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# AC Mitigation Design Considerations for Pipeline Facilities

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## ABSTRACT

AC interference between co-located pipelines and high voltage AC powerlines can result in safety hazards to operating personnel and the public under powerline steady-state and fault conditions.

Under steady-state conditions, AC voltages are induced on the pipeline via electromagnetic coupling. Under fault conditions, high AC voltages can be present via electromagnetic coupling and AC currents discharging into the earth from the powerline structures, i.e., conductive coupling. These high voltages can result in serious injury or death to any person in contact with any above-ground metallic appurtenance that is electrically continuous with the pipe.

The type and magnitude of AC interference hazards are dependent on many factors including the co-location configuration, the electrical resistivity of the soil, the AC currents on the powerline, and the powerline and pipeline characteristics. Consequently, AC mitigation strategies must be put in place to ensure the safety of all persons and must be tailored according to the various conditions.

This paper discusses the factors that should be considered when designing AC mitigation systems for pipeline facilities. Such factors include facility layout, isolation points, fencing, and ground conditions. The paper also discusses the different mitigation strategies that can be implemented including gradient control grids, ensuring electrical continuity, and grounding.

Key words: AC interference, AC mitigation, powerline faults, pipeline facilities, pipeline stations, valve sites, grounding.

## INTRODUCTION

When a pipeline is co-located with an AC powerline, it is subject to AC interference effects. These AC interference effects can result in safety hazards to operating personnel and the public under powerline steady-state (normal operation) and fault (short-circuit) conditions.

The possible AC hazards under fault conditions include electrical shock to personnel and the public resulting in serious injury, damage to the pipe coating and pipe wall, and damage to pipeline systems and components (e.g., cathodic protection rectifiers, sensing devices, gaskets, and valve motors).

The mechanism of interference and the type and magnitude of hazards depend on many factors including the co-location geospatial configuration, the electrical resistivity of the soil, the AC currents on the powerline, the duration of the hazard (fault clearing time), and the powerline and pipeline characteristics.

To ensure the safety of all persons contacting the pipeline and to maintain integrity of related systems, a mitigation strategy must be developed and implemented. Mitigation of AC hazards may also be required for compliance depending on the jurisdiction.

This paper discusses how to evaluate the risk of AC interference hazards at pipeline facilities and the different factors and strategies to consider when designing an AC mitigation system. The paper focuses the discussion on AC interference hazards within pipeline facilities and does not cover hazards from high voltage DC power systems and lightning or other integrity issues such as AC corrosion.

## BACKGROUND

The mechanisms and factors by which AC interference hazards can become present on a pipeline which is co-located with a powerline are well established in the existing literature.[1, 2] The main two mechanisms of concern for buried pipelines are electromagnetic (inductive) coupling and conductive (resistive) coupling.

To predict the effects of AC interference for pipeline/powerline co-locations, the most effective method is to use specialized modelling software. After having collected all the data required to build an accurate model of the co-location of interest, different simulation scenarios can be computed. Typical simulations include powerline steady-state conditions (e.g., average load and maximum load) and powerline fault conditions.

For assessing AC interference hazards at pipeline facilities specifically, powerline fault conditions are normally the primary concern. This is because under fault conditions the voltages on influenced pipelines can reach magnitudes between several hundred volts and a few kilovolts; this is significantly higher than steady-state conditions.

During powerline fault conditions, there are three situations which must be assessed for personnel safety: touch voltage, metal-to-metal or hand-to-hand voltage, and step voltage. The objective for the designer of the mitigation system is to ensure that the predicted voltage for any of these situations does not exceed its admissible limit.

To assess the risk of AC hazards at pipeline facilities, the fault condition AC voltages along the pipeline must be predicted. Since fault conditions cannot be measured in-situ, the only way to predict AC hazards is to simulate the fault conditions using specialized computer software.

