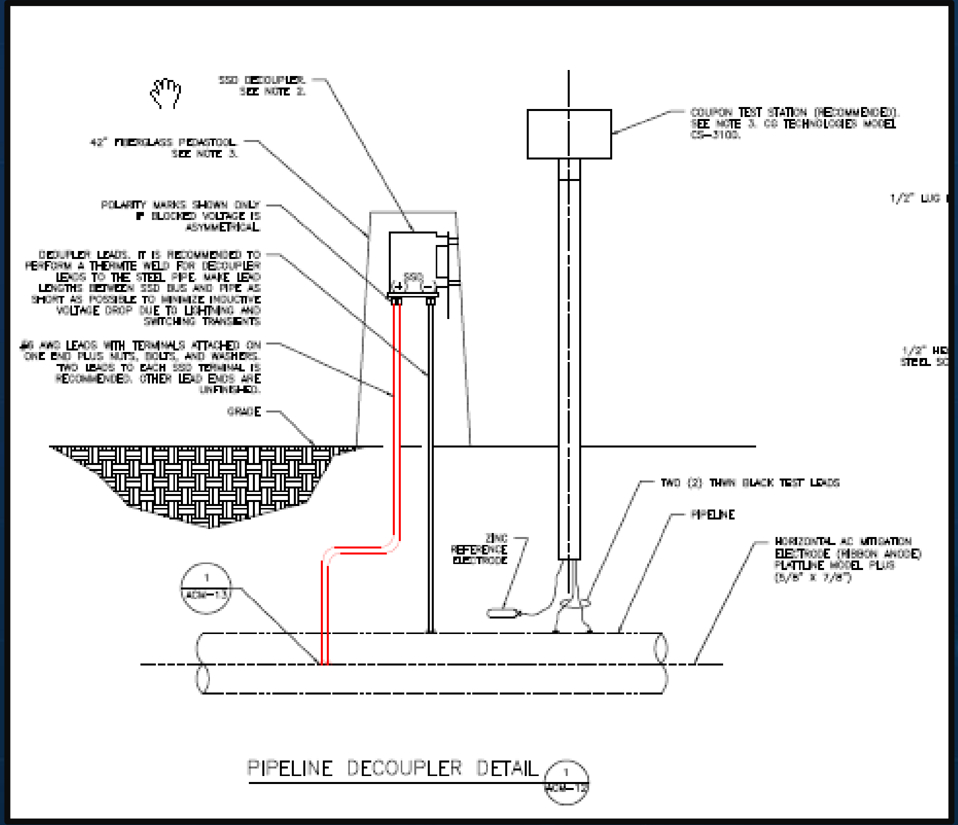
AC Mitigation Layouts | Horizontal





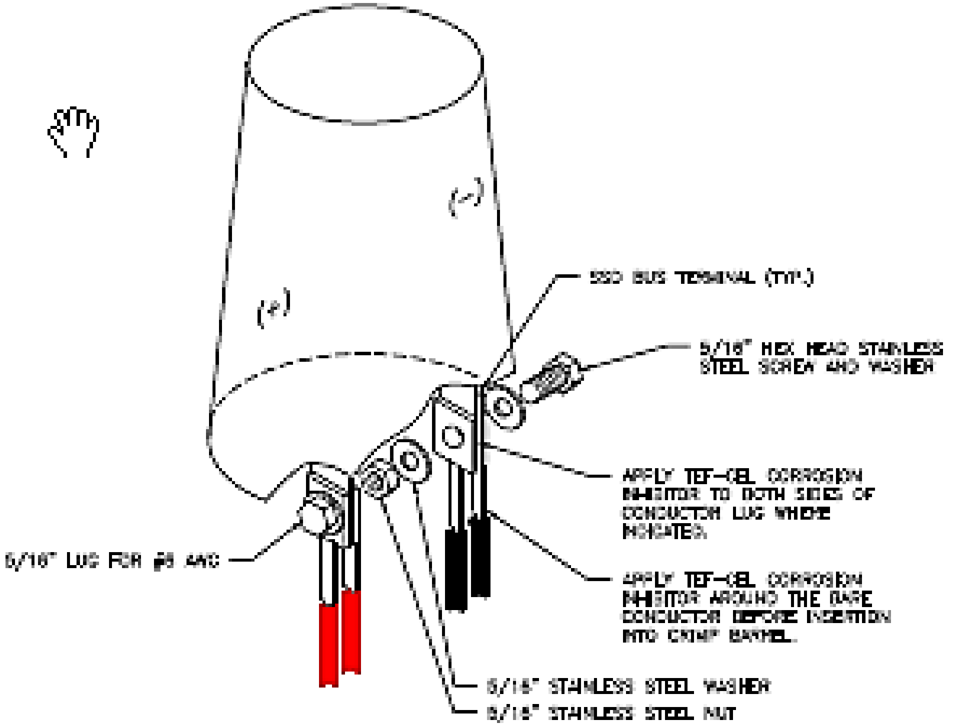
Typical AC Mitigation Install for Existing Pipeline | Parallel

