

Use of Decouplers for AC Voltage Mitigation



Application Note 6A

Introduction

AC voltage mitigation is primarily of concern when cathodically protected pipelines are adjacent to electric power distribution or transmission lines. NACE Recommended Practice RP0177-2000 recommends mitigation if the pipeline voltage exceeds 15V.

The general technique for mitigating induced AC voltage is to connect the pipeline to a suitable low impedance grounding system so as to load the induced voltage source, thereby causing the voltage to collapse to an insignificant value. This must be accomplished without affecting cathodic protection (CP) levels. One method is to utilize anodic type materials for the grounding system, such as zinc, or magnesium. Another method is to bond to a grounding system through a decoupler, thereby enabling other materials to be used for the grounding system because the grounding system is DC isolated from the pipeline. There are a number of distinct advantages to using solid-state decouplers in the design of an AC mitigation system as described in this article.

Product Description

The products primarily used for AC mitigation are the DEI model PCR and SSD because they have the ability to provide AC grounding and DC decoupling simultaneously under normal operating conditions. The PCR and SSD are listed for Division 2 hazardous locations and ordinary locations. For Division 1 locations, use the model PCRH. On rare occasions, the higher rated Isolator/Surge Protector (ISP) is required. The designer of the grounding system for AC mitigation (a task generally referred to consultants who have the necessary software and knowledge in designing such systems) has control over the product ratings that

will be required. When decouplers are incorporated into the overall design, the following ratings must be determined in order to select the appropriate product model number, namely, the steady-state AC current rating and the AC fault current rating. This information should be available from the mitigation system designer.

In those cases where a user chooses to do their own AC mitigation design without the appropriate software, DEI can provide general guidelines for selecting product ratings upon request.

Product Connections

When decouplers are used in AC mitigation applications, they are normally connected in one of the following ways: (1) from the pipeline to bare gradient control wires comprised of zinc, copper, or other materials, (2) from the pipeline to an isolated ground bed (such as a gradient control mat used at above ground appurtenances), or (3) across an insulated flange, one side of which is grounded. DEI does not recommend that decouplers be connected between the pipeline and an adjacent electric transmission tower ground, for reasons described in Part 2 of this application note. The product catalog sections in the DEI literature describe product installation and mounting options for typical installations.

PART 2: DESIGN CONSIDERATIONS

Introduction

Solid-state DC decoupling devices introduced to the corrosion protection industry in 1990 are now commonly used in the mitigation of AC interference (inductive and conductive) voltages and currents on pipelines. Inductive interference refers to an indirect electrical coupling of the power line to the pipeline that results in voltages being induced onto the pipeline. Conductive interference refers to a direct resistive coupling between a power system facility and the pipeline, typically the result of line-to-ground fault current or lightning current (from a power line tower or substation structure) that travels to the pipeline through the earth. This article reviews typical applications and provides guidelines for use in voltage mitigation.

Background

Under normal system conditions, if the open-circuit AC voltage on a pipeline is 15 volts, or the available current is 5 milliamperes or more, NACE Standard RP0177-2000¹ considers this a condition at which a potential shock hazard exists. Voltages and currents above this level warrant analysis to determine if they should be mitigated. Two different operating conditions of the adjacent electric power system (i.e., the source of the induced voltage) should be considered in the analysis; namely, the effects of both normal and abnormal power system conditions. Even when the induced AC voltage is below the 15 volt level under normal system conditions, analysis is warranted to determine if potentially hazardous conditions exist under abnormal system conditions. This analysis requires access to specialized software and knowledge in using this software, a task often contracted to consultants specializing in the design of AC mitigation systems. Whenever mitigation is warranted, the voltages and currents associated with abnormal power system conditions should also be analyzed because this condition may present the greater risk of damage to equipment and harm to personnel.

Mitigation Options: Spot vs. Continuous Mitigation

When AC interference is addressed, there are two options; namely, spot mitigation and continuous mitigation. Spot 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.

Spot Mitigation

For spot mitigation, two approaches are commonly used; (1) the installation of buried zinc or magnesium grounding electrodes which are connected directly to the pipeline, or (2) the installation of a grounding system that is AC coupled but DC decoupled from the pipeline through a decoupling device. Decoupled grounding systems can be comprised of other materials (in addition to zinc or magnesium), such as copper ground rods, horizontal buried copper conductor, sections of steel pipe casings, etc. Gradient control mats (commonly used to reduce the touch and step voltages near above ground appurtenances) represent a common form of spot mitigation that is low cost and provides personnel protection under both normal and abnormal system conditions.