Ideally, the computer model would reflect all real-world conditions that affect the outputs. However, like most real-world problems, there are limitations to the amount of data that can be captured. Therefore, it is critical that all required parameters be included to the best of the designer's ability to ensure accurate and representative model outputs. The general parameters required for such modelling are well covered in the literature.[3, 4]

One of the important parameters for accurate modelling and mitigation design is the soil resistivity at the facility of concern. The soil resistivity plays a critical role in determining the current distribution within the facility, the ground potential rise (GPR) in and around the facility, the ground resistance of various structures, and the admissible voltage limits for personnel. The design of any mitigation systems also highly depends on the soil resistivity within the facility.

Another set of critical parameters are the facility's electrical grounding systems and other buried metallic structures. Depending on the location and size of the facility there could be extensive grounding systems/structures including copper wire, gradient control grids, ground rods, ground wells, and support piles.

Additionally, all isolation points, pipeline electrical equipment, and foreign structures within the facility should be identified and accounted for. This includes, but is not limited to, isolating flanges, electrical buildings, third-party pipelines, and facility gates and fences.

## ADMISSIBLE LIMITS

In Canada, CSA(1) Standard C22.3 No. 6 requires that the maximum touch, metal-to-metal, and step voltages not exceed the limits defined in IEEE(2) Standard 80.[5, 6] A similar requirement is included in NACE Standard SP0177.[7] The equations provide safety limits in volts based on a person's body resistance ($R_B$), foot resistance ($R_f$), and the tolerable body current ($I_B$) to prevent ventricular fibrillation. The tolerable body current is a function of a person's weight and duration of electric shock (fault duration).

The touch voltage is the potential difference between the GPR at the soil surface where a person is standing and any exposed pipe appurtenance(3). In this situation, the current travels through the body and then is split between the two feet as shown in Figure 1a. The touch voltage limit is defined by Equation 1.[6]

$$E_{touch} = \left(R_B + \frac{R_f}{2}\right) I_B \qquad (1)$$

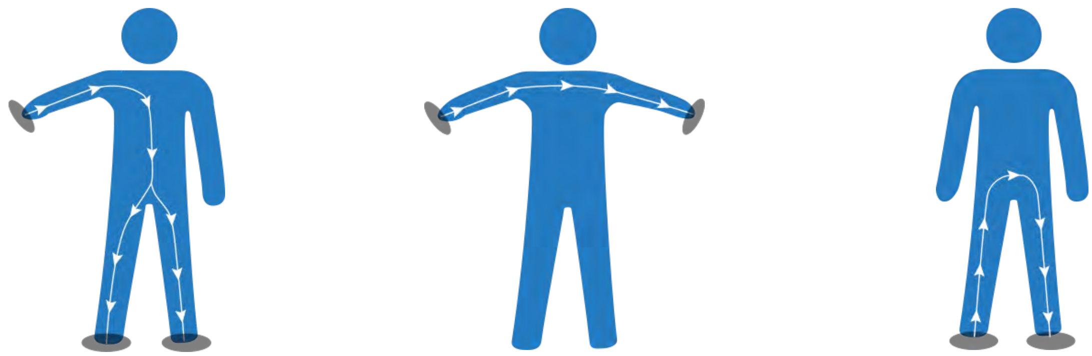
The metal-to-metal voltage is the potential difference between any exposed pipe appurtenance and any independent metal structure, where a person can touch both structures simultaneously. An independent metal structure is a grounded structure that is not electrically continuous with the pipe and is within 2 m of the pipe appurtenance. In this situation, the current travels through the body from one hand to the other as shown in Figure 1b. The metal-to-metal voltage limit is defined by Equation 2.[6]

$$E_{mm} = R_B \times I_B \qquad (2)$$

(1) CSA Group, 178 Rexdale Blvd, Etobicoke, ON, M9W 1R3.
(2) IEEE, 3 Park Avenue, 17th Floor, New York, NY, 10016-5997.
(3) This includes any above-grade structures which are electrically continuous with the pipeline.

