APPLICATION GUIDE

# AC VOLTAGE MITIGATION

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## INTRODUCTION

AC voltage can appear on cathodically protected pipelines adjacent to electric power distribution or transmission lines. This paper discusses the phenomena, as well as mitigation goals, products, and grounding systems needed for effective reduction in induced AC voltage.

The general technique for mitigating induced AC voltage is to connect the pipeline at appropriate locations to a suitably low impedance grounding system in order to collapse the voltage to a safe value. This must be accomplished without negatively affecting impressed current cathodic protection (CP) systems used for corrosion management on pipelines, and is covered as we transition from the problem description to the solution description.

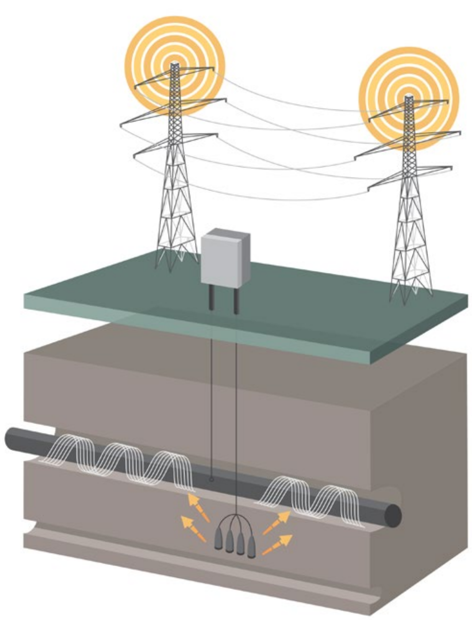
## ELECTRICAL EFFECTS UPON PIPELINES

Pipelines are typically steel construction with very effective dielectric coating to aid in minimizing CP current requirements. While good coatings help with cathodic protection, they act as insulation for other electrical signals as well, allowing AC induction from overhead power lines to appear on the pipe. The same principle is at work in transformers that use magnetic induction to cause a voltage and current to appear on the output side. This unintended effect on pipelines can be a significant safety concern for pipeline personnel, as the voltage is accessible at metallic contact points.

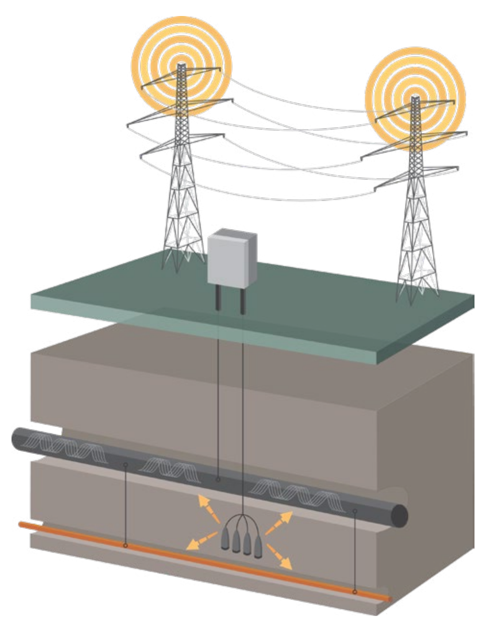
AC voltage and current can appear on pipelines due to three different mechanisms. During construction, capacitive coupling from the voltage on the power line can cause an isolated section of unburied welded pipe to elevate in voltage, acting as a capacitor. This effect is negated when the pipeline is buried and in contact with earth. A second transfer method, resistive coupling, results during AC powerline faults, when there is adequate voltage present to initiate an arc through the soil to the pipeline. This is a function of soil resistivity, separation distance, and voltage. Mitigation systems can address resistive coupling-related damage if such systems are installed where arc propagation is possible, but in some cases these systems are not present unless users have also focused on the third method of transfer, AC induction.