Terminations Aboveground

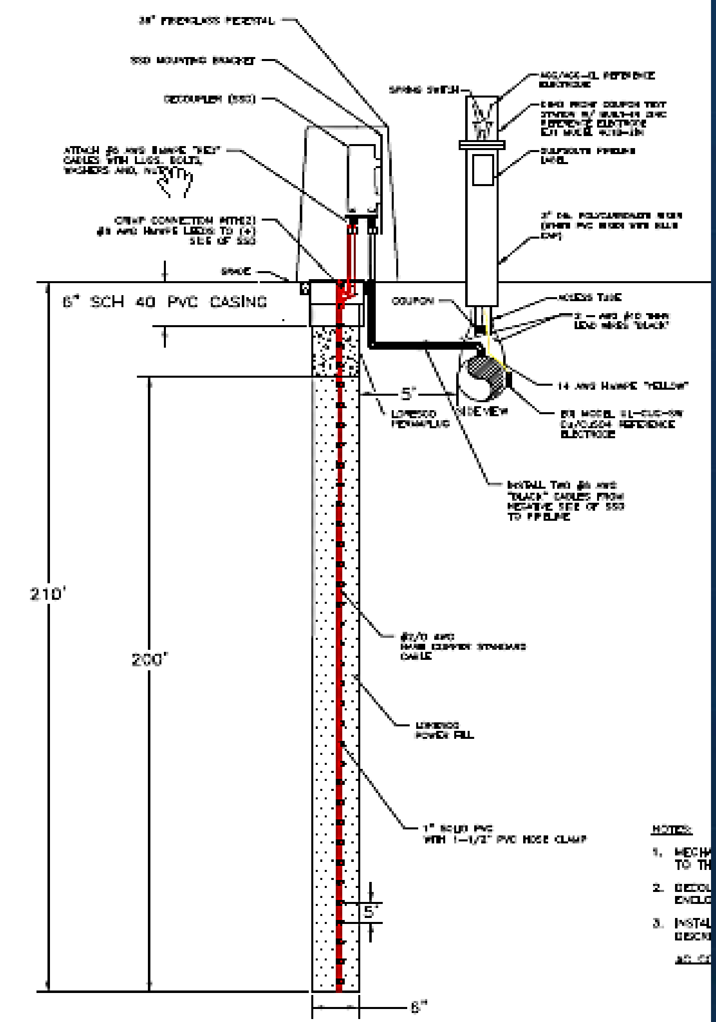
Cable Plow With Zinc Reel Trailer

Cable Plow Installing Zinc Ribbon

Typical AC Mitigation Design Layout | Vertical



CABLE TO SSD TERMINAL CONNECTION DETAIL



VERTICAL DRAIN POINT GROUNDING SYSTEM DETAIL

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Typical AC Mitigation Design Layout | Vertical

Typical AC Mitigation Layout | Stations

Testing the Effectiveness of AC Mitigation:

- AC pipe-to-soil potential (at test stations and above ground appurtenances) to test for shock hazard voltage
- A CIS (both VDC and VAC) to test the effectiveness of the cathodic protection system as well as the AC potentials on the line. (ON/OFF, the use of decouplers is critical to collect OFF (IR Free) potentials)
- Soil resistivity measurements at high VAC locations
- Calculation of IAC to determine risk of AC corrosion
- Additional localized mitigation measures if needed

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Testing - Interruption Warning

- Isolating decoupler from AC mitigation system removes AC reduction function
- AC voltage on pipe will increase
- Increases with additional decouplers removed
- Wire from pipe (or Iso Switch terminal) will be at pipeline AC voltage
- Minor arcing will occur as system is disconnected/reconnected with associated current flow

AC Mitigation Effect on Potential Readings

Solid State Decoupler: Purpose

- Mitigate induced AC voltage
- Maintain CP voltage
- Provide over-voltage protection for: AC faults, lightning, static, or other sources
- Do so while meeting codes for: safety grounding, hazardous locations use, etc.

Solid State Decoupler: Potential Effect

- Voltage of interest depends upon AC current across Decoupler
- The capacitive voltage of Decoupler electrically charges the pipeline
- Pipe-to-soil voltage is different value from real potential
- CP voltage across de-coupler is present when close interval survey occurs

Solid State Decoupler: Potential Effect

- Interrupted surveys create fast changes in DC voltage
- Apparent voltage appears a step change
- Capacitance of system (decoupler, coating, etc.) doesn’t allow voltage to change quickly
- Result can slow down waveform changes
- Recording equipment then captures VPS too electro-negative vs real value

Solid State Decoupler: Potential Effect

Traditional Pipe-to-Soil Potentials are likely to be more electronegative due to DC voltage build up at SSD's.

There is a difference between DC voltage and DC potential in this situation.

This DC voltage must be corrected in some manner to reflect our true pipe-to-soil potential.

http://www.dairyland.com/knowledge-base-article/34-video-training/31-decoupler-interaction-with-close-interval-surveys