The step-to-step voltage is the difference in surface potential (or GPR) between a person's feet 1 m apart without contacting any other grounded structure. In this situation, the current travels between the two feet via the body as shown in Figure 1c. The step voltage limit is defined by Equation 3.[6]

$$E_{step} = \left(R_B + 2R_f\right)I_B \tag{3}$$



a) Touch b) Metal-to-Metal c) Step

**Figure 1: Touch, Metal-to-Metal, and Step Voltages**

## MITIGATION MEASURES

Once AC voltage risks at a facility have been identified, they must be mitigated. There are many mitigation approaches that may be used and there is no single correct way to mitigate. Different combinations of mitigation measures may be needed in some instances and in others only a single mitigation method may be sufficient. In this section, different mitigation measures that have been implemented in different regions in Canada are discussed.

### Monolithic Isolation Joint

A monolithic isolation joint (MIJ) is a pre-assembled component which is welded in-line with the pipeline and electrically isolates the two sides of the joint. The MIJ acts like an isolating gasket between two flanges. However, the MIJ differs in that all its components are entirely encased within the MIJ itself, making it a very robust method of isolation and well-suited for direct burial. Additionally, it can generally withstand much higher voltages than a typical isolating gasket.

By installing an MIJ on a mainline prior to coming above-grade in the facility of concern, any AC voltages would be prevented from entering the facility and any AC voltage hazards from the mainline would be mitigated. Additionally, no AC hazards from the mainline would be transferred to third-party systems or other facilities.

While MIJs can withstand higher voltages than typical isolating gaskets, they are still limited by their dielectric strength. Typical dielectric strength values for commercially available MIJs range between 3-5 kV for 1 minute. It is likely that an MIJ can withstand much higher AC voltages for the very short periods of an AC fault, however, the available data is limited.[(4)]

[(4)] The authors are aware of only one MIJ manufacturer that specifies a dielectric strength value of >10 kV; however, no upper limit or time duration are provided.

MIJs are typically not practical or cost-effective for existing pipelines because installation would require a full shut down of the pipeline.

**Mainline Pipe Grounding**

Electrical grounding of a pipeline outside a facility is an effective method of reducing AC voltages on the pipeline by draining AC current via bare metallic components with low electrical resistance to remote earth. It can also be a very cost-effective method of mitigation if there is already an open-trench (e.g., for a new pipeline or maintenance). This method of mitigation is also most commonly used to mitigate steady-state AC voltages along mainline pipes.

By using mainline pipe grounding to reduce the AC voltages below the admissible limits, any AC voltage risks from the mainline would be mitigated. Additionally, no AC hazards would be transferred to third-party systems or other facilities.

Many different methods of grounding mainline pipelines have been utilized in the industry. These methods include, but are not limited to, bare copper wire or zinc ribbon installed in the pipeline trench, AC grounding wells, and anode groundbeds.

Mainline pipe grounding is only an effective mitigation method under powerline fault conditions if the predicted AC voltages are not much higher than the admissible limits. Consider the simplified equivalent circuit of a pipeline entering a facility shown in Figure 2, where $V_{AC}$ is the voltage on the pipeline, $Z_L$ is the longitudinal impedance of the pipeline, $Z_S$ is the shunt impedance of the pipeline (coating and defects), $Z_M$ is the impedance of the mainline grounding, and $Z_F$ is the facility impedance. To meaningfully reduce the AC current flowing through $Z_F$, $Z_M$ must be significantly smaller than $Z_F$. For many facilities $Z_F$ may already be relatively low if the site is well grounded, thus the effect of any mitigation at $Z_M$ would be small, especially for high $V_{AC}$ values.