Another commonly used form of spot mitigation that is not recommended is that of connecting a pipeline to the tower ground of an electric transmission line through a decoupling device because this 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. The resulting pipeline-to-earth potentials can readily exceed the levels that will damage pipeline coatings, cause flashover of nearby insulated joints, and create a potential shock hazard. NACE Standard RP0177-2000 and Canadian Standard C22.3 No. 6-1987 both caution against using power system grounds for voltage mitigation. Spot mitigation alone cannot address all of the problems associated with induced AC voltage (e.g., it will not prevent pipeline coatings from being over-stressed.)

Continuous Mitigation

Continuous mitigation, which can be used for induced and conducted AC voltages under both normal and

abnormal conditions, is accomplished by using bare 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 two gradient control wires may be used. These wires may or may not assist in cathodic protection of the pipeline depending on the mitigation design and material selected for the gradient control wires.

Function of Gradient Control Wires

Gradient control wires provide a more thorough solution than spot mitigation because they: (1) prevent the pipeline coating from being electrically overstressed during abnormal power system conditions all along the mitigated section of pipeline, (2) minimize the possibility of arcing damage to the pipeline due to high potentials during abnormal power system conditions, (3) minimize both touch and step potentials along the entire pipeline (though gradient control mats are still recommended at above ground worker access sites).

Connection of Gradient Control Wires

One or two gradient control wires may be placed parallel to the pipeline and connected to the pipeline at different intervals and in different configurations. The connection interval, connection configuration (whether connected at each end versus the mid-point of a segment), and the length of each segment will determine the magnitude of both the steady-state current and fault current that will flow into a given segment. These parameters can be selected to minimize the overall mitigation system cost by using software specifically developed for designing AC mitigation systems. Connection intervals typically vary from about 500 to 2000 feet.

Gradient Control Wire Material Options

The following factors should be considered when selecting a gradient control wire material. The material selected should: (1) not interfere with the cathodic protection design for the pipeline or the ability to subsequently take pipeline potential measurements, (2) result in the lowest installed cost for the mitigation system and the cathodic protection system, (3) provide

a low and stable conductor impedance to earth in order to minimize the potentials around the pipeline, particularly under abnormal power system conditions, and (4) carry the required AC fault current under abnormal conditions. Zinc has been the material traditionally used for gradient control wires. More recently, copper is also being used because copper can offer economic and other benefits. A voltage mitigation design analysis should consider the economics of both material options, taking all known factors into account.

When copper gradient control wires are used, they must be DC decoupled while remaining AC coupled to the pipeline through an appropriately rated decoupling device. The size of the copper conductor must be capable of carrying the available fault current and be sufficiently rugged for handling during construction; a size that can be smaller than typically used zinc conductors. Table 1 shows the size of copper grounding conductors recommended for various AC fault currents.

The overall cost of the mitigation system will be minimized if the mitigation design is tailored to limit the steady-state AC current and AC fault current flowing into a given segment of gradient control wire to about 40 amperes and 4000 amperes respectively. Limiting these two currents will minimize the cost of the decoupling device. These current values are under the control of the mitigation system design specialist and feasible in most applications.

Bonded Zinc versus Isolated Copper Gradient Control Wires:

Following is a comparison of two commonly used gradient control wires. When zinc is used it is normally bonded directly to the pipeline. When copper is used it must be connected to the pipeline through a decoupler.

Zinc Advantages:

1. May provide supplemental cathodic protection. Most often used in conjunction with an impressed current cathodic protection system.
2. Can be bonded directly to the pipeline without the need for a decoupling device, in some cases. (Connections should be made through an above

ground junction box in the event future access is required.)

Zinc Disadvantages:

1. Instant OFF potential measurements cannot be taken when zinc is bonded directly to the pipeline.
2. Stray DC current (e.g., from DC transit systems, other impressed current protection systems, etc.) can access the pipeline through the direct zinc-to-pipeline bonds, but may exit the pipeline where no zinc conductor exists, thereby creating a corrosion problem.
- 3 The effectiveness of zinc, when used both as an AC grounding conductor and an anode, may deteriorate with time due to surface passivation in certain soil conditions, from being consumed as an anode, and from the effects of AC current. A backfill may be required in certain soils.

The above disadvantages can be eliminated by connecting the zinc conductor to the pipeline through a decoupling device.

Copper Advantages:

1. Extensively used in the electric power utility industry, with a long and successful history.
2. Less material is required per unit length to achieve comparable mitigation results because copper is highly conductive, corrosion resistant, and is not consumed as an anode (i.e., it is DC decoupled).
3. Enables instant OFF cathodic potential measurements to be taken.
4. The potential adverse effects of stray DC currents are eliminated because access to the pipeline is blocked by the decoupling device.