The most identifiable AC interference effect relates to steady-state induction caused by the magnetic field associated with current flow on the power line. Steady-state AC voltage can easily be measured or felt to understand that the pipeline is subject to unwanted electrical effects. The continuous nature of the phenomenon makes it easy to detect. The level of induction is affected by many factors, including powerline load current, separation distance of each phase from the pipeline, phase transpositions, changes in pipeline distance or orientation, soil resistivity, coating quality, and others.

AC mitigation is intended to address the steady-state nuisance or hazard, but there are additional risks that must also be addressed. AC faults on the powerline occur when some form of insulation breakdown has occurred, and result in a very short term, high amplitude current flow. This temporarily causes coupling to the pipeline of high current and voltage in exactly the same manner as the steady-state effect, but at unsafe levels. The result on a coated pipeline, without mitigation, will be unacceptable touch voltage and step voltage for workers, and possible insulation breakdown and arcing on pipeline systems. Mitigation involves properly addressing both steady-state and fault conditions to limit such voltage hazards.



*Electric and magnetic fields can cause unwanted voltage to appear on nearby pipelines creating a safety risk and corrosion threat.*



*Mitigation systems such as zinc ribbon direct bonded to address safety and corrosion risks from induced AC cause adverse affects on your CP system.*

Mitigation typically begins with software modeling by specialized consultants, inputting the various factors listed above to arrive at a voltage map at all points along the pipeline. Then, applying low impedance grounding points at various locations along the affected area indicates the likely performance achieved by the final installation, which would include the appropriate grounding system arrangement and the decouplers used as the connection device between the pipeline and the grounding system. Decouplers prevent DC interaction between the pipeline and grounding system, but pass AC signals and collapse the induced voltage. These devices are explained later in this article.

Lightning presents one additional risk to pipeline systems, as the nearby well-grounded power line structures increase the exposure. With a fast rising waveform, lightning current produces large voltage differences as it flows through the inductance of the conduction path (wire, pipe, etc). Lightning and AC have different characteristics, but the basic risks are similar to the pipeline operator. AC mitigation systems which reference the pipeline to local earth can have the effect of limiting coating stress, arcing, and worker hazards, however additional step and touch voltage review is needed to assure such protection for lightning. Properly designed grounding mats are necessary to address step and touch voltage risks specific to lightning, and are commonly applied at test stations, around above grade piping, and near other structures which could be contacted. More information on grounding mat application is included further on in this article.

## GOALS AND CRITERIA FOR SAFETY AND CORROSION-PREVENTION

Industry identifies the human health concerns associated with AC and lightning effects in NACE Standard Practice SP0177, which can be downloaded from the NACE website www.nace.org. That document outlines guidance of keeping AC touch voltage limited to below 15V for human health. This value presumes certain factors, and should be considered a mere guideline. AC induction can vary widely due to seasonal soil variations and power line loading. Pipeline AC voltage readings should be obtained using a datalogger over a period of time, to assure that peak potentials have been identified. Recall that these readings are steady-state values, and under fault conditions the induced voltage will be much higher – far beyond the 15V safety limit. Therefore, it is very shortsighted to ignore AC fault conditions, even if low steady-state voltages are found. Many AC mitigation systems are installed to address such conditions.

Beyond human health issues, AC corrosion also warrants examination from a mitigation perspective. Even when low levels of induction are unmitigated, or when mitigation systems yield partial AC voltage reduction, the remaining value may seem insignificant, however, AC corrosion phenomena can easily occur. AC corrosion can be found when adequate AC current density exists at small coating defects. An unwanted consequence of new, high resistance coatings, AC induced current exchange between the pipeline and soil at small coating defects can achieve very high current densities – the amount of current flow per square unit of area. Industry studies point the user to concern at values approaching and exceeding 100A/m$^2$. Note that at a more comprehensible scale, this equates to 10mA per cm$^2$ – a value easily achieved on many pipelines. Coupons designed with a 1 cm$^2$ area are useful in taking current density measurements to determine risk. In general, only areas with low soil resistivity typically have AC corrosion occurring at small coating defects. See NACE document 35110 for more information on AC corrosion phenomena. AC mitigation consultants should always consider AC corrosion while performing analysis for worker safety, as it necessarily involves possible further reduction of the resulting mitigated AC voltage from that level adequate for human health issues. This in turn has effect upon the final grounding system design to achieve that criteria, involving additional material (if all other factors are held the same) and additional cost.