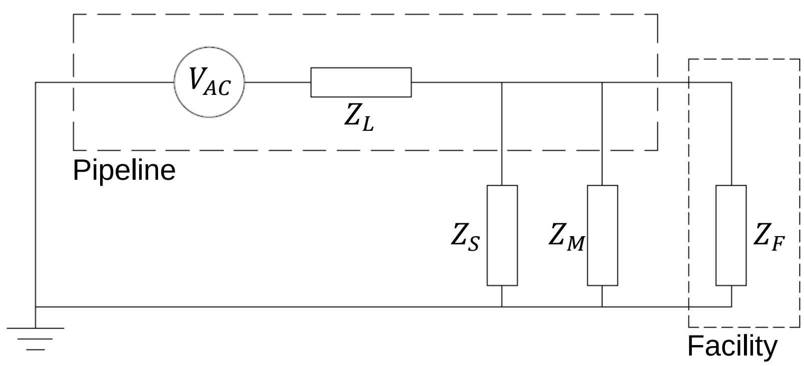



**Figure 2: Equivalent Pipeline Circuit**

**Facility Grounding**

Existing facility grounding can often help mitigate hazardous AC voltages within the facility itself. Most facilities have electrical buildings and services that require grounding to meet the electrical code in their respective jurisdiction. Typical facility grounding systems in Canada consist of ground rods buried around the facility buildings and structures, interconnected via bare copper wire. Depending on different factors such as the size and age of the facility, the grounding may be electrically continuous across the entire site or may be limited to certain areas. Moreover, there may be additional buried metallic structures such as steel piles or rebar in concrete that may provide additional grounding.

Similar to the mainline pipe grounding, facility grounding alone may not be enough to mitigate AC hazards below the admissible limits; additional complimentary measures may be needed as well. Furthermore, it is not enough to mitigate a facility using a discrete impedance value in a computer model. It is important to consider the current distribution within the facility and between metallic structures to ensure that there are no overlooked AC hazards.

**Gradient Control**

In facilities where it is not possible nor practical to reduce AC voltages below the admissible limits by isolation or grounding methods, gradient control measures can be a very effective alternative. Gradient control is effectively designing ground grids/loops/mats around above-grade appurtenances at risk. By connecting the gradient control grid to the appurtenance, the GPR at the soil surface on top of the grid will be close to the pipe AC voltage (or vice-versa). Thus, the voltage difference between the appurtenance and the soil GPR can be reduced below the limit.

Figure 3 shows an example of a simple gradient control grid at a pipeline valve site (cathodic protection conditions omitted for simplicity). The site has a single above-grade appurtenance and a surrounding fence. To ensure that the valve site is safe for personnel, a gradient control grid is installed around the appurtenance and a gradient loop is installed around the fence. With all structures bonded together, the touch voltage must be assessed around all structures electrically continuous with the pipe (locations 1 and 2). Step voltages are also assessed throughout the site (location 3) and outside the site as well (locations 4 and 5).

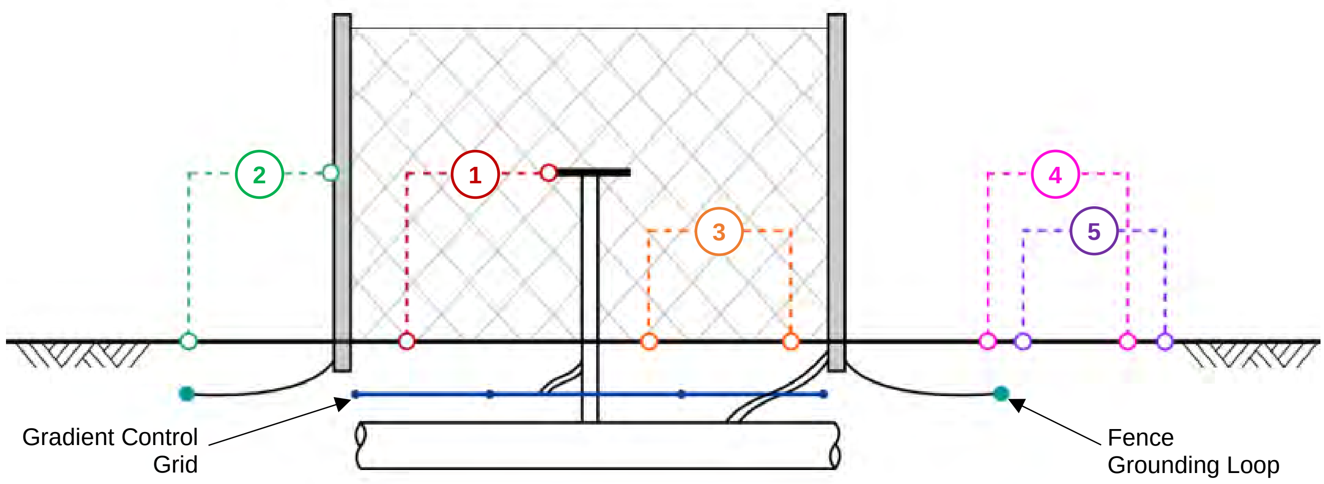



**Figure 3: Simple Gradient Control Grid**

The design of the gradient control grid will depend on several factors including the magnitude of the AC voltages, the size and layout of the facility, and the soil resistivity. The size, depth, and conductor density of the grid will depend on these factors.