Solid State Decoupler: Potential Effect

Decoupler has voltage across it

Current will flow as result when voltage attempts to go OFF

Until current dissipation, voltage measurement will be in error to a degree

Solid State Decoupler: Potential Effect

If mitigation is excessive, results in more decouplers than necessary

Decoupler capacitance values are additive when closely spaced

Short, well-coated lines are well insulated, and suffer worse effects

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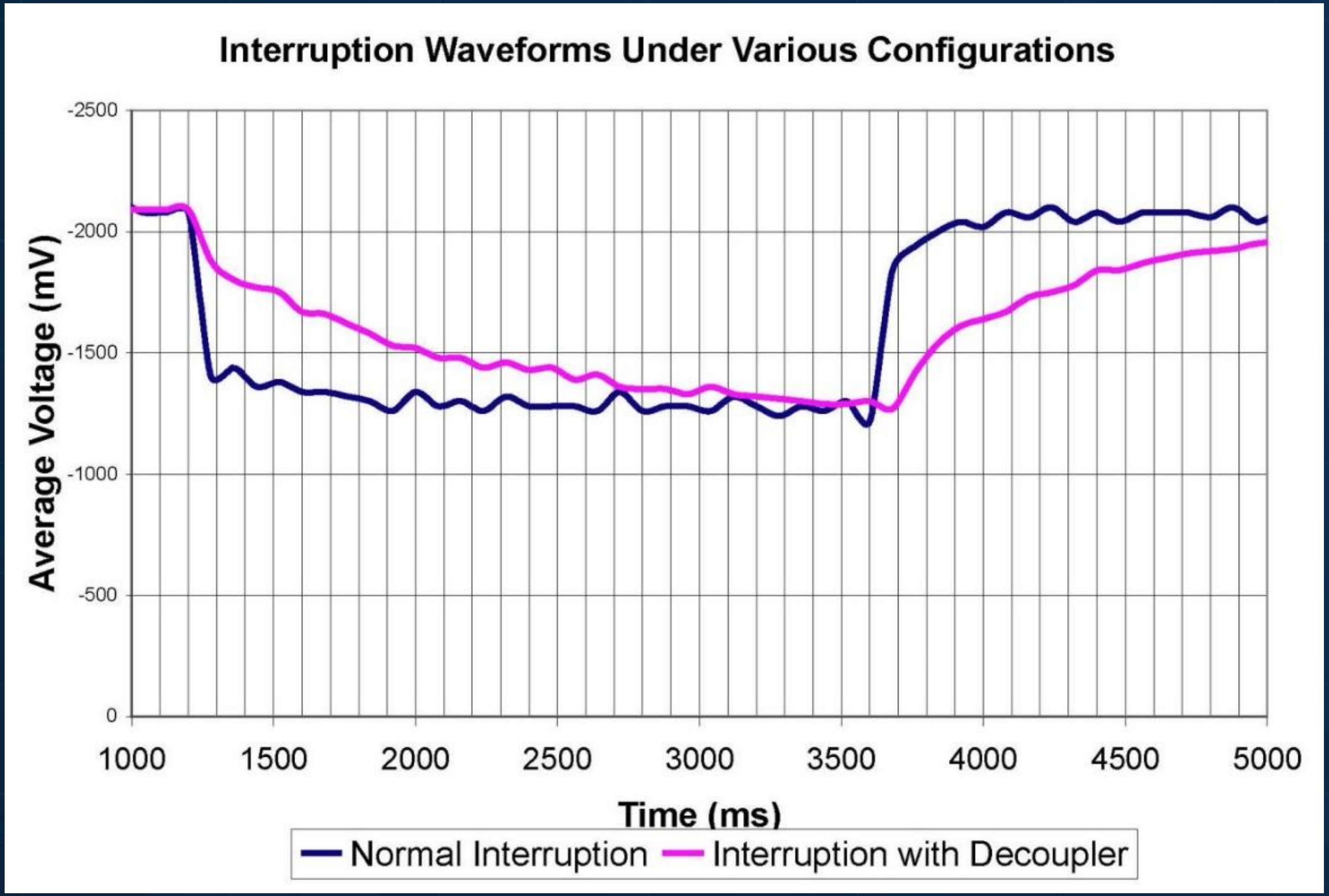
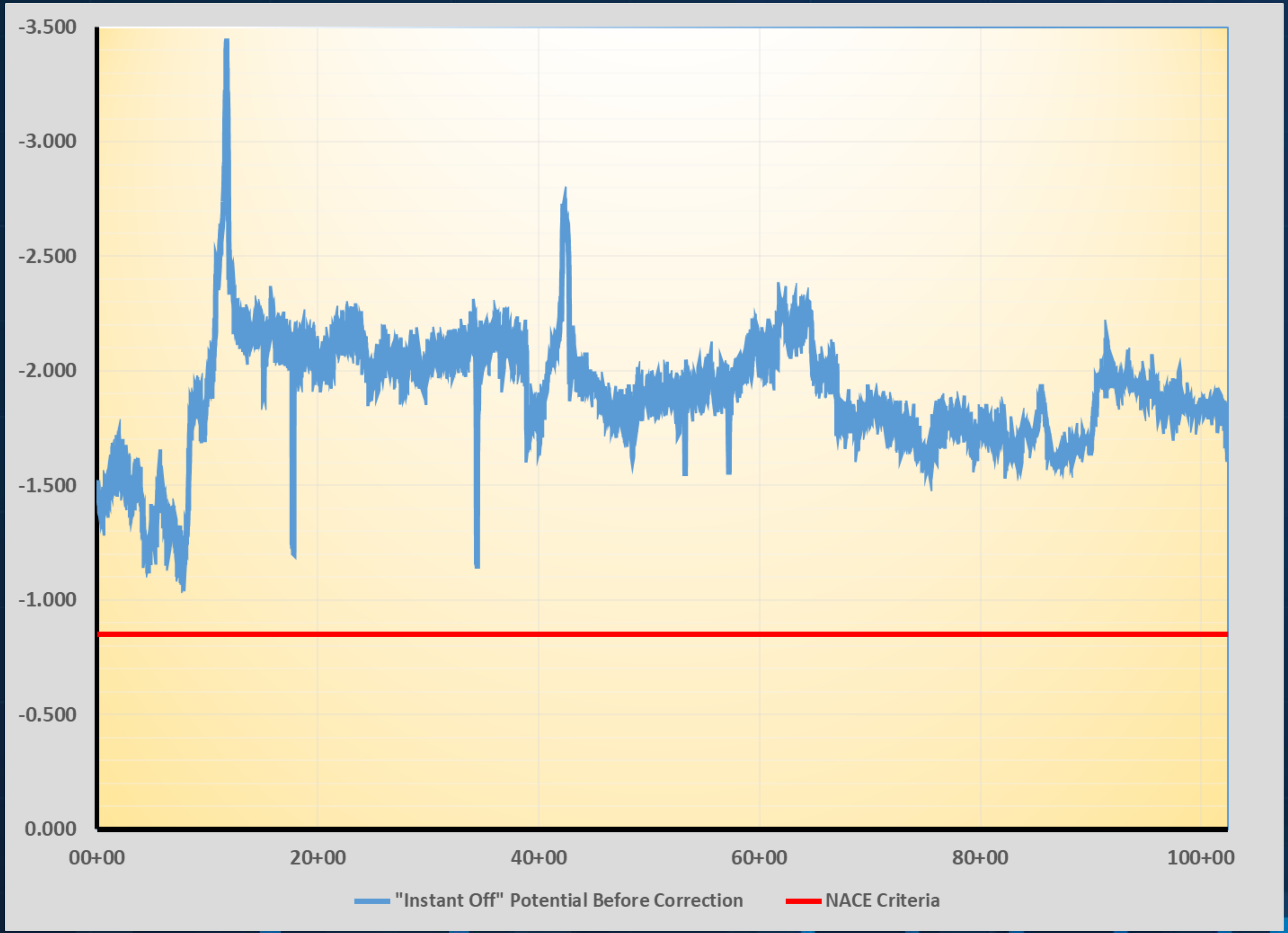
Waveform With Interruption



Measurements on a 6”- 40 mile, 16 mil FBE well coated pipeline

AC Mitigation Effect



Potential Measurement Analysis

- Traditional Pipe-to-Soil Potentials are likely to be more electronegative due to DC voltage build up at SSD's.
- There is a difference between DC voltage and DC potential in this situation that our data.

$$\mathrm{PIO_{VDC}} = \mathrm{PTI_{VDC}} + \mathrm{VE_{VDC}}$$

- Pipeline "Instant Off" = $\mathrm{PIO_{VDC}}$
- Pipeline "True Instant Off" = $\mathrm{PTI_{VDC}}$
- "Voltage Error" = $\mathrm{VE_{VDC}}$

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Solid State Decoupler: Effect Correction

- Removing decoupler from system results in no over-voltage protection for faults, lightning
- Removal eliminates AC mitigation; VAC jumps to pre-mitigation levels
- Drastic capacitance change conflicts with need for collapsing AC voltage to low levels: voltage directly tied to capacitance
- NACE SP0177 guidance: 15V limit
- AC corrosion concerns

“NOT ACCEPTABLE”

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Solution Options | Acceptable

- Adjustment of voltage reading capture time
- Take reading later in OFF cycle
- Adjustment of rectifier cycling periods
- Longer OFF period allows waveform to stabilize
- Use of correlation factors, such as IR free coupons for independent reading

