Induced AC Interference, Corrosion & Mitigation

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Bryan Evans
Vice President
Corrosion & Integrity Solutions
Grayson, GA
770-985-0505
bevans@ci-solutionsllc.com

About the Speaker

Bryan Evans, E.I.T.
B.S. Civil Engineering Technology
Southern Polytechnic State University, Marietta, GA, 1993

- NACE Cathodic Protection Specialist – No. 9754
- NACE Coating Inspector Level 1 – No. 21458
- 15 years of experience in corrosion, cathodic protection, pipeline integrity and AC mitigation as a consultant & installation contractor. Experience in both field testing, design and construction.
- Former Chairman of the NACE Atlanta Section
- Currently, a co-owner/operator of a woman owned, small business providing consulting/contracting in corrosion and cathodic protection services based in Grayson, GA.

WHAT IS INTERFERENCE?

As understood in the pipeline industry:

"Any detectable electrical disturbance on a structure caused by a stray current"

To further clarify:

"Stray current is defined as unintended electrical path"

Possible Sources of Interference

- AC and DC Transit Systems
- Welding Operations
- Cathodic Protection Systems
- High-voltage DC transmission systems
- High-voltage AC transmission systems
- Low-frequency communication systems
- Telluric (Geomagnetically induced) currents

Types of Interference

- DC Interference - most commonly thought of within the pipeline industry and potentially most damaging
- AC Interference – becoming more common due to HVPL joint-use corridors
- Telluric Interference – least common but problematic due to dynamic changes

DC Interference

- Stray current interference occurs when DC current travels along a non-intended path.
- Where DC stray current is received by a structure, the area becomes cathodic and generally, no corrosion occurs
- Where DC stray current exits the structure to return to its source, corrosion occurs and depending on magnitude of stray current, can lead to highly accelerated corrosion failures.

DC Interference

Using Faraday's Law, weight loss is directly proportional to current discharge and time …

Steel is consumed at ~ 21 lbs/amp-year

Example: A 1-inch diameter cone shaped pit in 0.500" thick steel weighs 0.04 pounds.

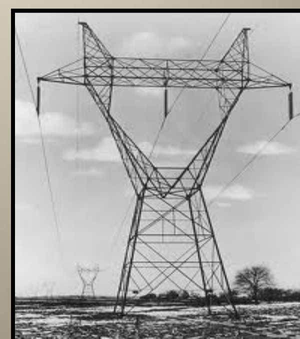
One ampere of DC current discharging from a 1-inch diameter coating holiday would cause a through wall, cone shaped pit to occur in 0.0019 years or 16 hours.

DC stray current corrosion can be a serious problem!!

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 because* these involve both high currents (during steady-state and fault conditions) and high voltages. Moreover, these system are more likely to run parallel to pipelines for long distances.

A 3ϕ power transmission system consists of three energized conductors; Each conductor ~ same voltage to ground, and each carries ~ same current.



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Why is AC Interference a Problem?

AC Interference introduces a series of issues into the operation of pipeline system:

- ❖Potential of Personnel Safety Issues
- ❖Potential for AC Corrosion
- ❖Potential for Pipeline and Coating Damage

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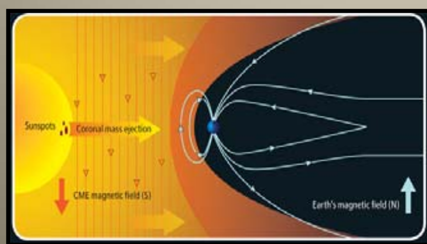
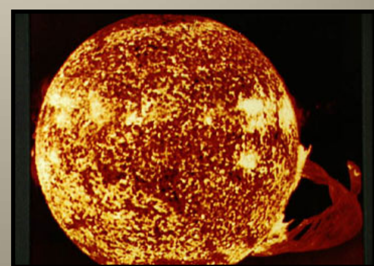
Telluric Interference

Telluric currents are currents that are geomagnetically induced on the earth and on metallic structures, such as power lines and pipe lines, as a result of the interaction of solar particles on the earth's magnetic field.

The solar plasma arises from two solar phenomena: sun spot activity and corona mass ejections (CME), which are commonly referred to as solar flares. The geomagnetic storms that result from the interaction of the solar plasma with the earth's magnetic field cause currents to be induced in the earth and metallic structures on the earth.

Note: Solar activity typically runs ~ 11 year cycles of activity. The next solar maximum is predicted to peak in May 2013.





Severity of Corrosion

The severity of corrosion depends on the magnitude of the stray current and time as related by Faraday's Law:

$$W_{total} = (M/nF) * t * I_{corrosion}$$

Where: W_{total} = weight loss (grams) at anode or weight gain at cathode

M = Atomic weight (grams) of the material corroding or being produced

n = number of charge transfers through the oxidation or reduction reactions

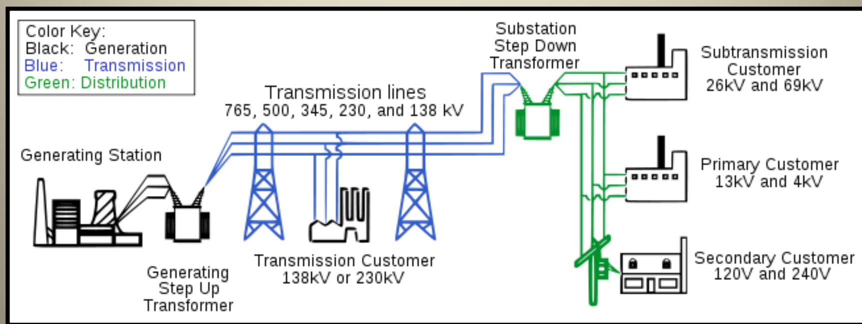
F = Faraday's constant (96,500 coulombs per equivalent weight)

t = time the corrosion cell operated (seconds)