Copper Disadvantages:

1. Care must be taken to avoid direct contact between copper gradient control wires and the steel pipeline during installation.
2. The requirement for a decoupling device may result in added cost (versus bonded zinc) if the mitigation design is not optimized for decoupled gradient control wires.
3. A backfill may be required in certain soils.

Cost Comparison

Table 2 shows the cost savings per foot of pipeline for the gradient control conductor material when using decoupled copper versus bonded zinc (installation costs were assumed equal). These costs are based on material prices as of September 2005. For a single conductor mitigation system, copper saves an estimated \$2.41 per foot versus zinc. For a mitigation system with two parallel conductors, copper saves an estimated \$2.22 per foot versus zinc. Table 3 shows the gradient wire-to-pipeline connection interval at which the cost of using decoupled copper is equal to the cost of bonded zinc (ignoring other benefits) taking into account the typical cost for decoupling devices with commonly used AC fault current ratings. As the connection interval is increased from that shown in Table 3, the cost savings of using copper increases.

Summary

There are several factors to consider in selecting a mitigation system for dealing with AC and lightning interference voltages and currents in pipelines. The mitigation system should; (1) consider the effects of both normal and abnormal power system conditions, (2) integrate with the cathodic protection system and user practices, and (3) minimize the introduction of secondary problems.

Spot mitigation is useful for minimizing touch and step potentials at worker access points along a pipeline but it will not provide protection for pipeline coatings under abnormal system conditions.

For continuous mitigation, there are three basic gradient control wire options listed in order of increasing cost for typical connection intervals; (1) decoupled copper, (2) directly bonded zinc, and (3) decoupled zinc. For any AC mitigation project, a thorough economic analysis should take into account the costs of both the cathodic protection system and the mitigation system for each alternative, since one can affect the other. Cost factors like back-fill, rectifiers/anode beds, gradient control wires, decouplers, etc., will have an impact on the overall economics with these different alternatives and should be considered.

The benefits of using a decoupling device between the pipeline and the gradient control wires, whether using zinc or copper gradient control wires; are (1) the ability to take instant OFF potential measurements, (2)

the elimination of potential pipeline corrosion due to stray DC currents, and (3) simplification of both the cathodic protection system and the voltage mitigation system by addressing each issue separately.

When a decoupled grounding system is being considered, the decoupling device should be third-party listed as meeting the appropriate codes requirements, such as NFPA 70 Articles 250.2, 250.4, and 250-6(E) along with Sections 500-505 if the decoupler will be installed in a hazardous location.

References

1. *NACE Standard RP0177-2000*, "Mitigation of Alternating Current and Lightning Effects on Metallic Structures

and Corrosion Control Systems".

2. *C22.3 No. 6-M1987*, "Principles and Practices of Electrical Coordination Between Pipelines and Electric Power Lines"
3. *Final Report for Contract No. PR-262-9809*, January 1999, "Cathodic Protection for Pipelines with AC Mitigation Facilities," Prepared for PRC International Corrosion Supervisory Committee (American Gas Association)

Table 1 Maximum 60 Hz AC Fault Current vs. Conductor Size

| Conductor Size- Awg | Current Duration - Cycles | Amperes-RMS |
|---------------------|---------------------------|-------------|
| 1 | 30 | 7,500 |
| 1/0 | 30 | 11,500 |
| 2/0 | 30 | 15,000 |
| 3/0 | 30 | 18,500 |
| 4/0 | 30 | 21,000 |

Table 2 Gradient Control Wire Material Costs Per Foot

| Description | Cost/ft. |
|-----------------------------------|----------|
| Parallel Zinc Wires, 1/2" x 9/16" | \$3.76 |
| Parallel Copper Wires, 1/0 | \$1.54 |
| Cost of Copper vs. Zinc | -\$2.22 |
| Single Zinc Wire, 5/8" x 7/8" | \$3.38 |
| Single Copper Wire, 2/0 | \$0.97 |
| Cost of Copper vs. Zinc | -\$2.41 |

**Table 3 Gradient Control Wire-to-Pipeline Connection Interval*
At which the Cost of Decoupled Copper = Cost of Bonded Zinc**

| Decoupler Fault Current Rating | Parallel Wire Interval, ft. | Single Wire Interval, ft. |
|--------------------------------|-----------------------------|---------------------------|
| 3.7kA | 439' | 405' |
| 5kA | 608' | 560' |
| 10kA | 863' | 795' |
| 15kA | 1516' | 1396' |

* Isolated copper is more economical for all connection intervals greater than the interval shown in Table 3, more costly for lesser intervals (ignoring other benefits).