It is critical to note that even though gradient control grids are very effective at reducing touch and step voltages in a facility, they may have a negligible impact on metal-to-metal voltages. This is because the metal-to-metal voltage is the potential difference between two isolated structures.

**Electrical Continuity and Independent Metal Structures**

At any facility where AC voltage hazards cannot be reduced below the admissible limits, the designed mitigation system must include provisions to ensure that no person will receive an electric shock when touching any pipe appurtenance and an independent metal structure. Mitigation is easily achieved by bonding the two structures or ensuring that a person cannot touch both structures at the same time (e.g., non-conductive fence).

Most pipeline systems are equipped with cathodic protection (CP) provisions for corrosion control purposes. In many cases, the pipelines and CP systems are not connected to facility grounding, which has several benefits including better CP current distribution along the pipeline and reduced current requirements. Therefore, whenever bonding of the pipeline to any other structure is required, an assessment of the CP system is required as well.

The most common method of bonding pipelines to other electrical systems is through DC decoupling devices. DC decoupling devices are designed to keep the two systems isolated in DC while simultaneously providing AC continuity. Subsequently, there is minimal impact to the CP system. Note that CP surveys may be affected by the presence of DC decouplers in the system because the decouplers are capacitive devices and will discharge current during CP interruption cycles.

Additional mitigation measures may be required when bonding independent metal structures to the mainline for electrical continuity purposes depending on the jurisdiction. For example, in Canada, CSA C22.3 No. 6 requires that if a fence is grounded for AC mitigation, it must be located at least 1 m inside the perimeter of station grounding, with tap conductors to the grounding at each end post, corner post, and gate post, and at intermediate posts at intervals not exceeding 12 m. Furthermore, tap conductors must be connected to the fence post, the bottom tension wire, the fence fabric, and each strand of barbed wire.

### Protective Surface Layer

Protective layers installed on the soil surface, such as gravel or crushed stone, can be an effective mitigation method. Since the resistance of a person's foot is dependent on the soil resistivity (Equations 1 and 3), an increase in resistivity will result in an increase in the touch and step admissible limits (no change to metal-to-metal limit per Equation 2). Note that if a protective surface layer is used, CSA C22.3 No. 6 requires that the step volage also be assessed for a person with one foot on the protective layer and one foot on native soil.[5]

NACE SP0177 cautions in Rule 4.3.4 that increasing the surface resistance should be used to augment the grounding system and not be the sole protection measure.[7] This is because the protective surface layer, e.g., gravel, may not be well maintained and kept clean. If the protective surface layer is not maintained in thickness and kept clean, its effectiveness will diminish as its resistivity drops over time. Therefore, a protective surface layer should be used with caution and only if there is a maintenance program in place. Periodic resistivity measurements of the surface layer should also be considered as part of the maintenance program.

## OTHER CONSIDERATIONS

### Seasonal Variation

Seasonal changes in soil moisture content and temperature can have a significant impact on the resistivity of soil as shown in Figure 4.[6] The resistivity of most soils rise significantly whenever the moisture content is less than 15% of the soil weight as shown in Curve 2 of Figure 4.

