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AC INTERFERENCE ANALYSIS & MITIGATION

Asset Integrity & Corrosion

November 2022

START WITH SAFETY

NACE SP0177

- If the open circuit potential on a pipeline is **≥ 15 VAC**

  or

- The available current is **≥ 5 mA**, then

Condition exists for a potential safety (shock) hazard

AGENDA

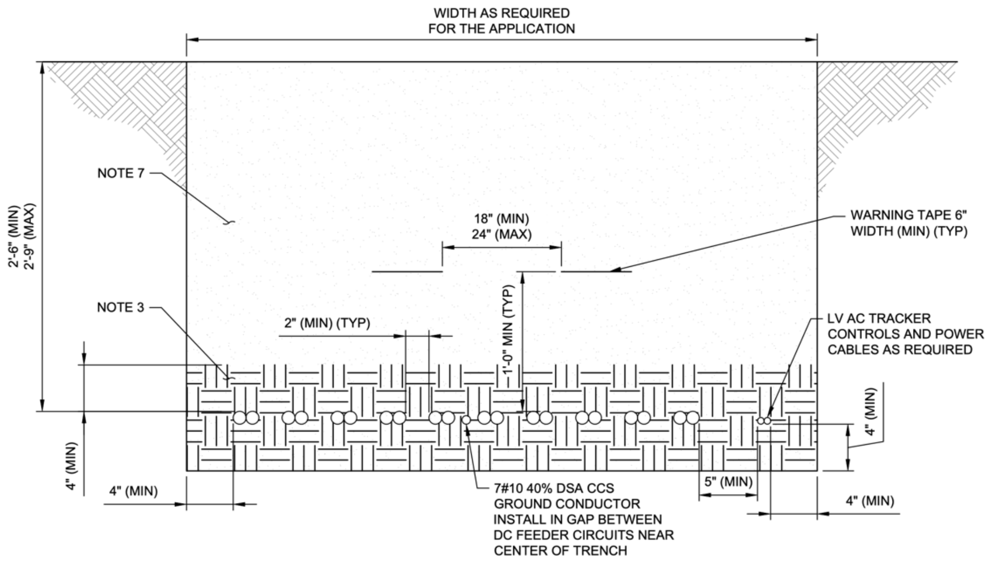
- Pipeline Interference Risks
- Regulatory Requirements
- Mechanism
- Personnel Hazards
- Pipeline Threats
- Screening
- Information Gathering
- Digital Simulation
- Monitoring & Mitigation Strategies

PIPELINE INTERFERENCE RISKS

SOLAR PV POWER GENERATION

- Solar Farms can present two forms of interference currents and risks
  - **DC Leakage**
  - AC Interference (Steady State and Fault/Transient State/Conditions)

- DC Leakage is a serious concern and occurs when there are DC imbalances between the Inverter Skid Assemblies (ISA) and current leaks between the "anodes" and "cathodes" and can create a DC interference risk for the pipelines. **20 Lb/Amp-Yr** corrosion rates are potentially applicable under wet/moist conductive soil conditions. Leakage currents can be as high as **15A**.



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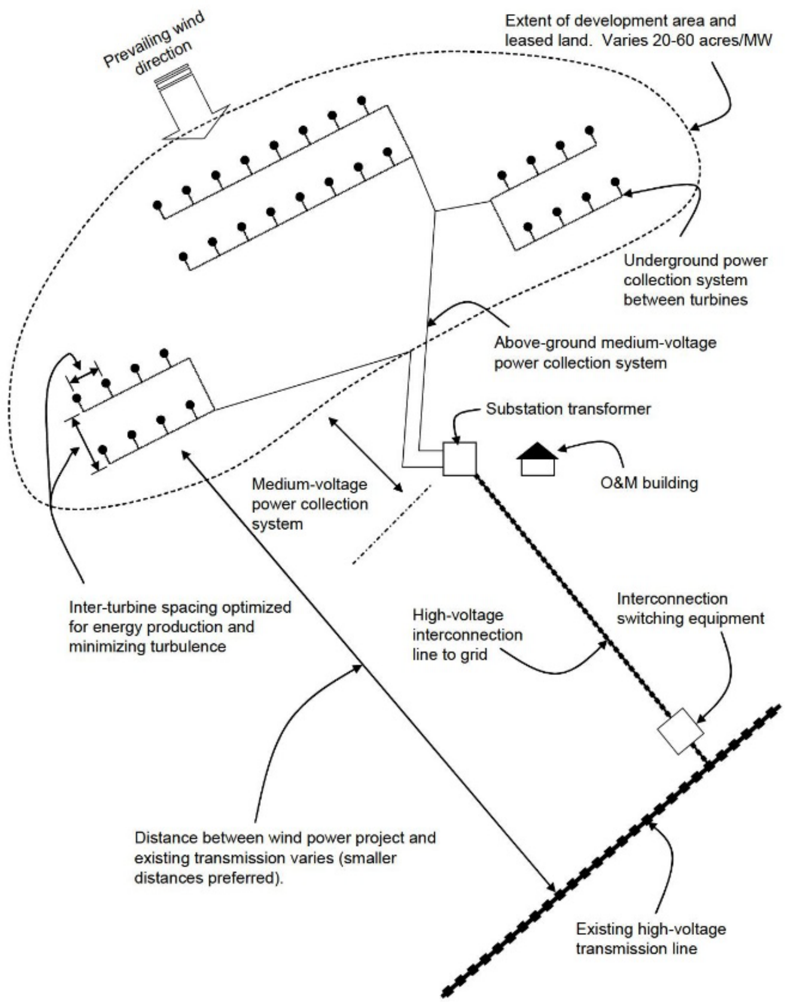
WIND POWER GENERATION

- Wind Farms can present mainly one form of interference current source and risks
  - **AC Interference** (Steady State and Fault/Transient State/Conditions)

- Overhead cables are handled as per typical AC Interference from Medium Voltage AC (MVAC) and High Voltage AC (HVAC) powerlines for both **steady and fault state conditions**.



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REGULATORY REQUIREMENTS

PHMSA – NEW REQUIREMENTS!

192 - Natural & Other Gas

- ***NEW*** Pipeline Safety: Safety of Gas Transmission Pipelines: Repair criteria, integrity management improvements, cathodic protection, management of change, and other related amendments
- § 192.473 External corrosion control: Interference currents.
  - (c)(1) Perform **surveys** to characterize stray current when monitoring indicates a significant increase or when
    - Colocation/crossing new or existing HVAC power lines
    - HVAC power line uprating
  - (c)(2) Analysis to identify **cause** and resulting **threats**
  - (c)(3) Remedial action plan (i ≥ 100 A/m2 or **conditional qualifiers**)
  - (c)(4) Complete remedial action NLT 15 months after survey
- § 192.467 External corrosion control: Electrical isolation.
  - (f) Where a pipeline is located in close proximity to electrical transmission tower footings, ground cables or counterpoise, or in other areas where fault currents or unusual risk of lightning may be anticipated, it must be provided with protection against damage due to fault currents or lightning, and protective measures must also be taken at insulating devices.

PHMSA

195 - Hazardous Liquids

- § 195.577 What must I do to alleviate interference currents?
  - (a) For pipelines exposed to stray currents, you **must have a program to identify, test for, and minimize the detrimental effects of such currents**

- § 195.575 Which facilities must I electrically isolate and what inspections, tests, and safeguards are required?
  - (f) If a pipeline is in close proximity to electrical transmission tower footings, ground cables, or counterpoise, or in other areas where it is reasonable to foresee fault currents or an unusual risk of lightning, **you must protect the pipeline against damage from fault currents or lightning and take protective measures at insulating devices.**

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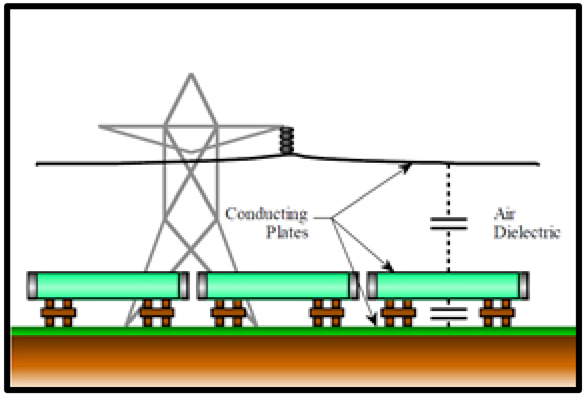
AMPP (NACE) STANDARDS

- **NACE SP0177**
  - Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems

- **NACE SP21424**
  - Alternating Current Corrosion on Cathodically Protected Pipelines: Risk Assessment, Mitigation, and Monitoring