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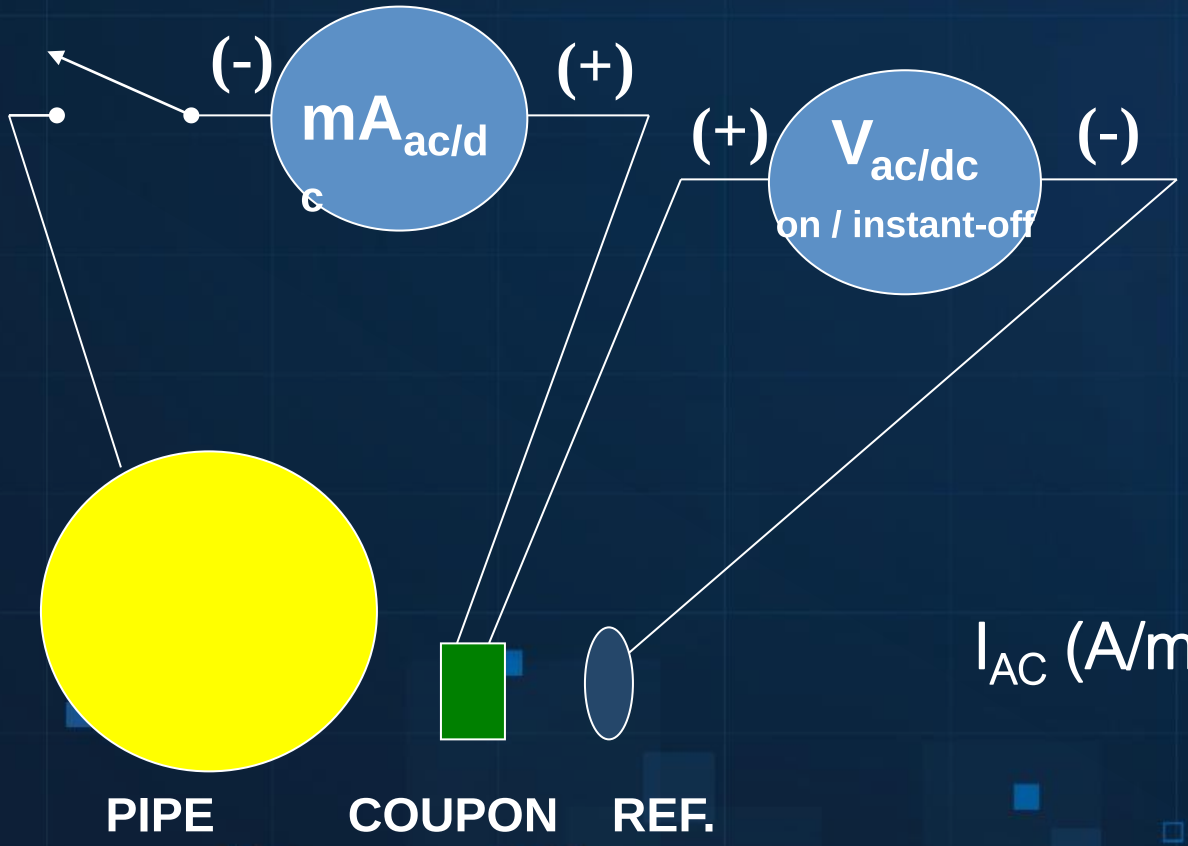
Solid State Decoupler: Effect Correction

- Use of correlation factors
- IR free coupons for independent reading



I_{AC} (A/m^2 or A/ft^2) = $I_{Measured}$ / SA_{Coupon}

AC Mitigation Effect Correction

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Correlation AC Mitigation Correction

- The Disconnect and Connected SSDs a significant influence from the SSD “Capacitive Effect”
- The Coupon Instant-disconnect Potentials Closely Relate to the Instant-off potential (4-1 cycle) with the SSDs disconnect (polarized potentials)
- The extended cycles with the SSDs connected were inconsistent and could not be relied upon to determine the polarized potential of the pipeline
- Over the time of the extended cycle survey, the instant-off potentials drifted more positive, indicating the line was depolarizing.
- The Extended Cycle Survey Should not be Used to Measure the polarized Potential

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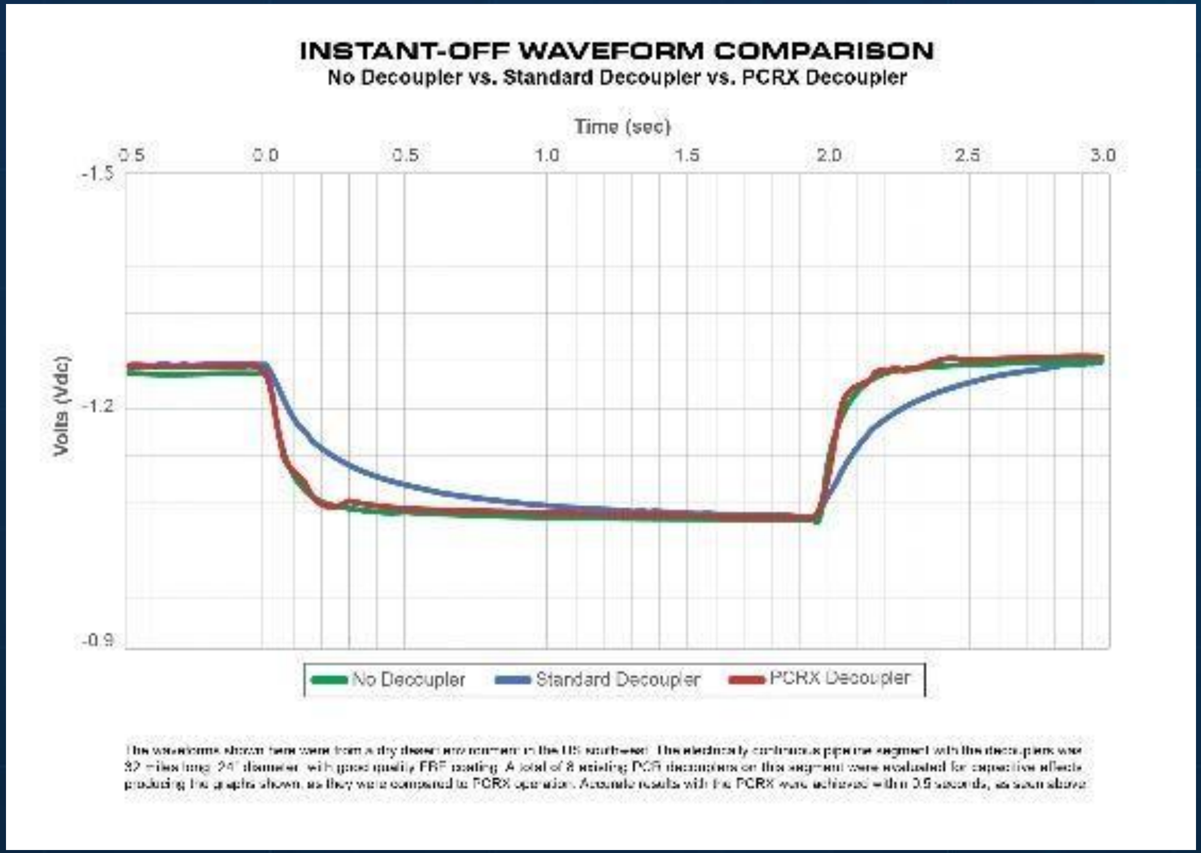