$I_{corrosion}$ = corrosion current in (Amps)

Alternating Current – Power Grid System

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



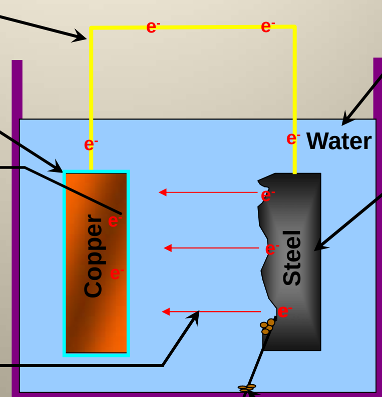
*Power travels from the power plant to your house through a system called the **power distribution grid**.*

Basic Corrosion Mechanism

Metallic Path

Cathode (protected)

Electrolyte
(water, soil, mud, etc.)



Anode (corrodes)

In typical soils, at Cathode:
Electrons consumed by water/oxygen – protective film forms

Corrosion Current
(Conventional Current Flow)

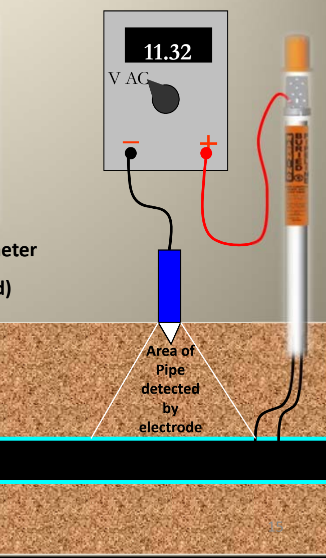
In typical soils, at Anode:
Iron goes into solution and combines with ions in the electrolyte to form corrosion Deposits

Corrosion
Deposits

AC Pipe-to-Soil Potential Measurement

Copper-Copper Sulfate
Reference Electrode

High Impedance Voltmeter
(Miller LC-4 Pictured)



Soil Resistivity Testing

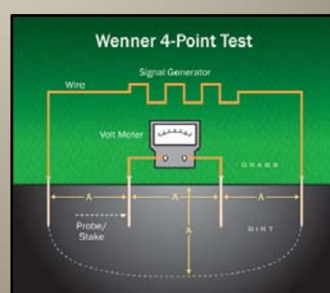
Typically, completed via ASTM G57, "Wenner 4-Pin Method".

- Field Resistivity Measurements
- Single Pin Resistivity Measurements
- Soil Box Laboratory Resistivity Measurements

$$\rho, \Omega\text{-cm} = 2\pi\, aR \;(a \text{ in cm})$$

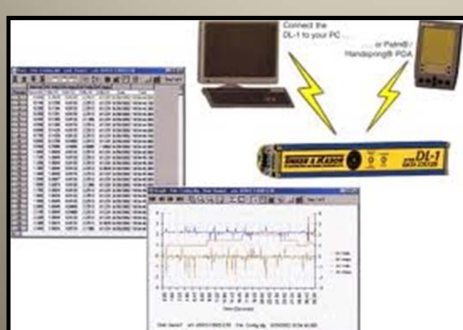
$$= 191.5\, aR (a \text{ in ft})$$

where:
a = electrode separation, and
R = resistance, Ω.
Using dimensional analysis, the correct unit for resistivity is ohm-centimetre.

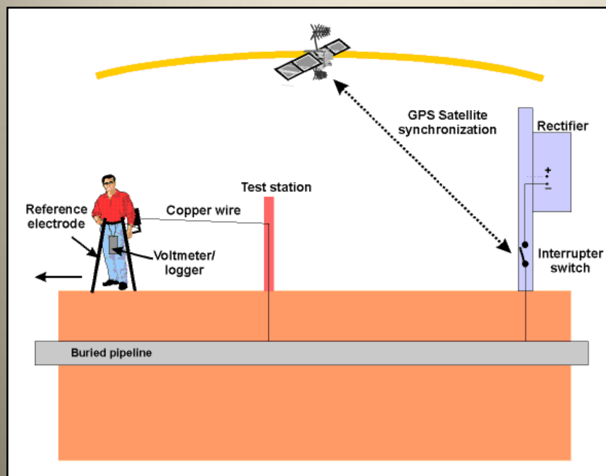


Soil Resistivity Testing

Dataloggers



Close Interval Survey (CIS)