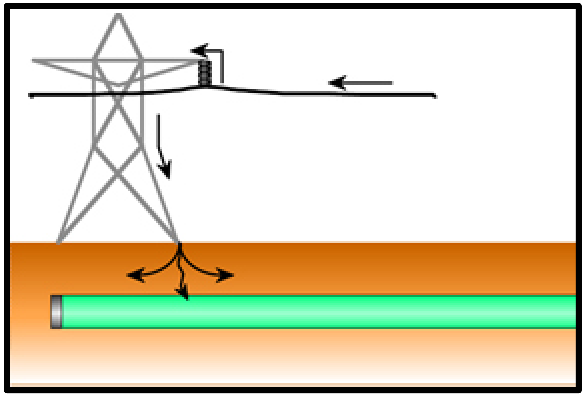
MECHANISM

COUPLING MECHANISMS



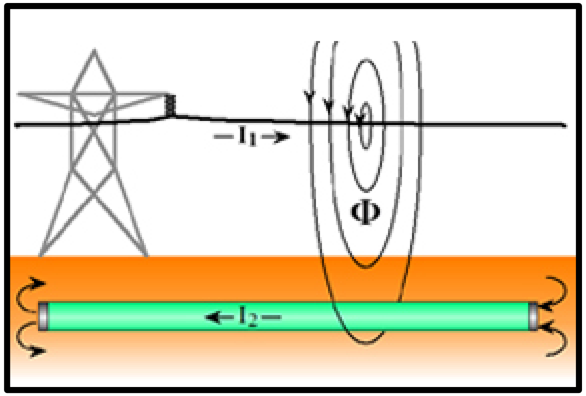
Capacitive

- Construction hazard



Conductive

- Operational fault condition



Inductive

- Operational steady state condition
- Pipeline becomes “secondary winding” of a transformer

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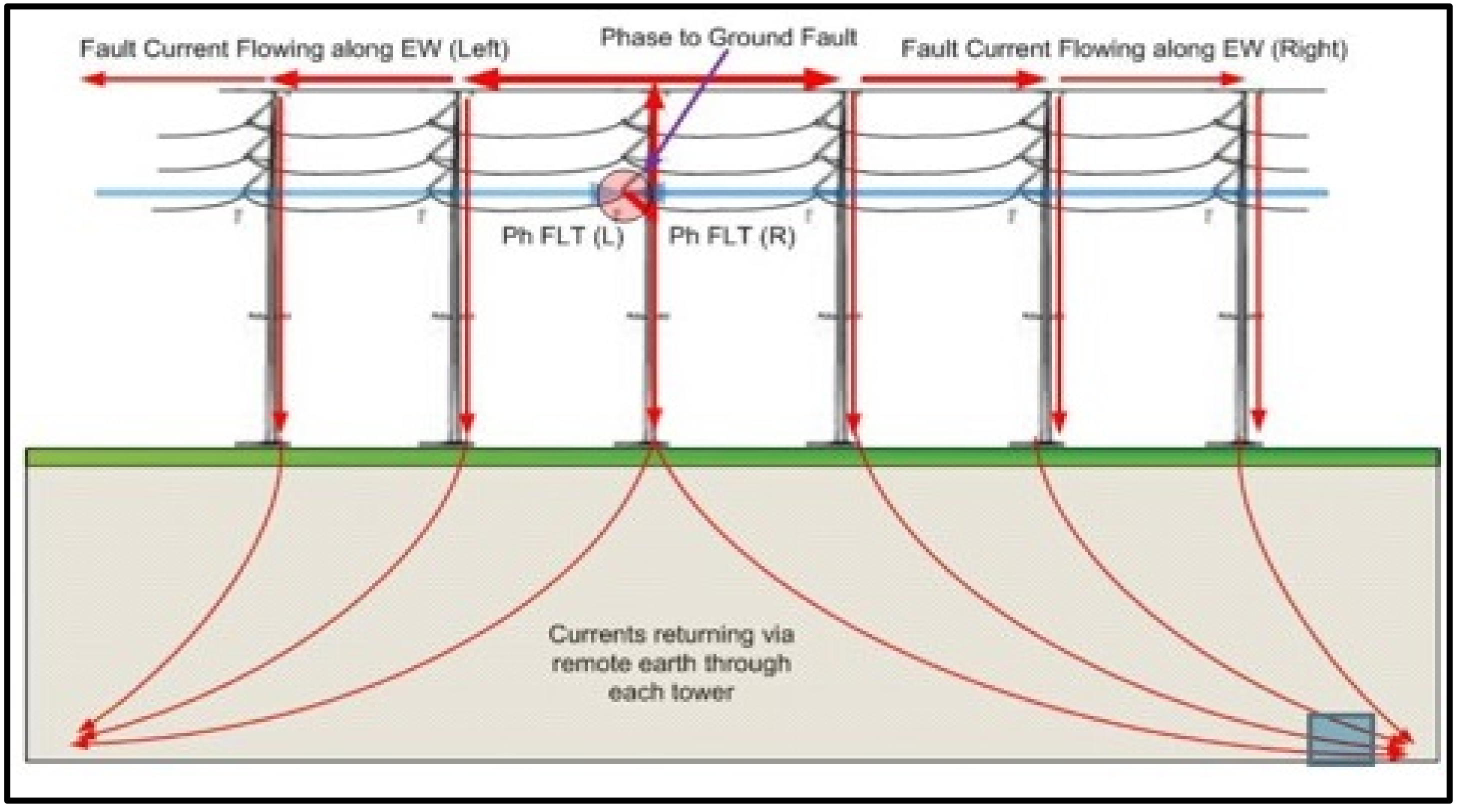
CONDUCTIVE COUPLING (TRANSIENT)

- **Integrity Threat** - potential damage to pipeline coating and WT

- **Safety Threat** – potential shock hazard during fault condition



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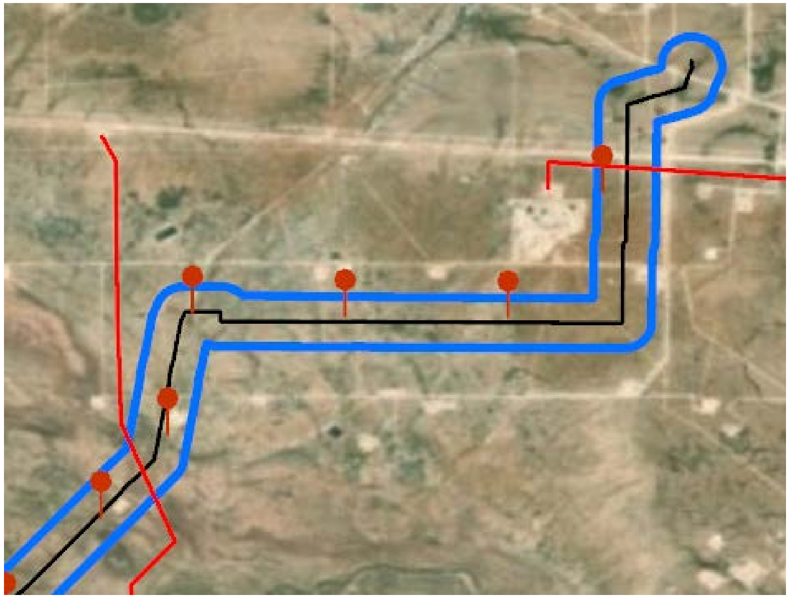
INDUCTIVE COUPLING (STEADY STATE)

- **AC voltage peaks** are typically associated with a physical **change in power line or pipeline orientation** to one another and/or at powerline transpositions and substations

- Induced AC current must leave the pipeline in order to “return-home.” **AC current discharge** from coating defects can cause corrosion damage to the pipeline