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Over Design Concerns

Installation Cost Analysis

Average AC Mitigation Cost per Linear Foot: $28/ft

Example:

- AC Mitigation Design Modeling (10 Miles Pipeline)
  - Low Price: $25,000
  - High Price: $50,000
- 10 miles of pipeline AC Mitigation Installation (Single Ribbon):
- 10 miles * 5280 ft * $28/ft = $1,478,400
- 10 miles of pipeline AC Mitigation Installation (Double Ribbon):
- 10 miles * 5280 ft * $28/ft * 2 Ribbon = $2,956,800

- Design Fee Cost Saving: $25,000
- Installation Cost Difference: $1,478,400
- Total Cost Saving: $1,453,400

RULE OF THUMB COSTS FOR FIELD DATA COLLECTION, MODELING AND DESIGN FEES FOR AC MITIGATION

RANGE FROM $2,500 TO $5,000 /mile on up

For computer modeling only, $1,000 to $1,500 on up depending on complexity of the HVPL corridor.

RULE OF THUMB – TYPICALLY IT TAKES 35 - 50% OF PIPELNE ALIGNMENT TO ACHIEVE ADEQUATE INDUCED AC MITIGATION.

IN GENERAL, EFFECTIVE MODELING WITH GOOD DATA WILL PAY FOR ITSELF.

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Project Case Studies

AC Corrosion : Case Study #1 (Typical Induced)

Here is an actual scenario:

- A number of anomalies were discovered after a regularly scheduled ILI run. The key information is as follows:
- 24” Diameter x 0.375” wall Natural Gas Transmission Pipeline
- Located in LA
- Pipe was installed in 1992, and has a FBE coating
- Soil resistivity ranged from 800 to 2000 ohm-cm (4-pin) and as little as 400 ohm-cm (via soil box)
- pH at and around the immediate vicinity of the defect 12.5
- Pipeline had effective cathodic protection IR Free pipe to soil potentials of -1100 mV vs. CSE
- Pipeline was found to have 6.1 volts AC on the line at the defect location. Given < 15 VAC, this is not a personnel hazard issue.

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AC Corrosion : Case Study #1 (Typical Induced)

AC Corrosion : Case Study #1 (Typical Induced)

Corrosion Pit (Anomaly) – 50% Wall Loss

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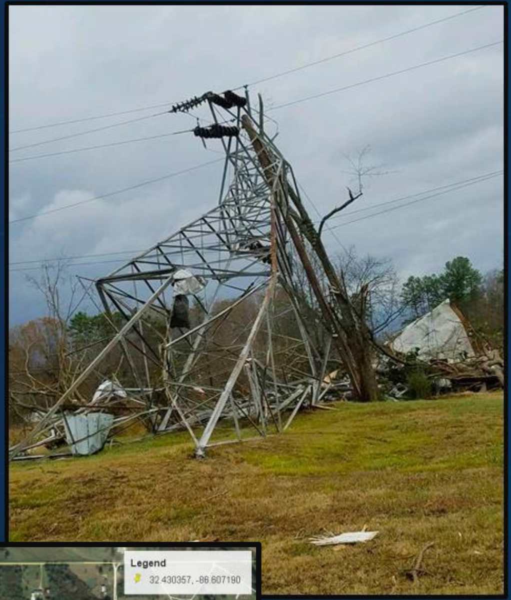
AC Corrosion : Case Study #2 (Ground Fault)

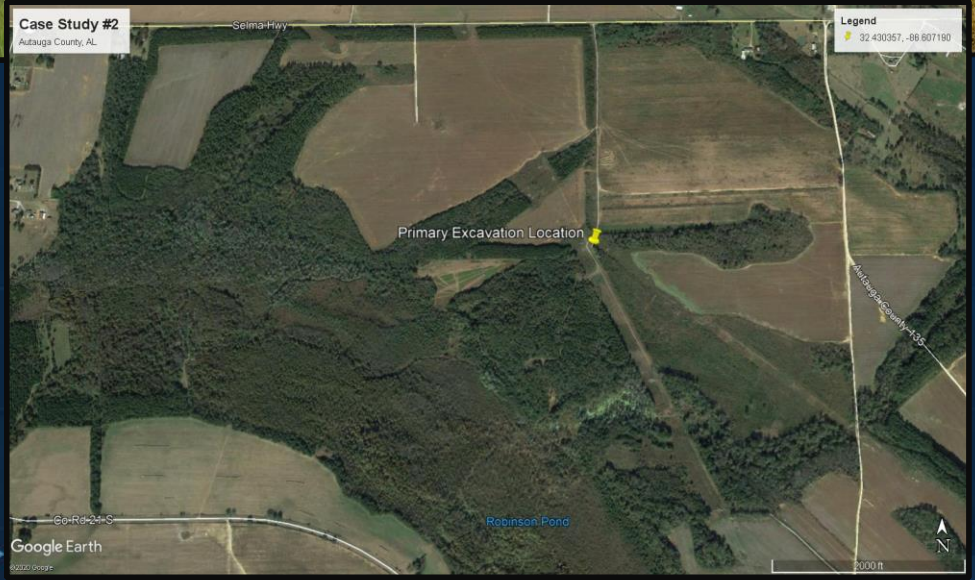
Here is an actual scenario:

- Original issue started with a tornado that toppled a HVAC tower in November 2004. Two (2) subsequent ILI runs (2009 & 2016) identified corrosion rate growth on the pipeline.

The key information is as follows:

- 24” Diameter x 0.375” wall Natural Gas Transmission Pipeline. High Pressure, MAOP >1000 psi
- Located in AL
- Pipe was installed in ~1999, and is externally coated with FBE coating
- Soil resistivity ranged from 1,000 to 2,100 ohm-cm (4-pin) .Moist soils with groundwater in trench.
- pH at and around the immediate vicinity of the defect 3.5
- Pipeline was found to have 5.9 volts AC on the line at the defect location. Given < 15 VAC, this is not a personnel hazard issue.