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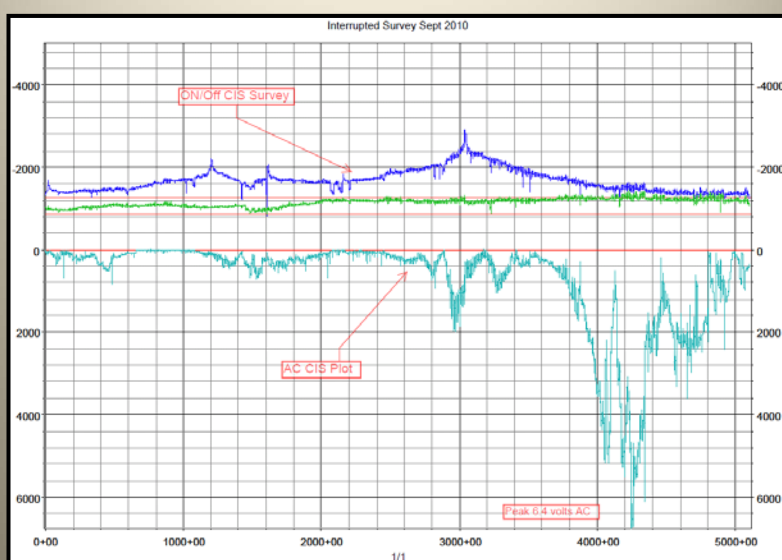
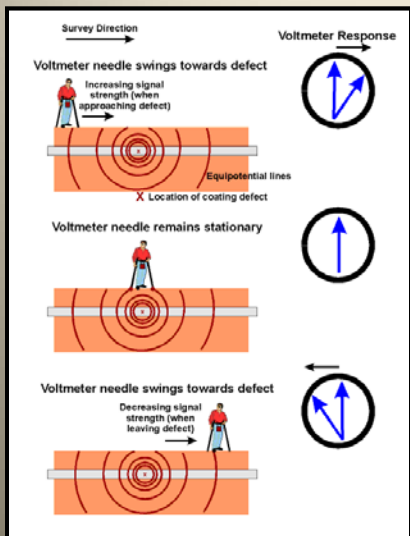
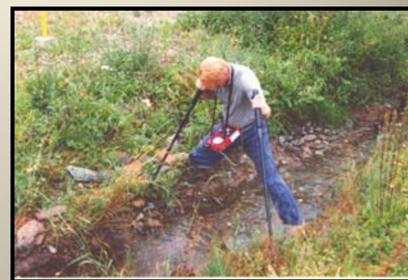


Direct Current Voltage Gradient (DCVG)



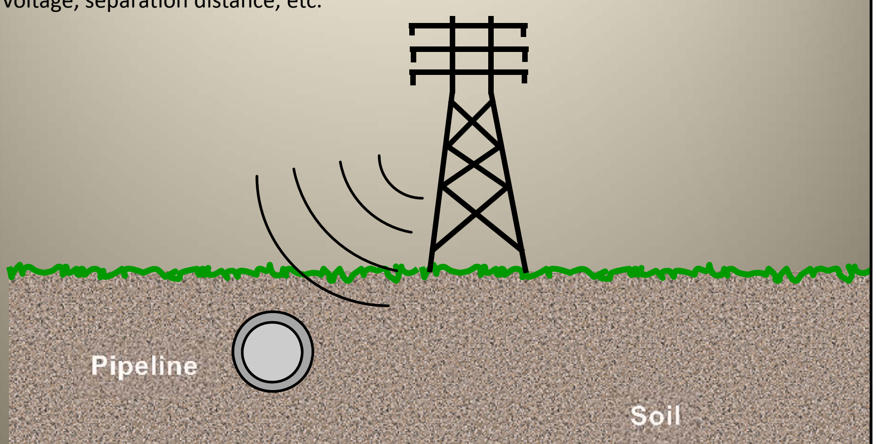


AC STRAY CURRENT INTERFERENCE

Pipelines in Congested Power ROW

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, separation distance, etc.



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 associated with acquiring ROW shared right-of-ways will be more and more common in the coming years.

AC Interference

- The electromagnetic field created by AC power changes 60 times per second per phase.
- Metallic structures subject to a changing electromagnetic field will exhibit an induced voltage (hence induced AC current).
- Phase to ground faults can expose an underground structure to very high AC currents

Code – CFR 192

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.

Code – CFR 192

§192.328 Additional construction requirements for steel pipe using alternative maximum allowable operating pressure. Special Permit Lines 80% SMYS

(e) 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.

Standards & Guidance Documents

- NACE SP 0177 "Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems".
- ANSI / IEEE Standard 80 "Guide for Safety in AC Substation Grounding".
- EPRI/AGA "Mutual Design Considerations for Overhead AC Transmission Lines and Gas Pipelines".
- Canadian Electrical Code C22.3 No. 6-M1987 "Principles and Practices of Electrical Coordination between Pipelines and Electric Supply Lines".

AC Interference

Electrostatic (Capacitive) Coupling

- Aboveground structures only

(such as an above ground test station, a car, or pipe stored near ditch)

Electromagnetic (Inductive) Coupling

- Structure acts as secondary coil
- Structure above or below ground

(most important component, causes AC corrosion of steel as well as personnel hazard potential)

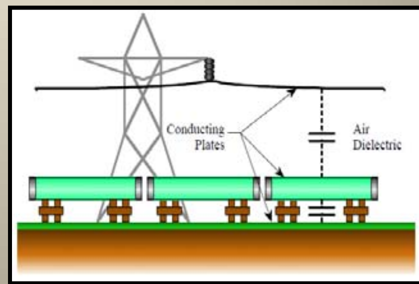
Conductive (Resistive) Coupling

- Buried structures only (during line faults)

AC Interference – Capacitive Coupling

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

- Typically, occurs during construction when coated and ungrounded joints of pipe are near a HVAC power line
- Common at above ground components; such as: test stations, risers, valves etc.
- Unlikely on buried pipeline because of the low pipe-to-earth capacitance



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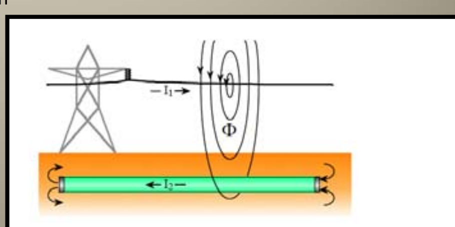
AC Interference – Inductive Coupling

Caused by current flow in the power line which creates an electromagnetic field surrounding the paralleling pipe line.