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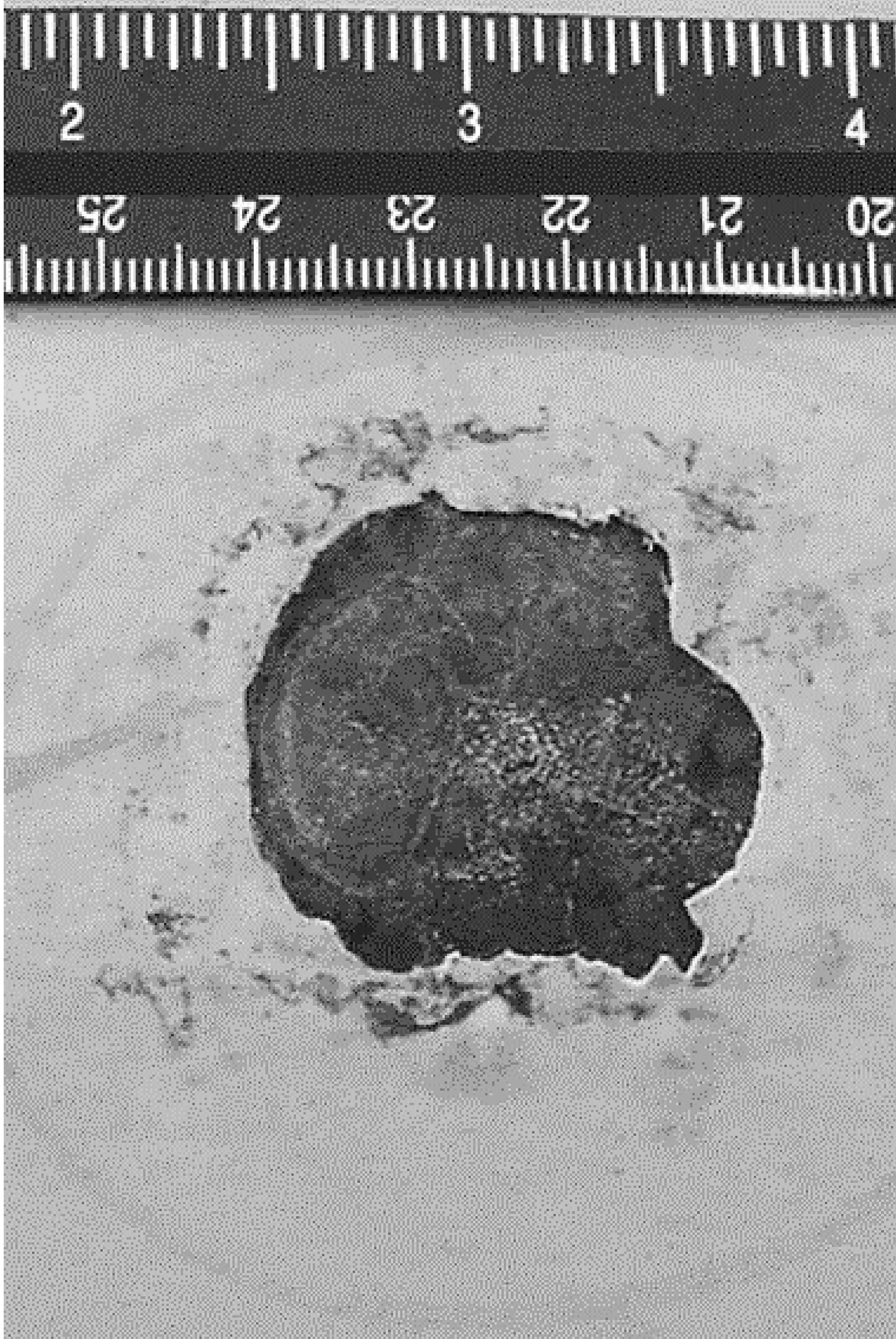
PIPELINE THREATS

COATING DAMAGE

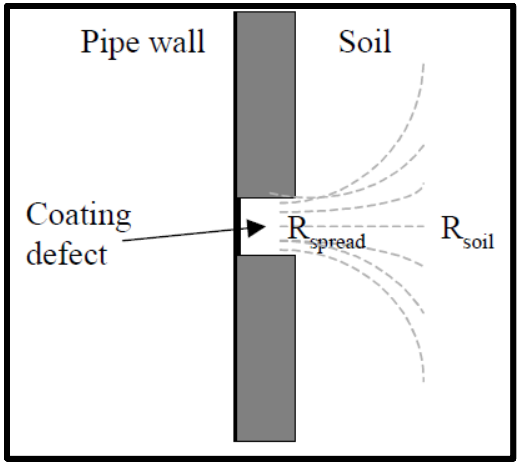
Typical Breakdown Voltage

COATING	PUNCTURE LEVEL (V)
Coal Tar Epoxy	3500
Coal Tar	4500
Coal Tar Enamel	5000
Asphalt	7000
Fusion Bonded Epoxy	1000/mil



PHMSA REQUIREMENTS

AC Does Not Cause Corrosion, Right?



- Current discharge vs. corrosion
  - CD < 30 A/m2 – ***No corrosion***
  - **30 A/m2** < CD < 100 A/m2 - ***???***
  - CD > **100 A/m2** – ***Corrosion***
- Highest rates occur at holidays
  - 100 mm^2 < SA < 300 mm^2
- AC (60 Hz) corrosion rate
  - Range 1% - 5% that of DC per unit current discharge

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UNDERSTANDING THE RISK

Soil Resistivity vs. AC Voltage and Current Density

$$J_{ac} = 8V_{ac}/\rho\pi d$$

Where:

J_{ac} : Pipeline AC current density, [A/m^2]

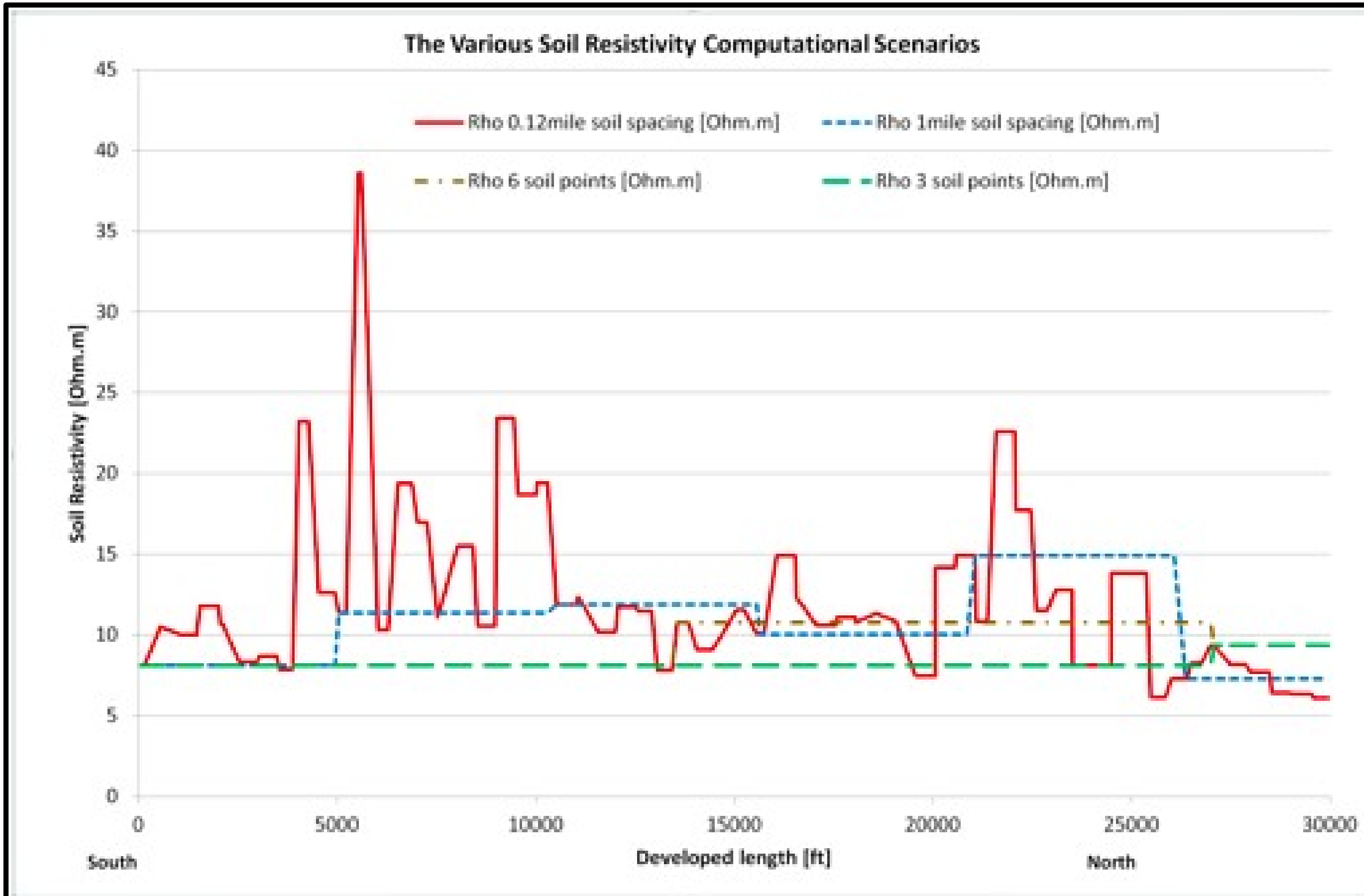
V_{ac} : Pipeline AC voltage to remote earth, [V]

ρ : Soil resistivity at pipeline depth, [Ω-m]

d : Diameter of coating holiday, [m]