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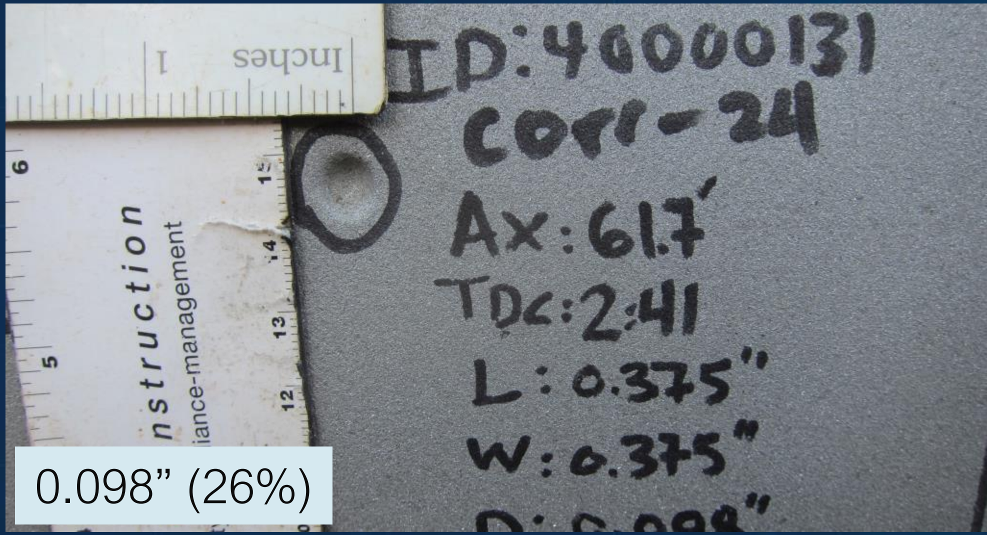
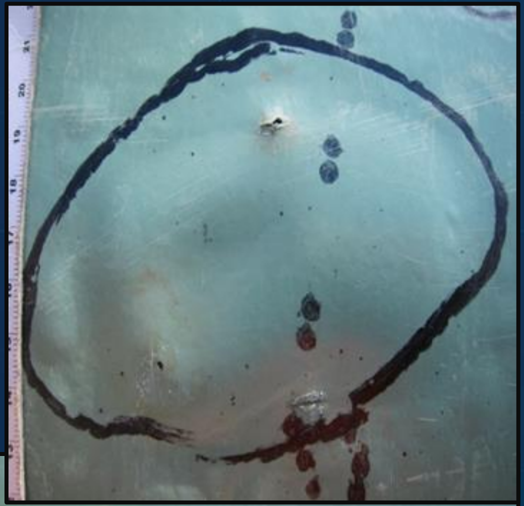
AC Corrosion : Case Study #2 (Ground Fault)

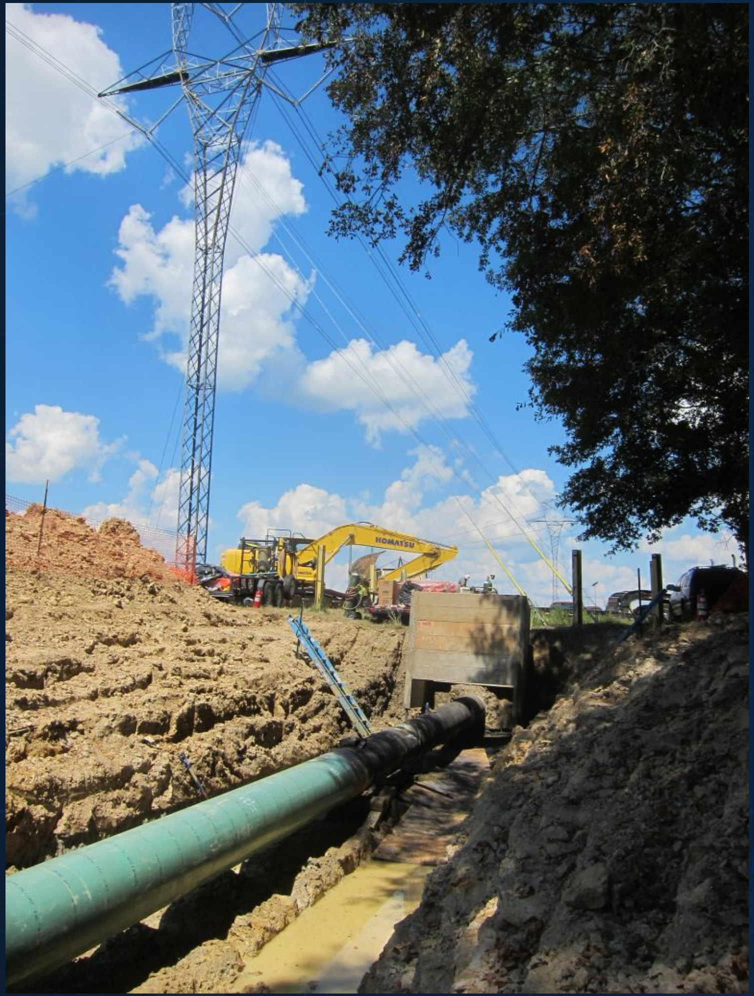


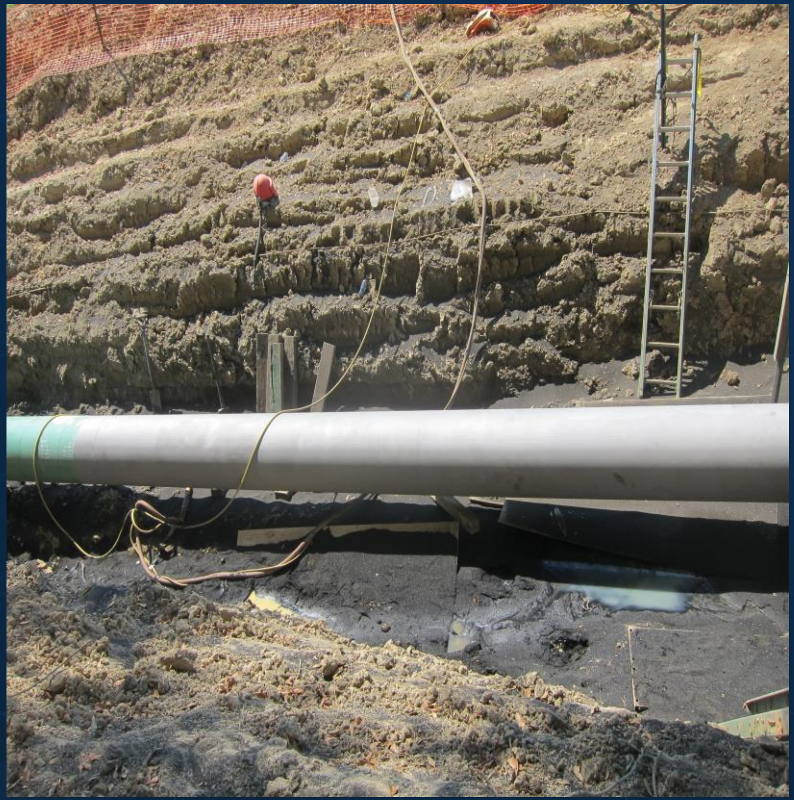
AC Corrosion : Case Study #2 (Ground Fault)

This location is ~ 0.65 miles from incident



AC Corrosion : Case Study #2 (Ground Fault)





AC Interference : Case Study #3 (Coupon Issues)

Here is an actual scenario:

- Original issue started with the client reaching a compliance issue related to a Special Permit Pipeline. Client was prepared to spend a significant amount of money to address measured AC current densities that were of concern.