## DECOUPLERS

AC mitigation can be accomplished by direct connection of the pipeline to a suitable grounding system, but such action would negatively impact cathodic protection. Decouplers have a long history of effectively providing DC isolation of cathodically protected structures from other objects or grounding systems, and eliminate the effects that come from direct bonds. Dairyland pioneered solid-state decoupler design and use to solve these challenges. Products such as the PCR, SSD and PCRX offer DC isolation and AC continuity under normal conditions, and instantaneously switch to a voltage clamping mode at a low and safe value of several volts – above any normal CP voltage, but low enough to provide worker safety. The fail-safe design provides for a failed-shorted result if the product is exposed to current/time beyond the device energy capability. However, product ratings, per project, are to be chosen to exceed the modeled AC steady-state and fault conditions, such that the device will not fail during or after exposure to the anticipated AC fault. Dairyland devices have been used for decades in harsh field conditions around the world, and failures are exceedingly rare. Products should be chosen and applied to meet the site conditions, ratings, and regulatory requirements. A summary table below shows the typical Dairyland products and ratings used for AC mitigation. Other Dairyland products and applications can be found at www.dairyland.com.


*Dairyland decouplers: SSD, PCR, PCRX*

Most decoupler installations are above grade, where a rain-proof product is suitable, while some installations require product out of sight and below grade. Below grade installations require a submersion-rated decoupler and suitable sealing over terminals and connections. Regarding hazardous locations, almost all locations above grade along a cross-country right-of-way are non-hazardous, but insulated joints, valves, equipment, and facilities often involve Div 2/Zone 2 sites, or possibly Div 1/Zone 1 in areas where flammable gases or vapors are present. All Dairyland decouplers for pipeline applications have at least a Div 2/Zone 2 certification, which can also be used in "ordinary" (non-hazardous) locations.

**AC Mitigation Grounding Systems**

Dairyland does not design grounding systems for mitigation, but can provide useful guidance on many factors that influence the design and help create a successful outcome. Design firms can model the AC effects under steady-state and fault conditions, and determine the suitable grounding system design that will achieve a low resistance and reduces AC voltage to the desired level, considering worker safety and AC corrosion issues. Consultants determine the quantity and spacing/location of each decoupler to achieve an adequately low induced voltage. Optimum spacing will consider the needed voltage reduction between connection points, balanced against the quantity and cost of decouplers.

**Grounding System Material and Decoupling**

Grounding systems can be constructed using any appropriate metal system that provides a resulting low impedance connection to earth, and which is compatible with the characteristics of the soil, considering corrosivity. While various metals have a range of galvanic potentials, the use of a decoupler electrically isolates the DC potential of the grounding material from that of the pipeline, allowing the use of any suitable material.

| | SSD | PCR | PCRH | PCRX |
|---|---|---|---|---|
| **Fault Current Rating** | | | | |
| 1.2kA | ✓ | | | |
| 2kA | ✓ | | | |
| 3.7kA | ✓ | ✓ | ✓ | |
| 5kA | ✓ | ✓ | ✓ | ✓ |
| 10kA | | ✓ | ✓ | ✓ |
| 15kA | | ✓ | ✓ | ✓ |
| **Blocking Threshold** | | | | |
| 2/2 | ✓ | ✓ | ✓ | |
| 3/1 | ✓ | | ✓ | |
| 4/1 | | ✓ | | |
| 3.0/0.5 | | | | ✓ |
| 3.5/0.5 | | | | ✓ |
| 4.5/0.5 | | | | ✓ |
| 6/1 | | ✓ | | |
| **Steady State Current Rating** | | | | |
| 45A | ✓ | ✓ | ✓ | ✓ |
| 80A | | Optional | | |
| **Steady State Current Rating** | | | | |
| 100kA (8x20) | ✓ | ✓ | ✓ | ✓ |
| **Hazardous Location Rating** | | | | |
| Div 1/ Zone 1 | | | ✓ | |
| Div 2/ Zone 2 | ✓ | ✓ | ✓ | ✓ |

