To meet growing demand for natural gas, hundreds of new pipelines are being installed in the same corridors as high-voltage alternating current (HVAC) transmission lines. Although collocating these lines is a cost-effective option from a land acquisition perspective, it can lead to pipeline corrosion and additional safety hazards.
High levels of alternating current (AC) voltage have been considered a risk for humans and wildlife for years, but few imagined it could pose a threat to nearby pipelines. In recent years, a new threat has been identified — the risk of AC interference corrosion. This risk has caught the attention of both corrosion experts and natural gas providers across the U.S.

Underground pipelines are coated and supplemented by cathodic protection (CP), a technique used to control the corrosion of metal surfaces. Despite the dual layer of protection, it has been observed with increasing frequency that when these pipelines can experience AC interference corrosion when collocated with or crossed by HVAC facilities.

Organizations have been compelled to share utility corridors for many reasons, including: government permissions for land access, public opposition to infrastructure projects, and the cost of land. While sharing corridors is beneficial in a lot of ways, pipelines collocated with one or more transmission lines for a significant length — at least 1,000 to 1,500 feet — can be exposed to an increased risk for AC-induced corrosion and shock hazards.

There are several ways alternating current can couple with parallel metallic structures:

- **Capacitive coupling:** The transfer of energy through a dielectric medium such as air between two or more electrical circuits. Capacitive coupling is observed during construction activities when lengths of pipe are resting on wooden skids before being lowered into the trench. It is common practice to temporarily ground each end of the skidded pipe segments to eliminate the risk for electrical shock. Once a metallic object is grounded, the capacitive effect is no longer a concern.

- **Inductive coupling:** Caused by the interaction between the electromagnetic field (EMF) generated by HVAC transmission lines and any parallel metallic structure. The current flowing though the transmission line conductors induces a voltage onto the paralleling pipeline by Faraday’s law of induction. The magnitude of interference can be affected by several variables, including:
  - Cathodic protection current density
  - Conductor height, material, phase arrangement and circuit geometry
  - Electrical isolation
  - Length of parallel collocation
  - Pipeline coating quality, diameter and depth
  - Separation distance
  - Soil resistivity and chemistry
  - Substation and pipeline station grounding
  - Transmission line current

- **Resistive coupling:** Happens when two circuits interact with each other through a conductive path such as soil. During a transmission line fault event, a large amount of current is injected into the earth from the tower ground. Due to ground potential rise caused by the injected current, a pipeline within the voltage gradient experiences a voltage stress because of the low AC potential of the pipe and the high potential of the soil surrounding the coating. This can result in severe coating damage and even direct arcing between the two structures.

**RISK ASSESSMENT AND MITIGATION**

There are many variables that can play into whether and how collocated pipelines can incur AC interference corrosion. Some of those factors and techniques, when properly identified and implemented, also can help mitigate the risks.

**AC MODELING**

Before taking the necessary steps to mitigate corrosion and fault interference along the pipeline, it is vital to understand and review the impact of fault currents and roughly calculate the steady-state induced currents that can be expected around the pipelines, as well as the environmental and electrical variables that contribute to elevated steady-state and fault currents. AC modeling software can help in determine the location and extent of mitigation required based on several factors, such as the attributes of the pipeline, soil resistivity, distance between the lines, and the operational limitations of the HVAC transmission system. While the nature of alternating current makes the degree of interference difficult to
determine without computer-based modeling software, there are several ways to predict whether a pipeline might be at risk. The following methodologies can assist in studying AC interference, analyzing historical data, identifying potential locations at risk for AC-induced corrosion, and subsequently designing a mitigation plan.

**COUPON TEST STATIONS**

Coupon test stations — remote monitoring units — should be installed at the centerline of pipe depth, within one foot of the pipe and facing the pipe. Readings collected from these test stations assist in real-time monitoring of AC density levels, which are always fluctuating based on hourly current demands and seasonal variations in soil’s electrical resistance. The collection of AC pipe-to-soil and current density measurements should be included in all corrosion surveys of pipelines collocated with HVAC transmission lines.

Test stations to collect AC pipe-to-soil measurements can provide valuable insight regarding the degree of interference. In accordance with the standard from NACE International on mitigation of AC and lightning effects on metallic structures (SP0177-2014), a steady-state touch voltage of 15 VAC or more with respect to local ground is considered a shock hazard, and the installation of AC grounding systems is necessary.