- Occurs during normal operating conditions of the power line.
- Magnitude can reach 100's of volts and presenting shock hazards
- Pipe lines within 1000 lf of a HVAC power line should be investigated, in particular if they share a common ROW in parallel.



Electromagnetic Coupling Between a Pipeline and an Overhead AC Powerline

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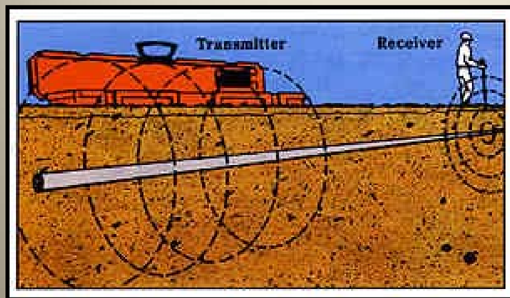
AC Interference – Inductive Coupling



Voltage and currents are electromagnetically induced on to a pipeline in the same manner that an inductive pipe locator induces an audio signal onto a pipeline.

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.
- Very short duration (breakers will trip). Typically, 0.1 seconds or less on high voltage systems.
- Potentials can exceed 15,000 volts.
- Pipe line ruptures have occurred due to these fault conditions. Can cause melting or cracking of the pipe wall.
- Pipeline coating stress is a large concern.
- 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

Factors contributing to AC Interference:

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

AC Interference

High Voltage AC Power Lines can cause:

1. Personnel Shock Hazard Due To Induced AC Voltages.
2. Corrosion of the steel.
3. Coating damage.

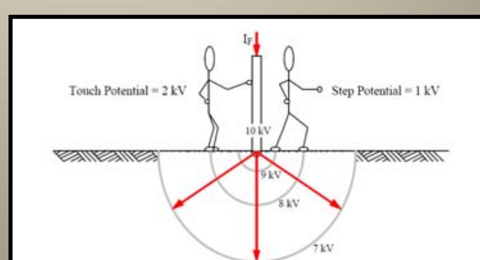
Personnel Safety

Industry standard for mitigation of induced AC voltage that a person should be exposed to is 15 volts to a copper-copper sulfate (CSE) reference electrode.

Safety standards for personnel are based on:

1. Step Potentials

2. Touch Potentials



Courtesy NACE

Personnel Safety

Safety considerations 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 Corrosion

Characteristics of AC corrosion:

1. Typically 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

AC Corrosion

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

- No AC induced corrosion at AC current densities < 1.86 A/ft^2 (20 A/m^2).
- AC corrosion is unpredictable for AC current densities between 1.86 A/ft^2 to 9.3 A/ft^2 (20 to 100 A/m^2).
- AC corrosion typically occurs at AC current densities > 9.3 A/ft^2 (~100 A/m^2).
- Highest corrosion rates occur at coating defects with surface areas between 0.16 in^2 – 0.47 in^2 (1 and 3 cm^2)

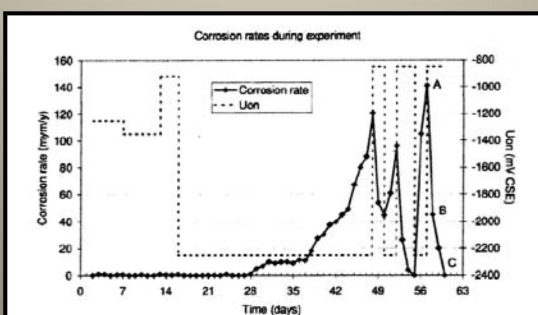
$$i_{ac} = \frac{8V_{ac}}{\rho \pi d}$$

i_{ac} – AC current density (A/m^2)
V_{ac} – AC Volts (V)
ρ – Soil resistivity (Ω–m)
d- holiday diameter (m)

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.*



AC Corrosion : Case Study

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

Power Line and Pipeline Alignment

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AC Corrosion: Case Study

Anomaly #1

AC Corrosion: Case Study

Anomaly #1

AC Corrosion: Case Study

Anomaly #1

AC Corrosion: Case Study

Anomaly #1 – ~ 20% Wall Loss

AC Corrosion : Case Study

Anomaly #2

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AC Corrosion : Case Study

Anomaly #2 – 50% Wall Loss

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AC Corrosion : Case Study

Anomaly #2

Fault Conditions - Pipeline Damage

- Fault currents from power lines can be collected and discharged from pipe lines in the vicinity of the fault.
- Coating damage can occur when the current picked up by the pipe line exceeds the dielectric strength of the coating material. Coating stress voltages:
  - 2 kV for tape wraps and coal tar coatings
  - 3 to 5 kV for fusion bonded epoxy and polyethylene
- Arching resulting from the discharge of the fault current can cause structural damage to the pipeline in excess of >5000 volts

REVIEW – 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 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)***

AC Interference Study – Data Necessary

Data required for AC Computer Modeling:

1. Soil conditions. Resistivity via ASTM G-57 (Wenner 4-Pin) at various spacings – to develop an "Apparent Resistivity"
   - Barnes Layer Analysis (Empirical Modeling)
   - Inverse Modeling Software
   - Curve Matching
2. Pipe line characteristics (materials of construction).
3. Pipe line and power line alignment.