With no resulting cathodic protection interaction between pipeline and grounding material, the decoupler optimizes the CP system and avoids interference issues. Experience with direct connected (e.g. no decoupler) mitigation systems has shown that notable interaction takes place between the impressed current CP system and the grounding system. Either the grounding material will appear as a massive coating defect and require CP current, or act as an anode and sacrifice itself. Decouplers avoid that issue and allow any material to be used, keeping separate the CP system from the grounding system as viewed from a DC standpoint. For AC effects, the pipeline and grounding system appear to be continuously bonded together by the decoupler, to mitigate (collapse) the induced voltage, and pass the available AC current.

**Point vs. Continuous Mitigation**

Mitigation grounding systems can be designed and constructed as point grounds or continuous systems. Point mitigation reduces pipeline potentials only at specific sites along the pipeline, generally at accessible locations (e.g., above ground valve sites) where only localized mitigation is desired. Continuous mitigation is used to reduce the pipeline potentials along an entire segment of pipeline.

**Installed Point Mitigation Grounds**

For point mitigation, local grounding will reduce the voltage in the vicinity, by connection to one of various types of grounding systems. Options for point grounding include copper rod stacks or arrays, CP anodes used as grounds, horizontal or vertical pipe in backfill, deep wells, etc. Care should be taken if using anodes to assure that the cables have adequate ampacity, as small diameter wires are often used. Recall that anodes used as mitigation grounds will not function as anodes for the pipeline, as the decoupler will block DC flow.

**Existing Point Mitigation Grounds**

Some existing objects can be used as grounds for the purpose of point mitigation. Care must to taken in considering the effects of bonding the pipeline to that structure via a decoupler, relative to safety. Acceptable structures include casings, culverts, fences, and abandoned bare or poorly coated pipelines. Some of these structures specifically should be bonded into a mitigation system via a decoupler, to avoid high voltage differences during fault or lightning conditions between the pipeline and the adjacent object. As an example, a road casing is located very close to the pipeline and has a very low resistance to earth, inviting an arc from an influenced pipeline if not bonded via a decoupler.

**Unacceptable Point Grounds**

There are structures that are unacceptable for use as a mitigation ground – namely distribution and transmission structures/grounds - because bonding will transfer very high potentials directly onto the pipeline in the event of a lightning strike or an AC line-to-ground fault to the transmission tower. Results can include arcing at insulated joints, coating puncture, and much higher magnitude AC current flow, as the pipeline is now part of the conductive circuit fault return path, instead of merely being subject to a modest induced current. In this case, the full phase-to-ground fault current of the transmission line will be assumed to flow, resulting in a large decoupler rating being required. Also, conducted fault current may flow in unintended paths that extend well beyond the pipeline AC mitigation installation, as conducted (not induced) current returns to the source – most likely a substation at either end. NACE Standard Practice SP0177 and Canadian Standard C22.3 No. 6 both caution against using power system grounds for voltage mitigation.

### Continuous Mitigation

Continuous mitigation is accomplished by using bare mitigation (gradient control) wires installed parallel to a pipeline. These wires, which are either buried in the trench during pipeline construction, or installed afterward, bring the earth potential near the pipeline close to the pipeline potential. Depending on the design of the mitigation system, one or more gradient control wires may be used. Typical construction uses zinc ribbon or bare copper wire as the continuous mitigation grounding system, as designed by the consultant. Ideally, zinc would be installed in suitable backfill, while copper would have some additional CP supplied to it via an independent set of galvanic anodes to assure long life.