The key information is as follows:

- Special Permit Pipeline compliance requirements operating under CFR 192. Within 6 months of engineering analysis, Threshold limit 50 A/m^2
- 16-inch pipeline, externally coated with coal tar enamel
- 10 miles of parallel co-location with HVAC
- Located in LA
- Soil resistivity averages 1,300 Ω-cm
- ILI inspection showed no corrosion rate growth despite the Corrosion Coupons indicating AC Current Density concerns.
- Confirm stationary coupon conditions and coupon size

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AC Interference : Case Study #3 (Coupon Issues)

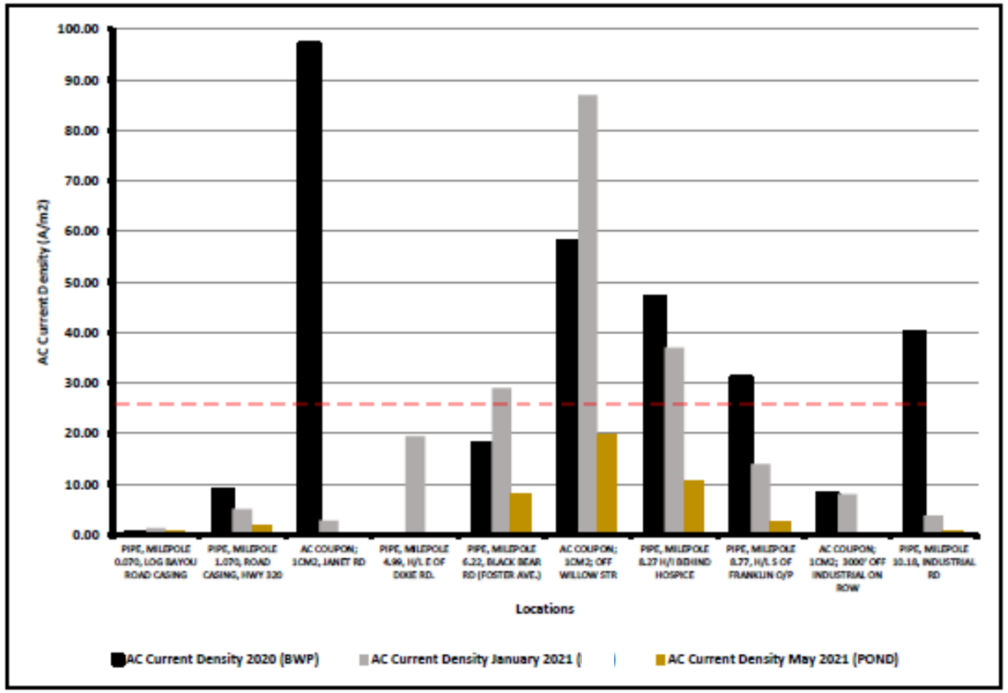

Figure 5 – AC Current Density Measurements 2020 and 2021 (1-cm² Coupons)

Table 4 – AC Current Density Measurements 2021 (1-cm² Coupons)

MP	AC Current Density (2020) A/m² (BWP)	AC Current Density (2021) A/m² (BWP)	AC Current Density (2021) A/m² (Pond)
0.07	0.30	1.30	0.70
1.07	8.80	5.10	1.70
4.18	97.00	2.80	0.20
4.99*	-	19.50	0.10
6.22	18.00	29.00	7.90
7.28	58.00	87.00	19.80
8.27	47.00	37.00	10.70
8.77	31.00	14.00	2.50
9.44	8.00	8.00	0.10
10.18	40.00	3.80	0.90