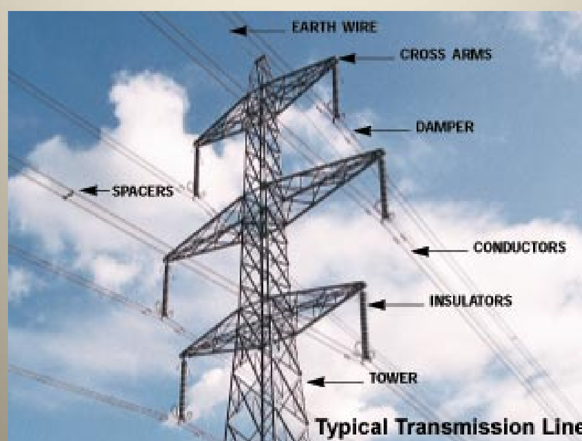
AC Interference – Data Necessary

Data required for AC Computer Modeling:

4. Power system characteristics:
    - Operating Voltage.
        - Peak Loading
            - Day time vs. night time
            - Seasonal: summer vs. winter
            - Weekday vs. weekend
    - Fault Currents.
    - Phase Transpositions – change in phase arrangement
    - Tower Configurations – height, horizontal distance, phase arrangement, shield wire arrangement
    - Horizontal separation from pipeline
    - Static (Shield) Wire.
    - Grounding Design.
    - Counterpoise Data.
    - Substation locations.

Note: Must consider steady state, peak loading, times of lower resistivity, and times of fault conditions:

AC Interference – Data Necessary



TYPICAL AC TRANSMISSION TOWER COMPONENTS

AC Interference – Data Necessary

Note: Must consider steady state, peak loading, times of lower resistivity, and times of fault conditions of each HVPL in the corridor

Methods for collecting Power Line Data:

Sub-meter GPS – Data Loggers

Methods for collecting Power Line Data:

Survey Grade – Laser Range Finders

Pipeline Electrical Characterisitics:

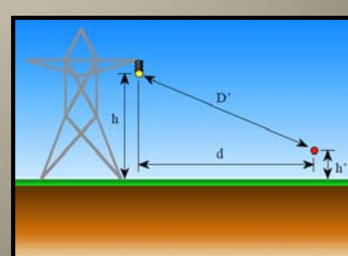
Longitudinal Electric Field (LEF):

The electromagnetic field produced by the powerline current generates an electric field running longitudinally with the pipeline. This is known as the LEF. It is a complex number that has both magnitude and a phase angle.

- Voltages that are induced on the powerline are directly proportional to the magnitude of the LEF.
- LEF is directly proportional to the electromagnetic field, and directly proportional to the powerline phase currents.
- Because electromagnetic field strength varies with distance, so does LEF.
- LEF is also a function of how conductors are arranged on the HVAC tower.
- Separation distance between phase conductors is a key factor. LEF increased linearly with increasing conductor separation.

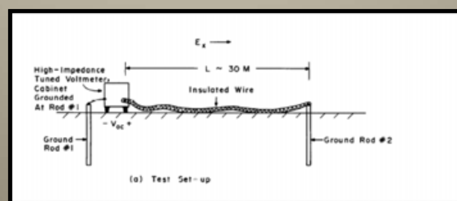
The LEF resulting from a $I\phi$ flowing in a powerline conductor is a function of the mutual impedance Z_M between the pipeline and the powerline.

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



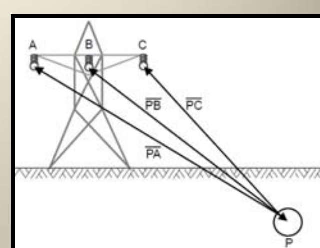
Pipeline-Powerline Geometry for Calculation of LEF

Longitudinal Electric Field (LEF):

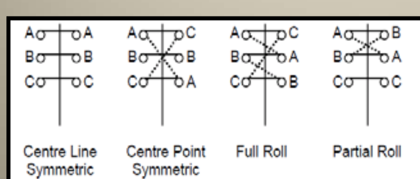


HVAC Tower Configurations:

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*

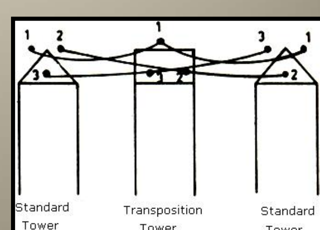


Effect of Phase Conductor Separation



Phase Arrangements for Double Vertical Circuit

Phase Transposition



AC Interference – Computer Modeling

- *Typical AC Conditions Modeled:*
  - Steady State Induced AC Levels
  - Pipe Potentials Under Phase-to-Ground Fault
  - Potentials to Remote Earth
  - Step Potentials
  - Touch Potentials
  - Identify high risk areas (phase transpositions, power line crossings, areas of convergence/divergence, etc.)