UNDERSTANDING THE RISK

Soil Resistivity Values vs. Data Collection Intervals



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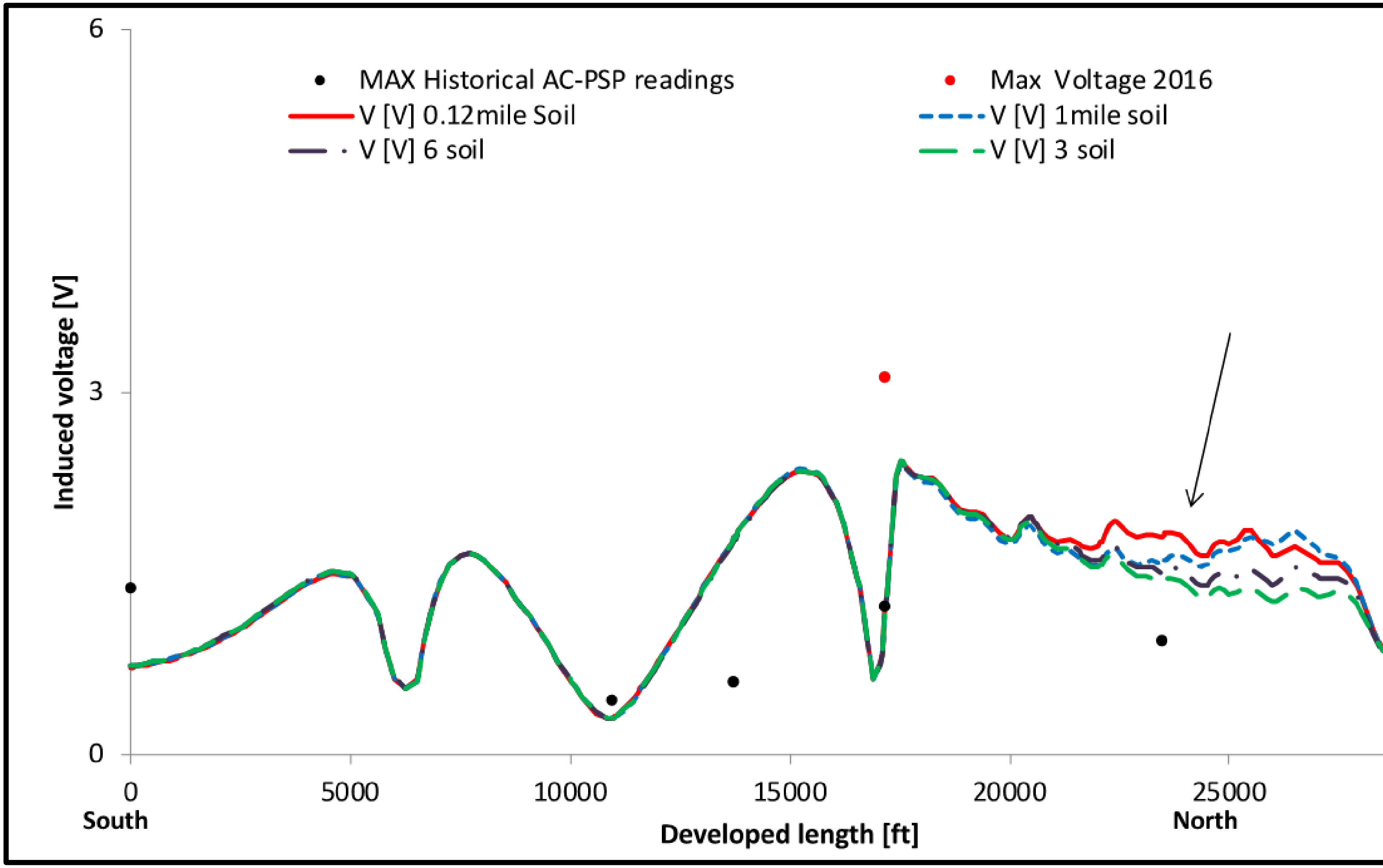
UNDERSTANDING THE RISK

Soil Resistivity has a ***Minor Influence*** on Induced AC Voltage



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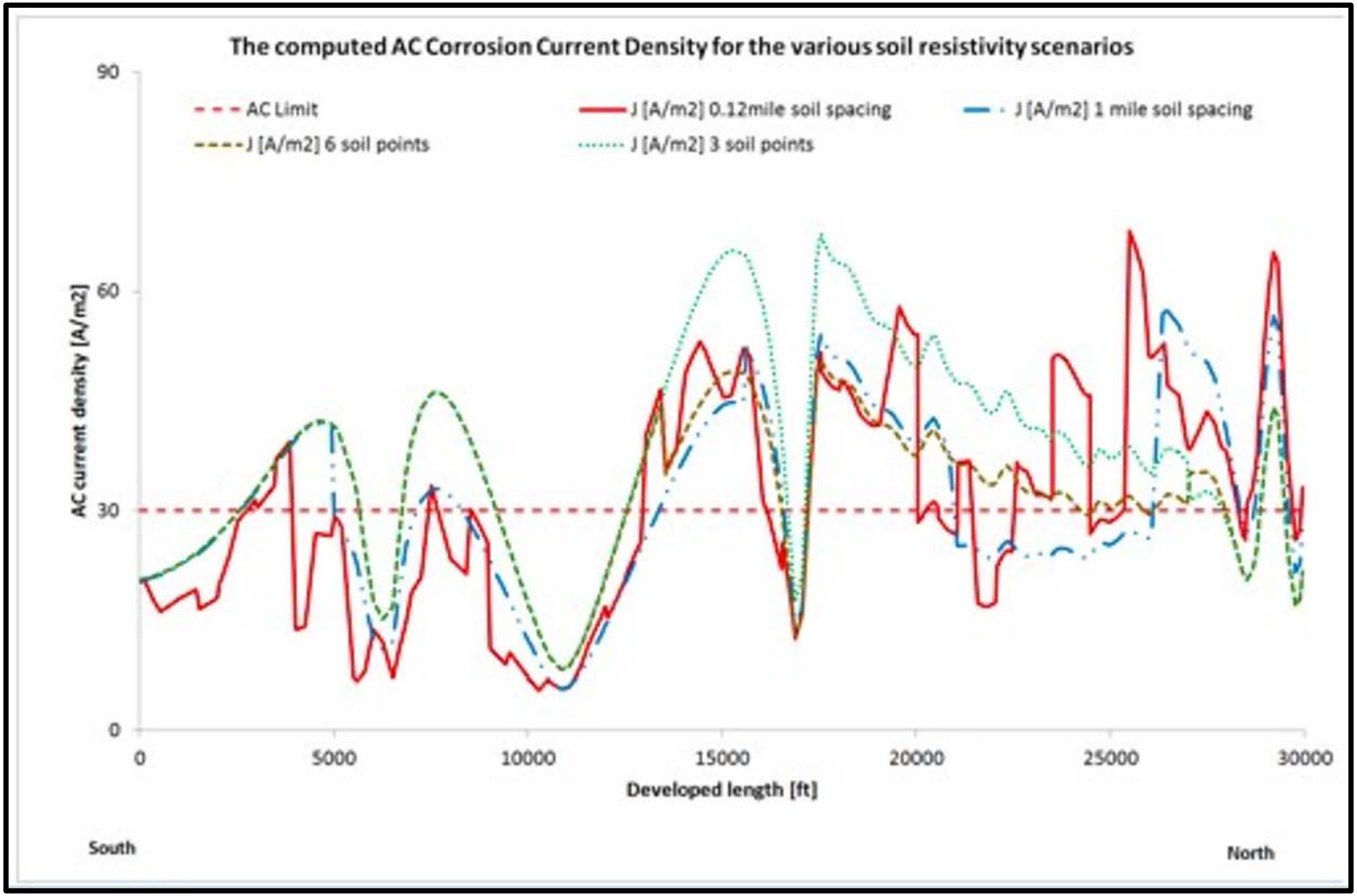
UNDERSTANDING THE RISK