### Function of Gradient Control Wires

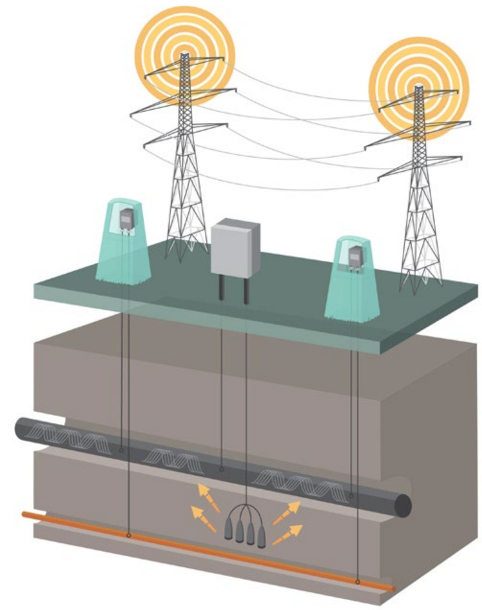
Gradient control wires provide a more thorough solution than point mitigation because they prevent the pipeline coating from being electrically overstressed during abnormal power system conditions all along the mitigated section of pipeline, and more uniformly minimize both touch and step potentials along the entire mitigated pipeline section. Note that gradient control mats are still recommended at above ground worker access sites.

### System Connections

Decouplers are often placed in Dairyland pedestals (ground-based enclosures) along the right-of-way to enclose the product securely, and to allow underground cable connections to the pipeline and mitigation grounding system. Insulated copper conductors bond the decoupler terminals to both structures. The minimum wire sizes associated with Dairyland decouplers are shown in the table below. Other Dairyland enclosures facilitate above grade post or wall mounting. Premade lightweight vaults are also available to secure a submersible-rated decoupler, allowing flush-with-grade covers that are load bearing.

| AC Fault Current Rating | Minimum Wire Size (AWG) | Minimum Wire Size (Metric) |
|---|---|---|
| 1.2kA, 2kA, 3.7kA | #6 | 16mm$^2$ |
| 5kA, 10kA | #2 | 35mm$^2$ |
| 15kA | #2/0 | 70mm$^2$ |

For the purpose of safe disconnection of the decoupler in the presence of AC induction, or for the purpose of testing, Dairyland recommends that a disconnect switch be installed in series in the conductor between the pipeline and the decoupler negative terminal. A recommended universal design is the Dairyland SWX series. Note, however, that these switches may be used only in "ordinary" (non-hazardous) locations. All cables from the pipeline, through the isolation switch and decoupler, to the grounding system should be of a consistent ampacity with minimum size according the above table.



*Decoupled systems provide simultaneous AC grounding and DC isolation optimizing your CP system and simultaneously mitigating induced AC to your grounding system.*

### Gradient Control Mats

Step and touch voltage protection for workers near above grade structures must be accomplished with purpose-designed gradient control mats. AC fault and lightning conditions produce these hazards, and it is especially challenging to limit voltage to fast-rising lightning waveforms. For this reason, Dairyland designed and manufactured gradient control mats that have been modeled for the worst case condition of limiting touch and step voltage due to lightning. Performance of the Dairyland mat compared to spiral or zig-zag single wire systems is especially notable. Due to the complexity of this topic, users are referred to the Dairyland website for more information about gradient control mats.

One note as it relates to AC mitigation systems is that gradient control mats, while they can be effective for limiting touch and step voltage, are not especially low resistance grounds for the purpose of AC mitigation. While these may incrementally improve the resistance of a mitigation system, their main purpose is to provide worker protection while standing over the mat, separate from the effectiveness of the AC mitigation system, or even in the absence of such a system.

## SUMMARY

AC induction and mitigation is a key topic in the cathodic protection and pipeline markets, raising significant safety issues which must be addressed. Dairyland offers notable resource material, products, and guidance to users who are planning an AC mitigation system. Reference the Dairyland website for more information, or contact our application support engineers for assistance. Dairyland freely offers relevant guidance on numerous related topics regarding over-voltage protection, DC isolation and CP system improvement, and safety grounding.