- 15 volt Limitation for Protection of Personnel
- 1000 volts - 3000 volts Causes Coating Damage
- >5000 volts Can Cause Pipe Structural Damage

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 (~ $50,000/license), and all have Pro's and Con's. Some industry available models are as follows:

- Pipeline Research Council International (PRCI)
- Safe Engineering Services & Technologies
  - CDEGS
  - Safe ROW
- ELSYCA
- OTHERS

RULE OF THUMB COSTS FOR FIELD DATA COLLECTION, MODELING AND DESIGN FEES FOR AC MITIGATION RANGE FROM $1,500 TO $3,500 /mile on up

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

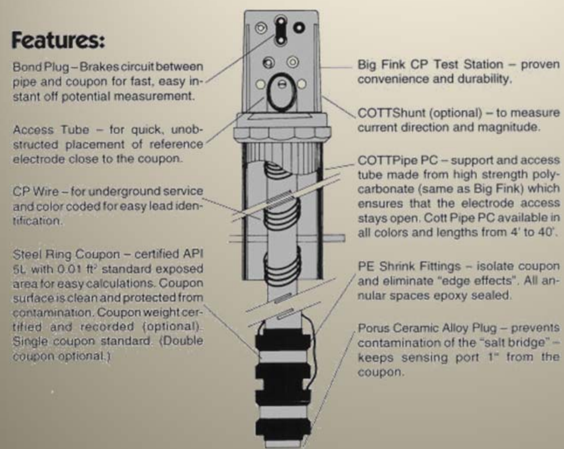
AC Interference – Mitigation Measures

- Separate structure and AC line.
- Use dead front test stations (to eliminate shock hazard).
- Install polarization cells to ground (grounding).
- Install semiconductor devices to ground (grounding).
- Use bare copper cables or zinc ribbon as grounds with DC decoupling devices (capacitors, polarization cells, ISPs).
- Install equipotential ground mats at valves, test stations (for shock hazard) and casing vents.
- Use no casing vents or non metallic.

COTT Dead Front Test Station (Personnel Protection)

Insulated Test Posts

COTT Dead Front Coupon Test Station (Pipeline Simulation – Corrosion Rates)



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Pipeline Decoupling:

DEALING WITH CONFLICTING ELECTRICAL REQUIREMENTS:

– Structures must be cathodically protected (CP)
– CP systems require DC decoupling from ground
– All electrical equipment must be AC grounded
– The conflict: ***DC Decoupling + AC Grounding***

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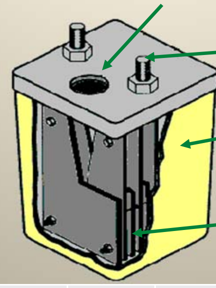
Pipeline Decoupling:

Reasons to DC Decouple From AC Mitigation and Electrical System Ground

If not decoupled, then:

- CP system attempts to protect grounding system
- CP coverage area reduced
- CP current requirements increased
- CP voltage may not be adequate

Polarization (Kirk) Cell – Grounding/Decoupling



Cell Model	Rated Capacity for 0.5 seconds (amps)	Steady State Rating (amps)	No. of Plates (pairs)	Conductor sizes (mm^2)	Total WT. lbs (kg)
K-5A	5,000	30	5	#8-2 AWG (10-35)	6 (2.7)
K-25	25,000	175	12	#2 AWG-250 MCM (35-125)	74 (33.5)
K-50	50,000	350	25	#1/0 AWG-500 MCM (50-250)	90 (40.8)

DISADVANTAGES:

1. Potassium Hydroxide Solution – Hazardous Caustic
2. Disposal of hazardous materials

Semiconductor Decoupling Devices - Grounding

PCR – Polarization Cell Replacement

SSD – Solid State Decoupler

Courtesy of Dairyland

Examples of De-Coupling Devices - Rating

Polarization Cell Replacement (PCR)

- 60 Hz Fault Current @ 1 cycle: 6,500; 20,000; 35,000 A
  @ 3 cycles: 5,000; 15,000; 27,000 A
- Lightning Surge Current @ 8 X 20 µseconds: 100,000 A
- Steady State Current Rating: 45 or 80 amps AC

Solid State Decoupler (SSD)

- 60 Hz Fault Current @ 1 cycle: 2,100; 5,300; 6,500; 8,800 A
  @ 3 cycles: 1,600; 4,500; 5,000; 6,800 A
- Lightning Surge Current @ 4 X 10 µseconds: 100,000A ; 75,000 A
- Steady State Current Rating: 45 amps AC

PCR

Solid State Decoupling Isolating Devices

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MATCOR – "The Mitigator"

ADVANTAGES

- A complete integrated grounding system with a copper conductor in a flexible fabric tube machine packed with corrosion inhibiting backfill designed for grounding systems.
- 433% more surface area than bare 2/0 copper cable.
- Significantly lower system impedance.
- Utilizes a 19 strand #2 bare copper cable for enhanced flexibility and ease of installation.
  - Also available in 1/0 and 2/0.
- Robust outer housing with green color coded stranding to identify the grounding cable assembly.
  - Can be easily installed using cable plow or conventional trenching.
- Available in 500, 1,000 ft, and longer reel lengths.
- Machine packed with special purpose grounding backfill to maintain intimate contact with the copper conductor.
- Additives are added to the backfill to inhibit corrosion of the copper conductor.

Corrosion Protection Engineering
Pre and Post-Installation Engineering

MATCOR
No stronger name in corrosion protection

THE MITIGATOR™

Introducing the pipeline industry's first engineered AC Mitigation grounding system, combining superior AC grounding performance with greater ease of installation and lower overall cost.

APPLICATION

This product is intended for use in pipeline AC Mitigation applications. Placed parallel to pipelines in high voltage AC transmission corridors, the MITIGATOR™ provides an easily installed, cost effective drain for induced AC current being picked up along the pipeline.