Soil Resistivity has ***Major Influence*** an AC Current Density



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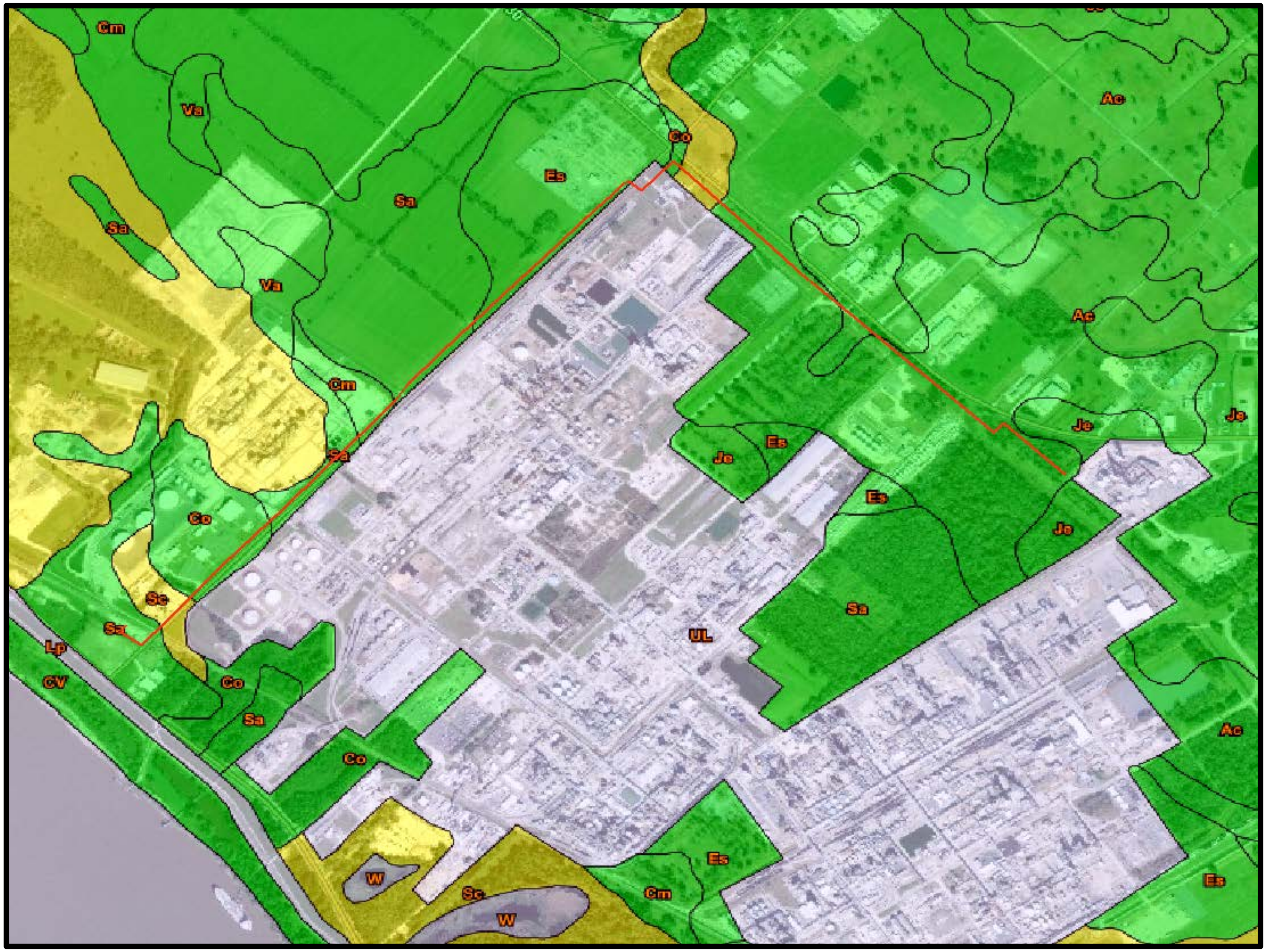
SITE SURVEY REQUIREMENTS - SOIL RESISTIVITY

Based on Knowledge of *Local Geologic Conditions*



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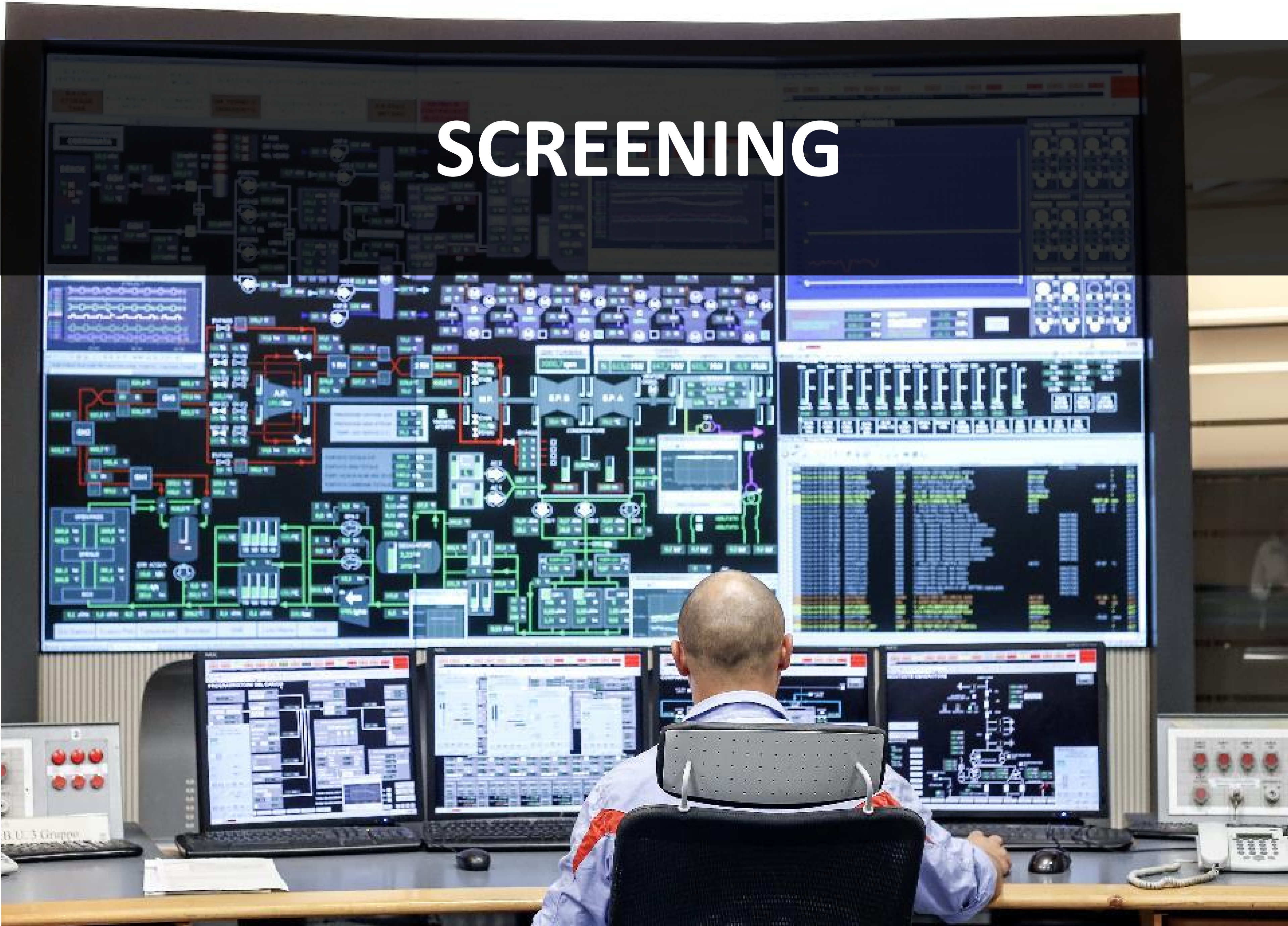
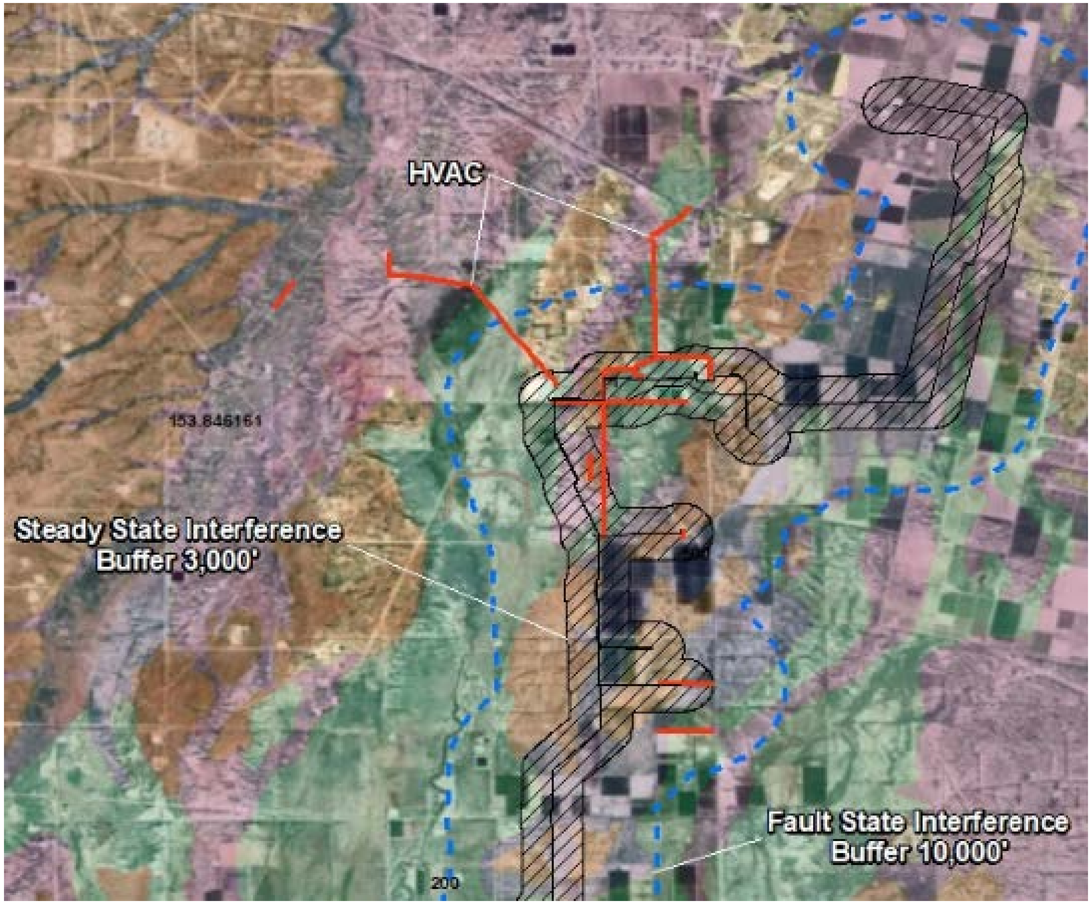
SCREENING