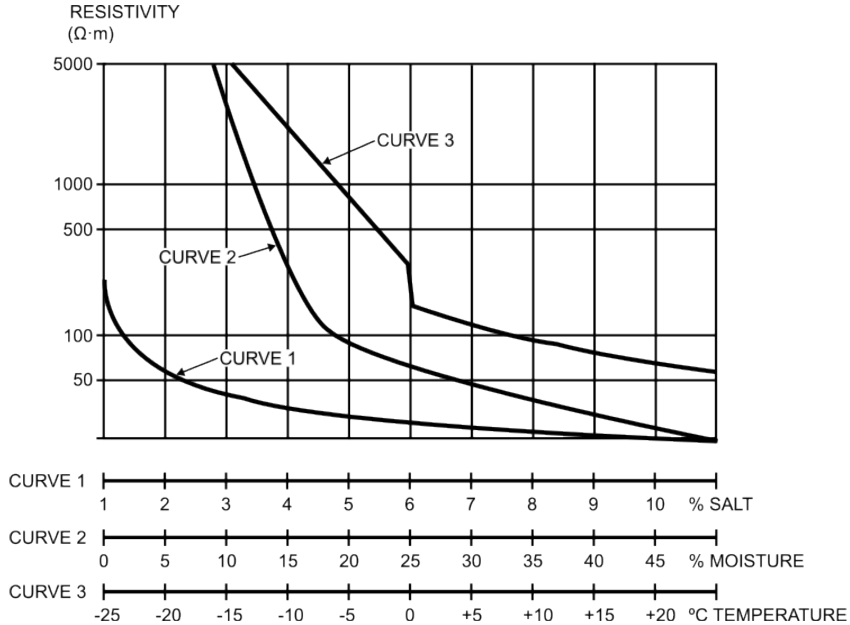



**Figure 4: Effect of Moisture, Temperature, and Salt Upon Soil Resistivity[6]**

The effect of temperature on soil resistivity is nearly negligible above 0 °C as shown in Curve 3 of Figure 4. Once temperatures drop below the freezing point, the resistivity of the soil increases rapidly. Depending on the mitigation system implemented these changes in resistivities may have an impact on the effectiveness of the system and should be considered.

For example, if the mitigation system depends on a discrete resistance value to reduce voltages below the limit, then depending on where the mitigation is installed the mitigation system may be compromised. If the mitigation is installed in a soil layer subject to freezing, its resistance could increase drastically, thus lowering its effectiveness.

In other cases, the increase in soil resistivity may have a negligible effect on the mitigation system. For example, an increase in soil resistivity in winter will raise the electrical resistance of the grid. An increase in surface resistivity will also raise the touch and step admissible limits, like a protective surface layer. If all structures in the facility are electrically continuous, there is also no risk of a metal-to-metal hazard. Therefore, depending on the magnitude of the AC voltages under fault conditions, there may be no concern due to seasonal variation.

Consideration should be given to spring partial thaw conditions, where the upper layer of soil may drop in resistivity but the layers beneath remain frozen. This could present a possible hazard where the electrical ground is in frozen soil, but the top layer is in thawed conditions and the higher winter touch and step limits discussed in the previous paragraph are no longer applicable.

The soil composition and amount of salts present may also considerably affect its resistivity as shown in Curve 1 of Figure 4 for a soil containing 30% moisture by weight. This is mainly a concern in regions where seasonal salting of roads could affect the soil within and/or around facilities.

## Material Selection

The selection of material for AC mitigation is subject to technical, operational, and economic considerations. The optimal material will generally be that which is effective at mitigation, requires little maintenance, and is readily available and inexpensive. Typical materials for grounding include copper, galvanized steel, copper-clad steel, aluminum, and existing steel structures.

When selecting a suitable material, some of the factors that should be considered are as follows.

- Ampacity
- Thermal stability or fusing characteristics
- Insulation
- Electrical resistance
- Corrosion characteristics
- Electrochemical compatibility with the existing system
- Construction and maintenance requirements
- Cost and availability
- Theft deterrence
- Environmental impact

## CONCLUSIONS

Pipeline facilities subject to hazardous AC voltages due to co-located powerline fault conditions must be mitigated to ensure the safety of personnel and the public. Since the only way to design mitigation systems is to rely on specialized modelling software, the designer should ensure that all factors affecting the model predictions are accounted.

Once the possible AC interference hazards are identified at a facility, a mitigation strategy should be developed based on the unique characteristics of the facility. Different mitigation approaches include mainline pipe grounding, existing facility grounding, gradient control grids, and ensuring electrical continuity. DC decoupling devices must also be included in any mitigation system, except when the CP system is sized to protect all buried structures in the facilities (i.e., “flood” CP systems).

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