The MITIGATOR™ with copper cable lead wire and green color coded external braiding.

ADVANTAGES

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Headquarters: 301 Airport Boulevard, Doylestown, PA 18902 USA • 800.523.6692 • f 215.348.2699 • www.matcor.com

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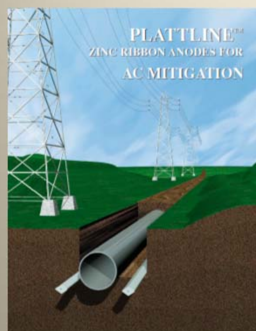
PLATTLINE– Zinc Ribbon



Specification Chart	◇	◇	◇	◇
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 Weight/Kg., Meters [1]	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

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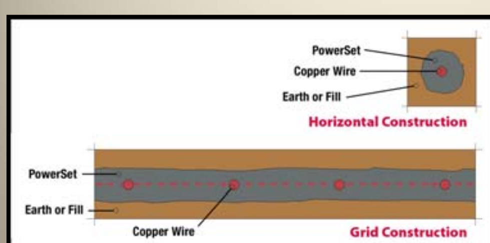
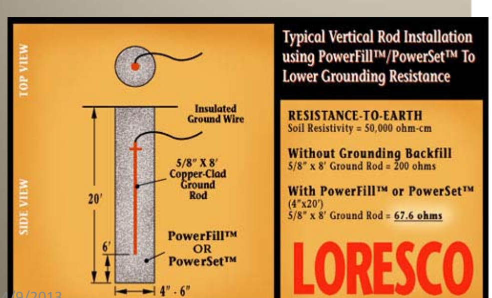
LORESCO – Earth Backfills





LORESCO® **PowerSet™**
Electrical Grounding Backfill

When the specification calls for a hard setting grounding material, PowerSet™ is the product of choice. PowerSet™ is compatible with all standard copper grounding systems and standard field applications. It is an economical permanent solution to difficult grounding problems in hard to deal with areas. PowerSet™ is manufactured from environmentally safe materials and is extremely stable. When mixed with water or exposed to moisture, PowerSet™ attains the hardening characteristics of cement while retaining its highly conductive properties. PowerSet™ will remain highly conductive during a drought or when exposed to arctic temperatures. Because it does not have any shrinkage or expansion properties it will remain in constant contact with the earth.

PowerSet™ can be poured in dry or pumped in slurry form. No tamping is required. It is very worker friendly. No special tools are required.

To calculate the amount of material required to fill a trench. First, determine your desired thickness of PowerSet™. Second, move to the right until you are under the known width of the trench. This number will be the weight of the material lbs / linear ft. Take this number and multiply by the length of the trench in feet. Your answer will be the amount of PowerSet™ material required to fill the trench to the desired level in lbs.

ADVANTAGES

- Positive low resistance, electrical connection to the earth.
- Compatible with all copper grounding systems.
- Does not contain any hazardous chemicals.
- Will attain a hardened state.
- Will not leech into the ground or wash away.
- Never needs recharging.
- Electronically conductive.
- Environmentally friendly.
- Contains a corrosion inhibitor to protect copper.
- Stable permanent ground for the life of the grounding system.
- Will not expand or experience any shrinkage.
- Not affected by freezing.
- Simple to install.
- Excellent shelf life with no performance effects.

MATERIAL REQUIRED PER LINEAR FOOT OF TRENCH

THICKNESS OF POWERSET™ (INCHES) \ WIDTH OF TRENCH (INCHES)	4	6	8	10	12	14	16	18	20	22	24
2	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2	18.0	19.7	21.5
3	5.4	8.1	10.8	13.5	16.2	18.8	21.5	24.2	26.9	29.6	32.3
4	7.2	10.8	14.4	18.0	21.5	25.1	28.7	32.3	35.9	39.5	43.1
5	9.0	13.5	18.0	22.4	26.9	31.4	35.9	40.4	44.9	49.4	53.9
6	10.8	16.3	21.5	26.9	32.3	37.7	43.1	48.5	53.9	59.2	64.6
7	12.6	19.0	25.1	31.4	37.7	44.0	50.3	56.5	62.8	69.1	75.4
8	14.4	21.7	28.7	35.9	43.1	50.3	57.4	64.6	71.8	79.0	86.2
9	16.3	24.4	32.3	40.4	48.5	56.5	64.6	72.7	80.8	88.9	96.9
10	18.1	27.1	35.9	44.9	53.9	62.8	71.8	80.8	89.8	98.7	107.7

EXAMPLE:
Thickness = 6 inches Width = 12 inches Answer = 32.3 lbs / linear ft
AMOUNT OF POWERSET REQUIRED:
32.3 lbs /linear ft x 50 ft of trench = 1615 lbs of PowerSet™