SCREENING GUIDELINES

- **Land Use**
  - Rural vs Urban
- **Soil Resistivity**
  - ≤ 300,000 Ω-cm
- **Mechanism**
  - Fault vs. Steady State



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INFLUENCING FACTORS

- Pipeline/power line **angle of intersection**
- **Separation** between pipeline and power line
  - D_{min} – 50 feet
- Length of **parallelism**
  - L_{min} – 1000 feet
- Power line **voltage** (kV)
  - V_{min} – 69 kV
- Soil **resistivity**
- Pipeline **coating** quality

FACTOR CORRELATION – INDUCED VOLTAGE

Property	Change	Impact to the Magnitude of AC Voltage on the Pipeline
Soil Resistivity	Increases	Increases*
Pipeline Coating Resistance	Increases	Increases
Pipeline Outside Diameter	Decreases	Increases
HVAC Current Load	Increases	Increases
Distance between the Tower and Pipeline	Decreases	Increases
Length of Collocation	Increases	Increases

**Soil resistivity will have the opposite relationship with AC density.*

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INFORMATION GATHERING

DATA GATHERING

Pipelines

- **General Information**
  - **Route**, diameter, thickness, material, DOC, etc.
  - Foreign pipeline crossings
  - HDD/Bores
- **Protective Coatings**
  - **Type**, thickness, age, and resistance
- **Cathodic Protection**
  - Components and locations (GPS)
  - Bonds
- **Other Records**
  - Drawings (plan and profile)
  - Above ground fixture locations

DATA GATHERING

Power System Network

- **General Information**
  - Route (kmz or point cloud)
- **Conductors**
  - Number, type, phasing, height, and offset
- **Shield Wires**
  - Number, type, resistance, height, and offset
- **Circuit Loads**
  - Max, peak, average peak, and emergency
- **Fault Currents**
  - Single line to fault at each tower, detection time, and clearing time
- **Grounding**
  - Separation distance from pipeline

Site Survey Requirements - Distance

Geospatial Relationships

Tower type	Configuration

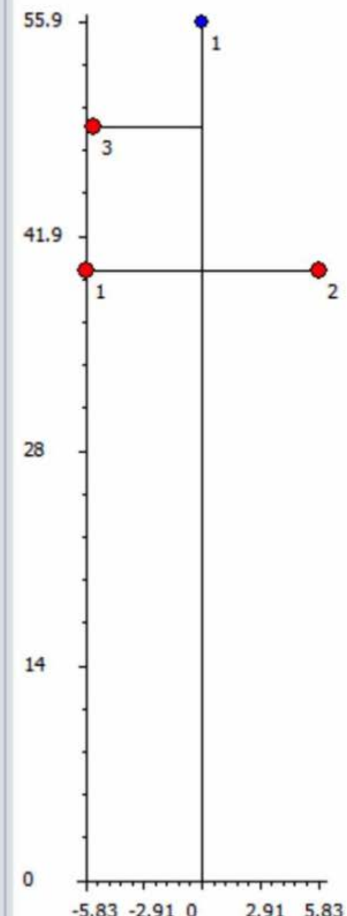
Type Name PG_T24

Phase Wires :

	D [ft]	H [ft]
1	-5.83	39.67
2	5.83	39.67
3	-5.42	49

Shield Wires :

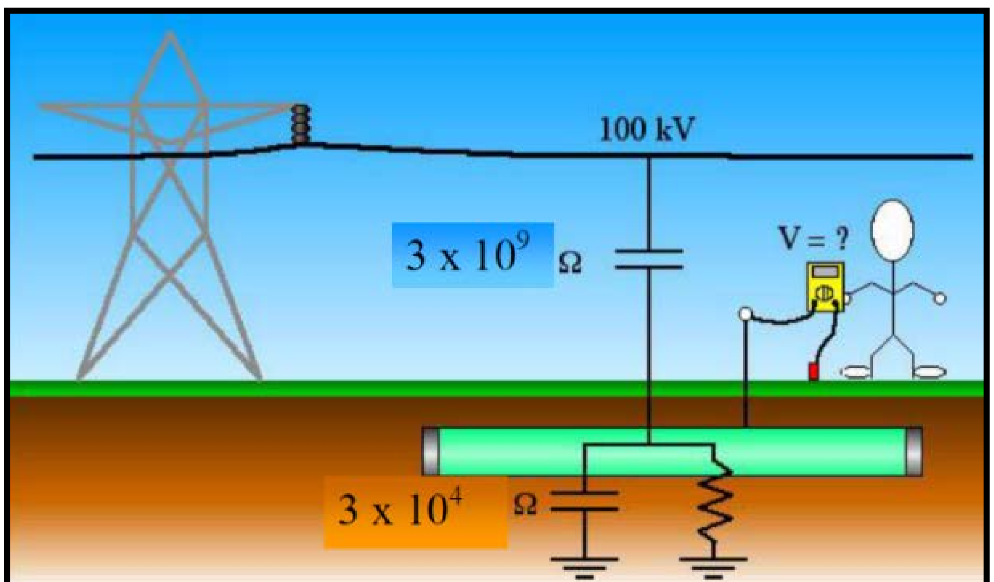
	D [ft]	H [ft]	R [Ohm/mi]	GMR [ft]
1	0	55.92	3.219	0.01642



DIGITAL SIMULATION

What is the Goal?

- **Protect People**
  - Minimize both **touch and step potentials** along the entire pipeline.
- **Protect Assets**
  - Prevent pipeline **coating damage** due to abnormal power system conditions.
  - Prevent **pipeline damage** due to arcing caused by high potentials during abnormal power system conditions.



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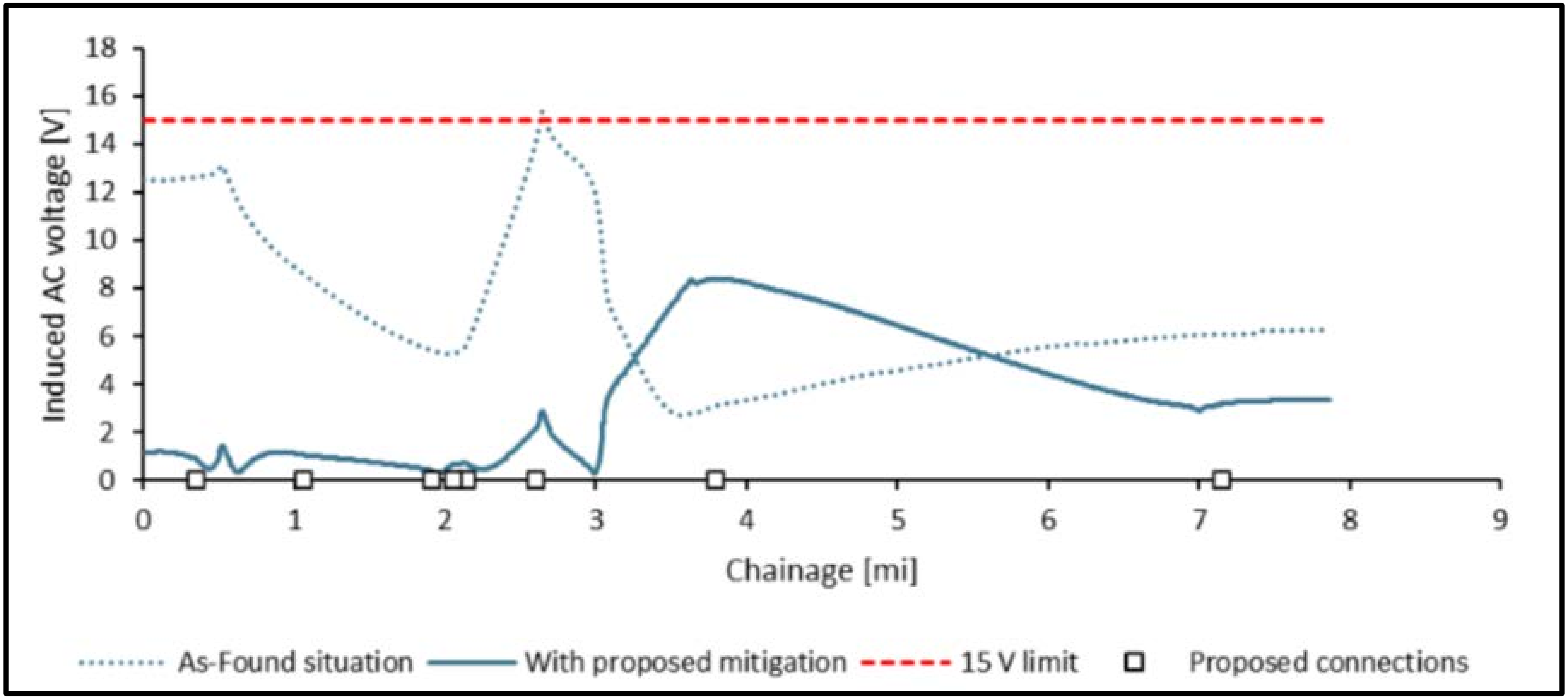
CALCULATED OUTPUT - INDUCTION