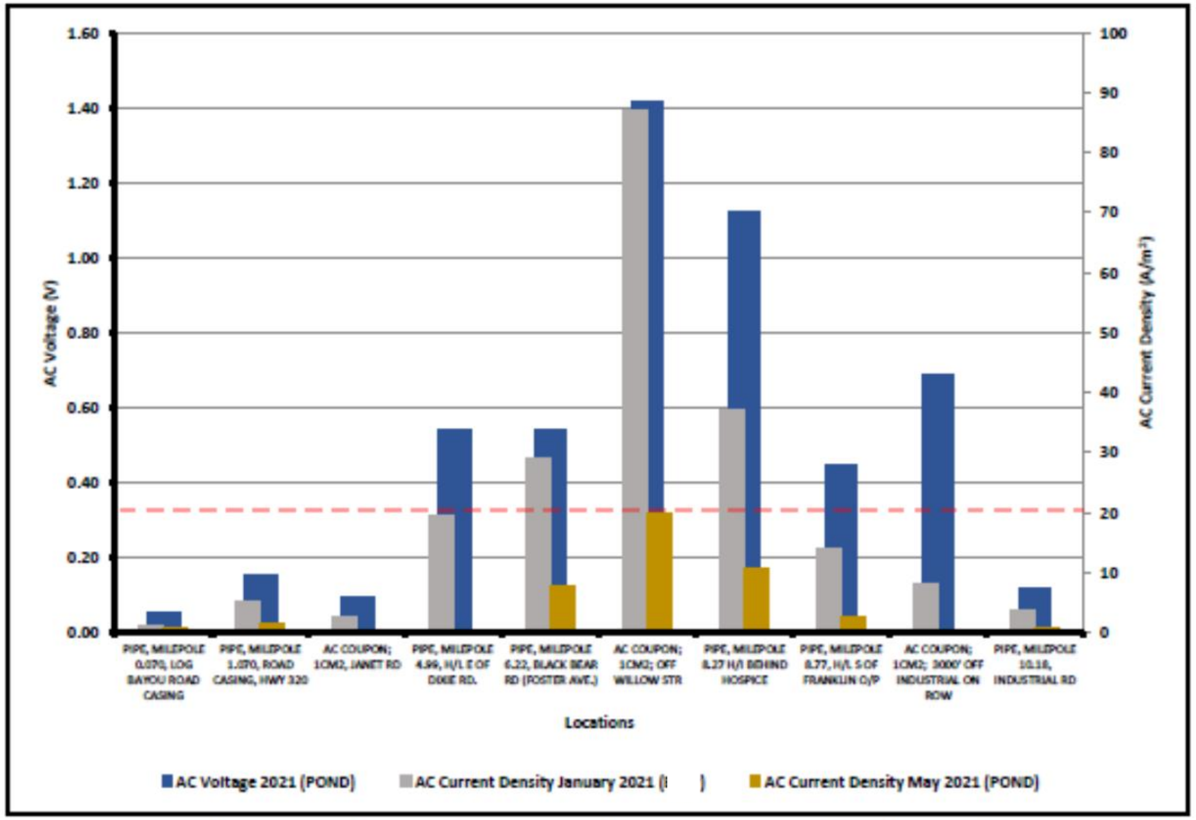

Figure 4 – AC Voltage and AC Current Density Measurements 2021 (1-cm² Coupons)

Table 3 – AC Voltage and AC Current Density Measurements 2021 (1-cm² Coupons)

0 - 20 A/m²	AC Corrosion Unlikely
20 A/m² – 100 A/m²	Corrosion Unpredictable
> 100 A/m²	AC Corrosion Expected

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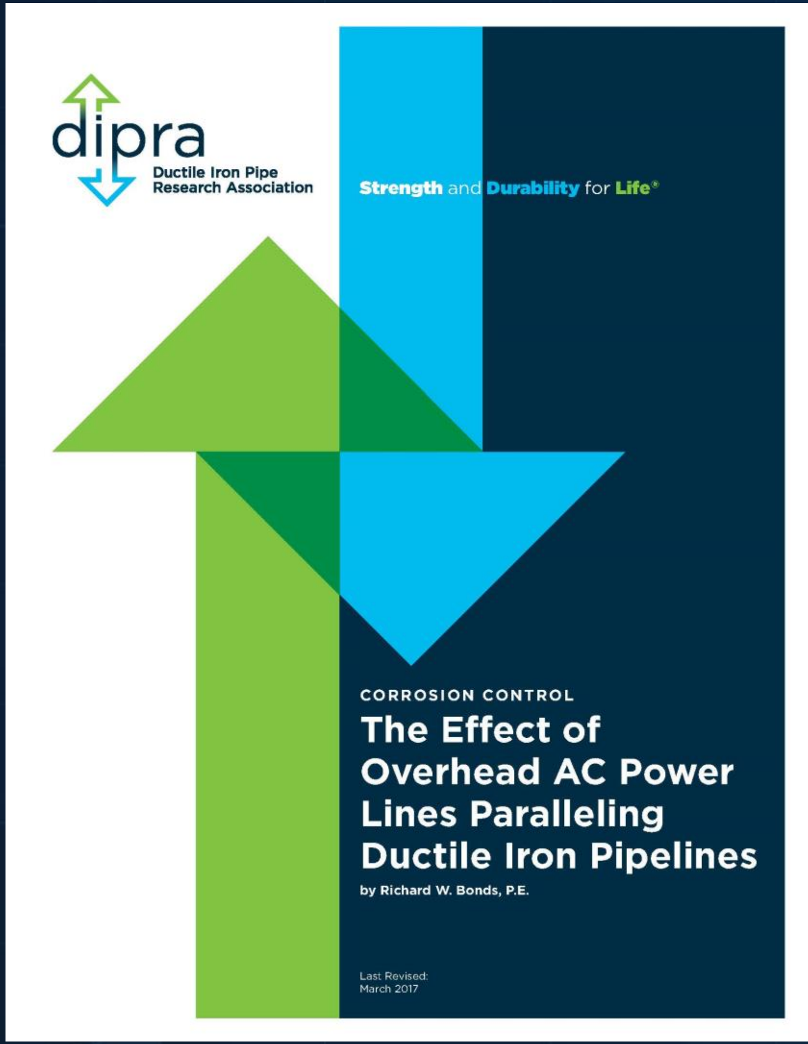
Other Pipeline Systems

Induced AC: Not Just Oil & Gas



dipra
Ductile Iron Pipe Research Association

Strength and Durability for Life®

CORROSION CONTROL

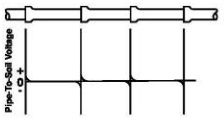
The Effect of Overhead AC Power Lines Paralleling Ductile Iron Pipelines

by Richard W. Bonds, P.E.

Last Revised: March 2017

FIGURE 8

Effect On Non-Electrically Continuous Bare Pipelines



Conclusion

A consequence of AC power lines and buried pipelines sharing rights-of-way is that AC voltages and currents can be induced on the pipelines by conduction during ground fault conditions and by induction from the expansion and contraction of magnetic fields. The magnitude of the induced voltage and current on the pipeline is a function of a number of variables, including the length of pipeline paralleling the AC power line, the longitudinal resistance of the pipeline, and the resistance of the pipeline coating.

Ductile Iron Pipe is manufactured in nominal 18- and 20-foot lengths and employs a rubber-gasketed jointing system. These rubber-gasketed joints offer electrical resistance that is sufficient for Ductile Iron Pipelines to be considered electrically discontinuous. In effect, the rubber-gasketed joints segment the pipe and prevent magnetic induction from being a problem. Also, in most cases, Ductile Iron Pipelines are installed bare and are therefore essentially grounded for their entire length, which further prevents magnetic induction on the pipelines. The fact that Ductile Iron Pipelines are electrically discontinuous and normally installed bare significantly reduces the potential difference between the pipeline and the surface ground during a ground fault condition. Additional safety precautions for ground fault conditions could include the installation of potential gradient control mats at exposed valves, hydrants, etc.

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11. Dabkowski, J., "Mitigation of Induced Voltages on Buried Pipelines," *Materials Performance*, January 1981.

6

CONCLUSIONS – INDUCED AC

1. AC Interference IS REAL and can be accurately predicted.
2. Induced AC Interference May Present a Safety Hazard – 15 V_{AC} Limit.
3. Under certain conditions, AC Interference may cause corrosion.
4. In ground fault conditions, (3) primary concerns for personnel safety, coating stress (>1000 volts) and or pipe damage (>5000 volts) can occur.
5. The mechanisms causing Induced AC can be quite complex and computer models are necessary to develop cost effective mitigation.
6. In the presence of AC, excessive CP or cathodic DC interference can increase corrosion rates dramatically
7. AC Interference can be safely and economically mitigated.
8. AC Mitigation systems can be reliably monitored and maintenance friendly.

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Questions

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