ELECTRICAL GROUNDING BACKFILL

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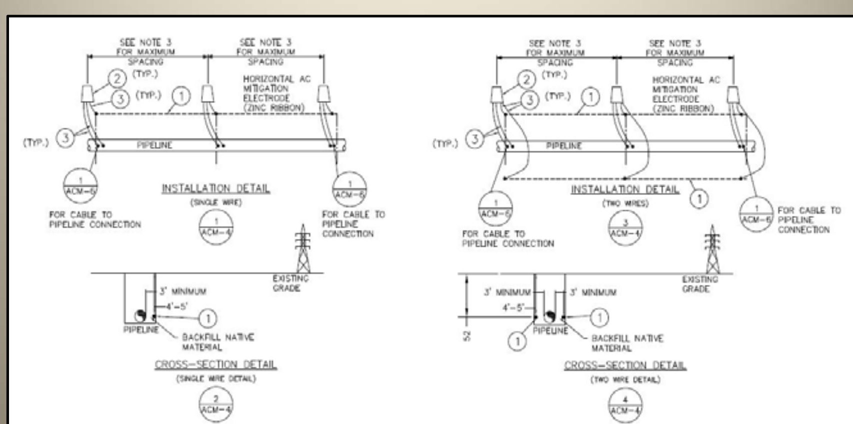
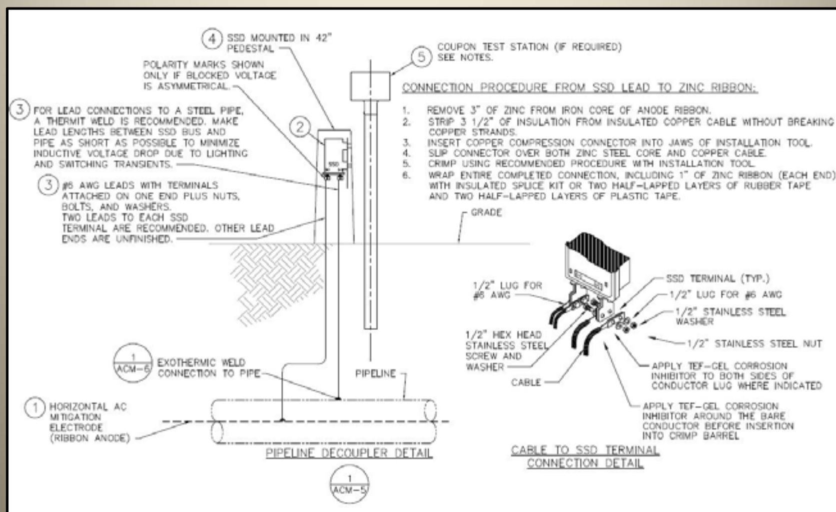
ERICO – Earth Grounding Materials

Typical AC Mitigation Design Layout



Typical AC Mitigation Design Layout



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Zinc Ribbon Installation for AC Mitigation - Grounding

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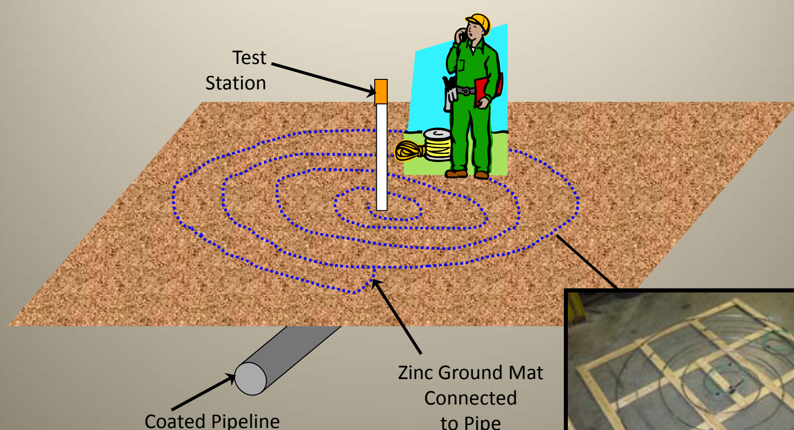
Equipotential Ground Mat



Used to Protect Personnel from Electric Shock (at test stations, valves, etc.)

Equipotential Ground Mat

Other AC Mitigation Design Layouts

- Point Grounding "Deep Anode Grounding Well"
- Faraday Cage
- Grounded Systems (Non-Decoupled)
- Combination / Multi Application Systems

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 V_{DC} and V_{AC}) to test the effectiveness of the cathodic protection system as well as the AC potentials on the line.

  Note: For ON/OFF surveys, the use of decouplers is critical to collect OFF (IR Free) potentials.
- Calculation of I_{AC} to determine risk of AC corrosion
- Locate/identify additional localized mitigation measures, if needed.

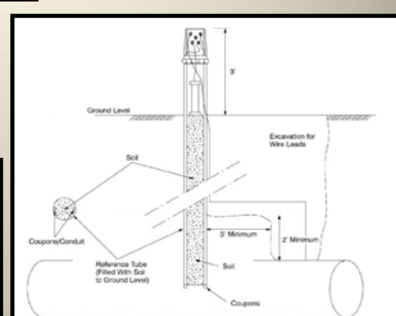
  Note: Collect additional, soil resistivity measurements at remaining high V_{AC} locations

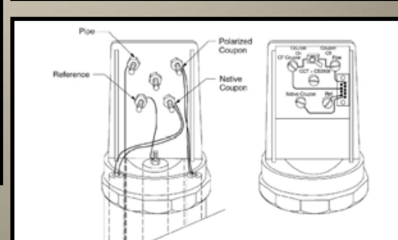
Testing the Effectiveness of AC Mitigation:

- AC Current Drains
- Ground Resistance

Testing the Effectiveness of AC Mitigation:

- Coupon Test Stations





Questions???

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Thank You

My contact information for any other follow-up questions or comments:

Bryan Evans
Vice President
Corrosion & Integrity Solutions
Grayson, GA
770-985-0505
bevans@ci-solutionsllc.com

CORROSION
& INTEGRITY SOLUTIONS

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