Voltage



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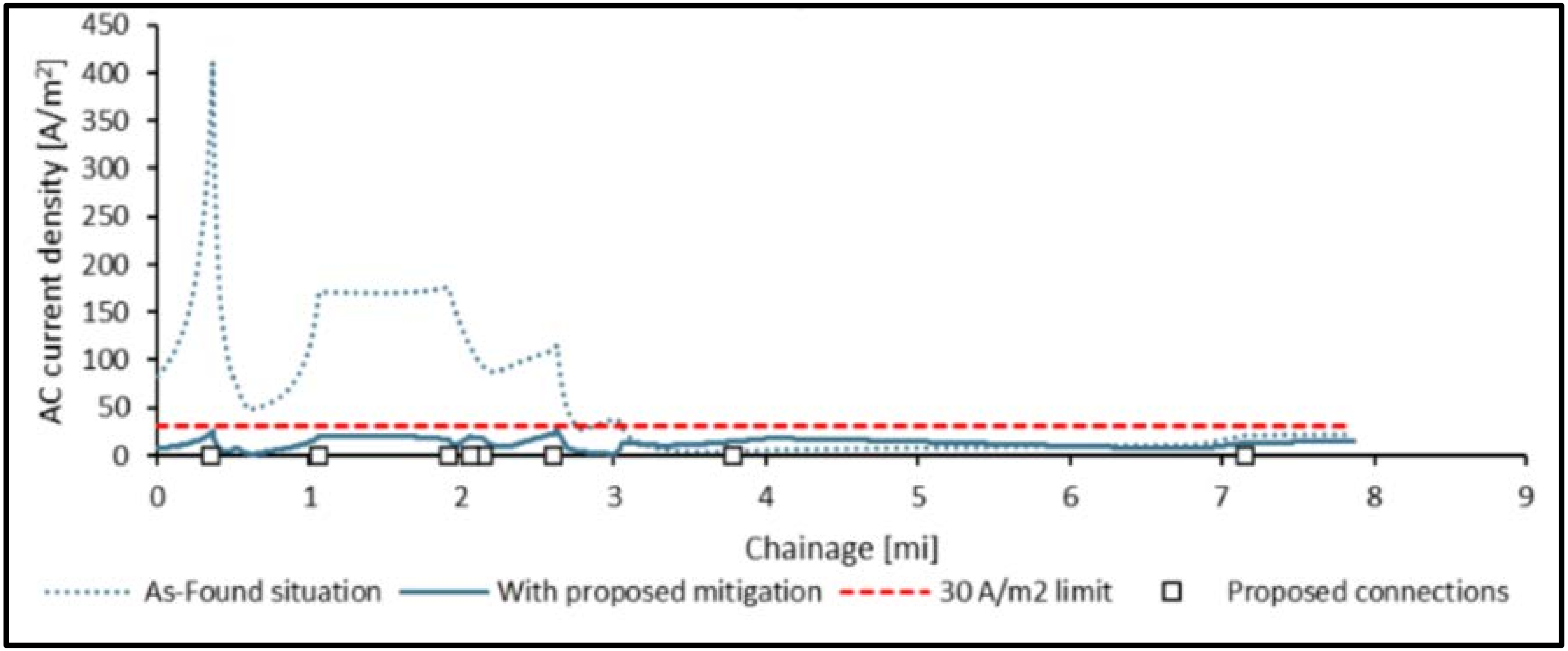
CALCULATED OUTPUT - INDUCTION

Current Density



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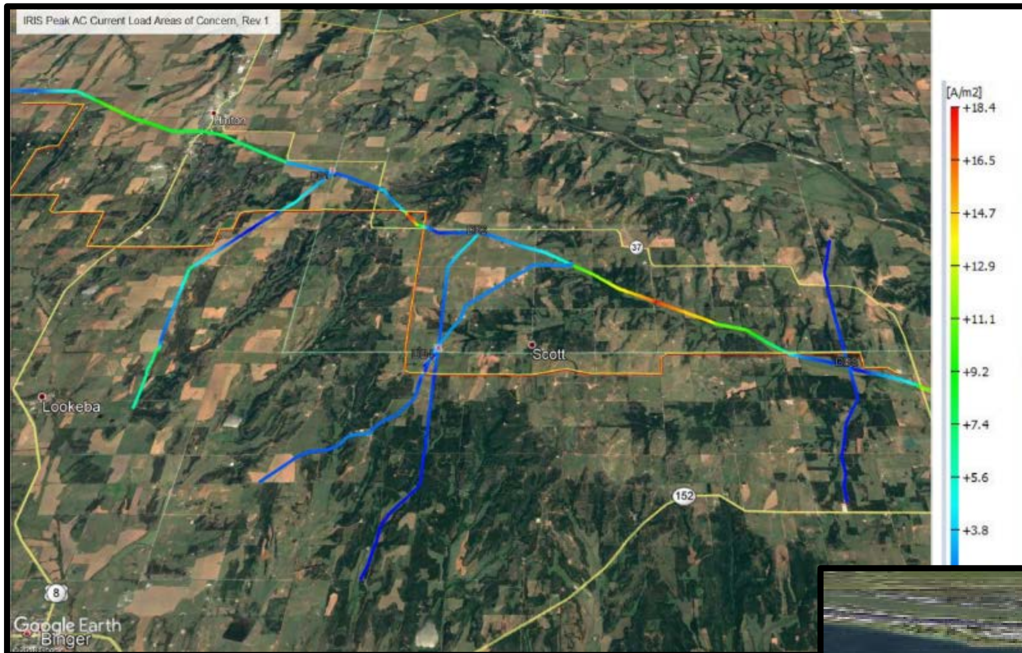
CALCULATED OUTPUT - INDUCTION



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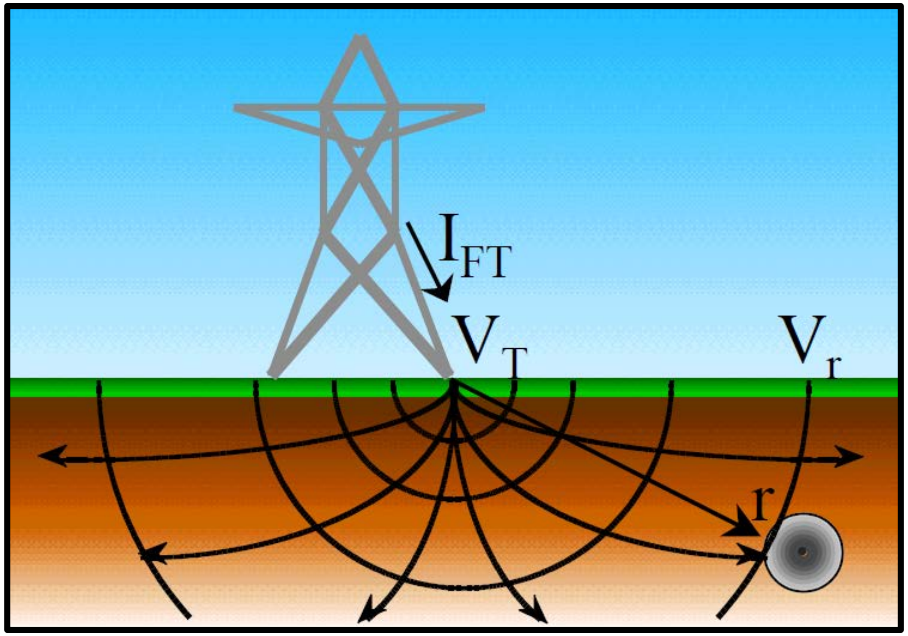
CONDUCTIVE ANALYSIS

- Targeted Outcomes
  - 2,500 to 5,000 VAC max fault structure-to-ground potential to protect against pipe and coating damage

COATING	PUNCTURE LEVEL (V)
Coal Tar Epoxy	3500
Coal Tar	4500
Coal Tar Enamel	5000
Asphalt	7000
Fusion Bonded Epoxy	1000/mil