After determining that the pipeline is safe, one can focus on the corrosion risks. After current is induced onto the pipeline and begins to flow longitudinally, it is going to look for a path to return to its source. The path of least resistance is mostly through a pipeline coating defect, and the subsequent discharge results in accelerated corrosion. The probability of AC-induced corrosion can be predicted based on current density levels. NACE International provides the following guidelines:

<table>
<thead>
<tr>
<th>Current Density</th>
<th>Risk Classification</th>
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<tbody>
<tr>
<td>$I &lt; 20 \text{ A/m}^2$</td>
<td>Low, corrosion is not expected</td>
</tr>
<tr>
<td>$20 \leq I &lt; 100 \text{ A/m}^2$</td>
<td>Medium, corrosion is unpredictable</td>
</tr>
<tr>
<td>$I \geq 100 \text{ A/m}^2$</td>
<td>High, corrosion is expected</td>
</tr>
</tbody>
</table>

If no coupon test stations have been installed along the pipeline route, the AC current density still can be calculated:

$$I = \frac{8 \times V}{(\rho \times \pi \times d)}$$

$I = \text{AC Current Density (A/m}^2\text{)}$

$V = \text{AC Potential (V)}$

$\rho = \text{Soil Resistivity (O-m)}$

$d = \text{Coating Holiday Diameter (m)} = 0.0113\text{ m}$

for worst-case scenario

It should be noted that elevated voltages do not necessarily mean that the pipeline is at risk for induced corrosion, as soil resistivity and coating defect geometry also influence the current density levels. The opposite is also true, as it is possible for AC corrosion to occur at very low voltage levels. Temporary coupons are also effective in determining current density without the use of calculation or soil resistivity data. There are current density probes commercially available that can be used to easily measure current density levels in the field.

**ENVIRONMENTAL FACTORS**

Mapping route geometry and environmental conditions can help identify locations most susceptible to AC interference. When analyzing the route, note that length of collocation and separation distance directly affect the risk for AC interference. That risk increases as the collocation length increases, as well as when the separation becomes narrower. Collocations over 1 mile and pipelines within 100 feet of HVAC transmission lines should be considered high-risk.

Low soil resistivity directly contributes to an increase in AC-induced corrosion rates. Water crossings, swamps and soil with high moisture content will exhibit low resistivity and should be considered high-risk areas. Collecting soil resistivity measurements in future pipeline surveys should be considered.

Collocation discontinuities also factor into the risk. Locations where the pipeline enters or deviates from the transmission line right-of-way have an increased risk for AC-induced corrosion due to disruptions in the electromagnetic field generated by the transmission line.
PIPELINE CHARACTERISTICS
Several characteristics of the pipeline can influence the degree of AC interference, including the coating quality and location of insulators. Factors as simple as diameter and depth of the pipeline can make a difference. As pipeline depth and diameter increase, the magnitude of AC interference is reduced.

High-quality pipeline coatings are one of the main variables that contribute to elevated AC voltages, because of the coating’s inability to self-ground. Most of the induced voltage is retained by the pipeline as a result of the absence of coating defects.

Locations where electrical isolation exists can experience a spike in AC voltage because the induced current is unable to flow past the insulator and attenuate further down the pipeline, causing a charge buildup.

AC MITIGATION SYSTEM DESIGN
AC mitigation techniques include designing and installing systems to reduce voltage spikes during network faults, upholding AC contact capabilities below 15 V_{Ac} for protection from shock hazards, and lowering AC intensity to provide protection against AC corrosion. The following methods have been effective in mitigating AC interference:

• Pipeline grounding electrodes: This system consists of grounding arrays (multiple ground rods or zinc anodes) or deep ground wells that are connected to pipelines at strategic locations to reduce voltage spikes around the pipelines. This protects the pipelines during steady-state or network faults from neighboring electric transmission lines. This method is also called lumped grounding.

• Fault shielding: HVAC transmission lines running parallel to underground pipelines can discharge fault current, causing direct current arcing in soil, which damages pipeline coatings. Fault shielding can be installed between the tower footing (or substation grid) to reduce pipeline voltage stress and intercept a possible arc. It should be noted that the installation of fault shielding cannot be fully relied upon to intercept an arc. While these conductors may help to reduce fault damage, the presence of low-resistance shielding conductors can also promote direct arcing between the grid and the conductor where arcing otherwise would have not occurred if the shielding were not present. Fault shielding should be considered with care.

• Gradient control mats: During steady state or a fault condition, high levels of AC voltage can be present along the pipeline. Any person near the pipeline can be at risk for shock. Gradient control mats installed around above-grade appurtenances provide protection from step and touch voltages.

• Parallel grounding conductors: This is the most commonly utilized AC mitigation technique. The installation of a parallel copper or zinc grounding wire will reduce AC voltage and current density levels experienced by the pipeline. This wire is often buried at pipeline depth, and separated anywhere from 1 to 10 feet laterally.

CONCLUSION
As the demand for natural gas increases, building robust pathways for pipelines will be extremely important. Considering the environmental permitting and construction costs and other factors, collocating utility infrastructure can be an attractive option.

Collocation has presented several challenges to natural gas providers. In the past, identifying the potential ill effects transmission lines could have on the pipelines was a challenge itself. With extensive research and newer technology, it has become easier to identify risks earlier. Bolstered by that awareness, pipelines and adjoining structures can be protected from those hazards. Addressing those risks preemptively can dramatically reduce maintenance and replacement costs.

BIOGRAPHY
FRANK ONESTO, CP3, is a staff pipeline engineer at Burns & McDonnell with experience in the energy and pipeline industry, serving on a team of corrosion control and integrity field service specialists. He is experienced in designing cathodic protection and AC mitigation systems, as well as surveys and inspections to assess pipeline coating and cathodic protection effectiveness. Frank has a Bachelor of Science in mechanical engineering from Marquette University.