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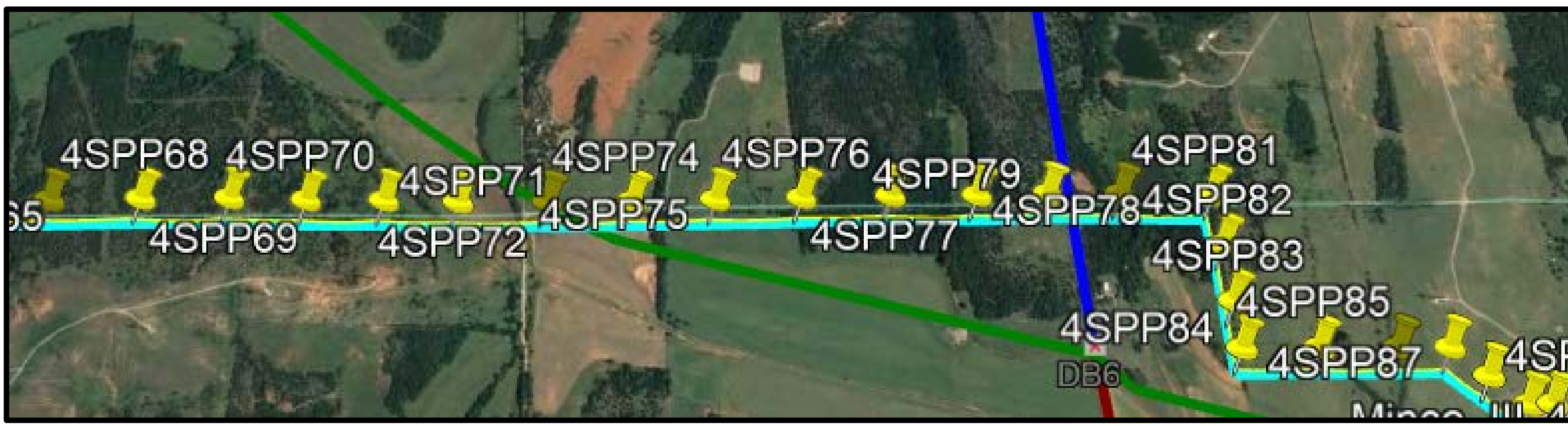
CALCULATED OUTPUT - CONDUCTION

- **Common Scenarios**
  - Phase to Ground Faults
  - Phase to Phase Faults
  - Broken Conductors
  - Phase Imbalances
  - Generation/Substation Upsets



MONITORING & MITIGATION STRATEGIES

MONITORING STRATEGIES

- **Coupons and Probes***
  1. Measure the AC and DC **Potentials**
  2. Measures the AC and DC **Current Densities**
  3. Measures the **Corrosion Rate**
     a) General/Uniform Corrosion
     b) Pitting Corrosion

- **Types of Coupons and Probes**
  1. Metal Coupons – Measures 1 to 3
  2. Electrical Resistance (ER) Probes – Measures 3a (Indirect)
  3. Ultrasonic (UT) Coupons – Measures 3a and 3b (Direct)
     a) AC corrosion exhibits a pitting primarily, therefore UT Probes are technically superior and more reliable

- **Test Stations**
  1. Yearly AC Potentials as part of **Annual Survey**

*** Make sure to pay attention to coupon size during conversions (1 cm2, 10 cm2, 100 cm2, etc.)**

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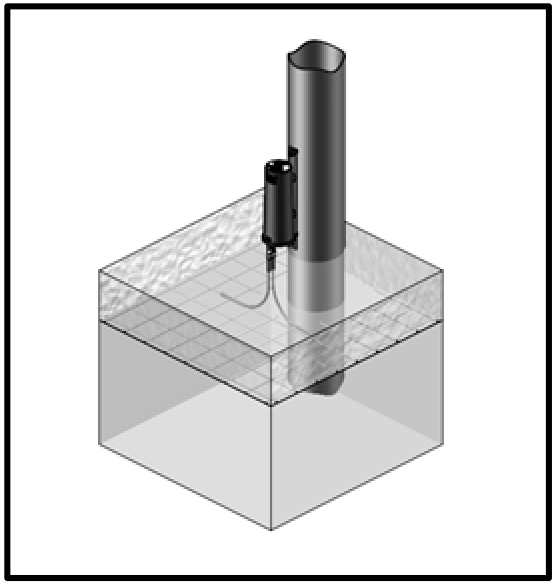
MITIGATION – TOUCH POTENTIALS

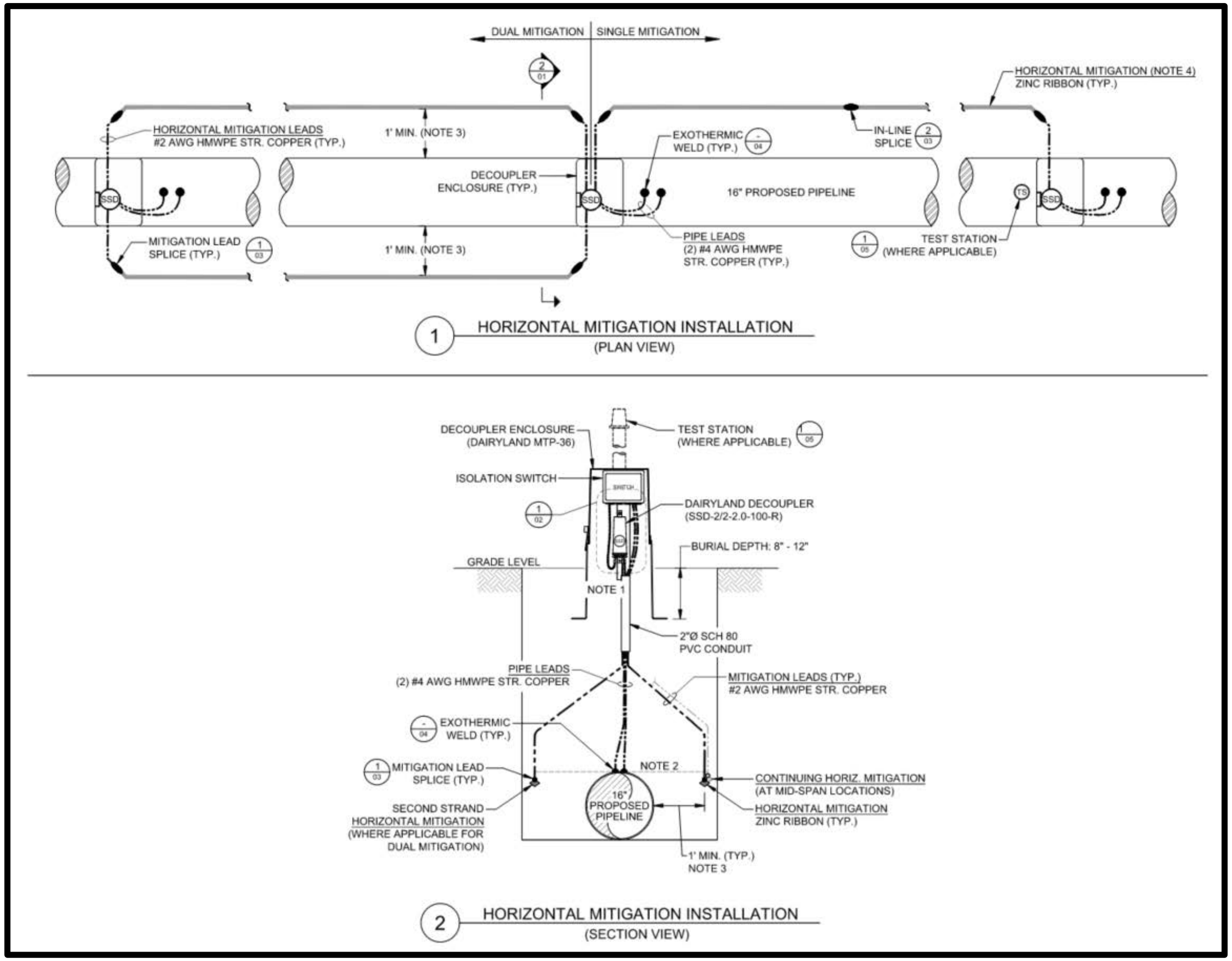


- Gradient control mats at above ground fixtures

- "Dead Front" test stations

MITIGATION – AC INDUCTION

- **Bond to Low Impedance Ground System**
  - Zinc ribbon
  - Copper conductor



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DECOUPLER CONSIDERATIONS

- Influence on **cathodic protection** operation and monitoring
- Existence of AC voltage / current activation threshold
- Ability to withstand and/or conduct surges and lightning overvoltage's
- **Size** of the device (kV)
- Maintenance

Gradient Control Wire Considerations

	Packaging	Standard Length (ft)	Weight (lb/ft)	Diameter (in)	Cross Sectional Area (in^2)	Consumption Rate (lb/A-yr)	Connection Method	Retail Price ($/lf)
Copper								
#4 AWG Bare, 7-Strand	Spool	1000	0.13	0.204	0.417	N/A	DCD	$0.58
#2 AWG Bare, 7 Strand	Spool	1000	0.20	0.258	0.664	N/A	DCD	$0.82
CopperWeld™	Spool	1000	0.41	0.431	0.513	20	DCD	$1.49
Zinc								
Aircraft Wire	Coil	1000	-	-	-	20	DCD	-
Small (11/32" x 13/32")	Spool	1000	0.25	N/A	0.140	23.5	D, DCD	$2.02
Standard (1/2" x 9/16")	Spool	500	0.6	N/A	0.281	23.5	D, DCD	$3.20
Plus (5/8" x 7/8")	Coil	200	1.2	N/A	0.547	23.5	D, DCD	$5.10
Super (1" x 1.25")	Coil	100	2.4	N/A	1.250	23.5	D, DCD	$12.45

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Q&A

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