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Over-Voltage Protection of Isolation Joints in Pipelines

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ABSTRACT

Isolation joints in pipelines may be subject to over-voltage failure due to lightning and, in some applications, AC voltage. When a pipeline is near an electric transmission line, it can be subject to significant AC voltage if a phase-to-ground fault occurs. Without proper protection, such over-voltage events can damage the isolation kit and/or the flange and possibly ignite flammable contents within the pipeline. Various types of isolation joints appear in pipeline facilities, including fittings in measurement tubing, threaded unions, flanged isolators, and monolithic isolators. All types can fail if not addressed, and should have over-voltage protection.

Over-voltage protection against both lightning and AC fault conditions is possible using appropriately rated products, and is required by many regulatory agencies for protection of equipment and personnel.

This paper will review safety regulations affecting pipeline isolation joints, provide a brief description of solid state over-voltage protection devices and their operation, compare solid state devices to other solutions for over-voltage protection and discuss device ratings and key application guidelines for these devices for use with isolation joints. Specific examples will be presented of damaged insulators, compromised CP systems and fire resulting from lightning and AC fault occurring on unprotected isolation joints on gas transmission pipelines and the over voltage protection solutions that were implemented following the failures.

Keywords: Solid State; Over-Voltage Protection; Isolation Joints; Insulated Joints; Lightning; AC Fault

INTRODUCTION

Isolation joints, often referred to as insulated joints, are commonly used to electrically isolate sections of pipe from each other to prevent unwanted flow of cathodic protection (CP) current to adjoining pipe sections which may be grounded or protected by a separate CP system. The most common types of isolation joints are bolted flange isolation joints, monolithic (weld-in) joints and insulated unions and fittings. These devices are very effective at insulating low voltages from CP systems. However, they each have limits as to the maximum voltage which they can support before the insulating material breaks down, often referred to as the “voltage withstand”. Typical levels of voltage withstand range from several hundred volts for insulated unions to a few thousand volts for bolted flange isolation joints to tens of thousands of volts for monolithic joints. Differential voltage across isolation joints due to AC faults and lightning can exceed these levels and result in arcing through or around the insulation. Arcing can damage and short out the joint and possibly ignite any flammable material in the pipeline.

Figure 1 shows an example of arcing damage resulting from lightning on an unprotected bolted flange isolation joint. The joint was located between a gas transmission pipeline and a storage well in rural Pennsylvania, US. Following a summer thunderstorm, the pipeline CP voltage was observed to be lower than normal and testing indicated that the flange was shorted. The arcing contaminants had created a short circuit along the path of the arc, allowing CP current to drain to ground. The joint was repaired by replacing the flange bolt insulation and adding a solid state over voltage protector. After the repair, the CP levels returned to normal and there have been no reported issues since.

Figure 1. Lightning damage on an unprotected isolation flange

Figure 2 shows an example of damage to isolation unions due to an AC fault at a natural gas regulator station in New York state, US. The isolation unions separated a CP-protected pipeline from grounded pressure sensing lines. The AC fault came in along the pipeline and caused arcs across the unions which had no over voltage protection. The arcs melted holes in the unions, causing a gas leak which was ignited by the fault current. A fire resulted, as shown in Figure 3, causing significant damage. Fortunately, no one was hurt.

Over voltage protection devices connected across the isolation joint are designed to mitigate such hazards by providing a conduction path for faults and lightning around the joint and thus limiting the voltage across the joint to safe levels. This protects the isolation joint while maintaining electrical

Figure 2. AC fault damage on unprotected isolation unions

Figure 3. Fire at a regulator station resulting from a fault near unprotected isolation joints

isolation at lower voltages. Various devices are available for this purpose - each has its own application requirements and some have limitations that should be well understood before use.

To protect personnel and the public against the possible hazards associated with unprotected isolation joints, Section § 192.467 (e) and (f) of the U.S. Pipeline Safety Regulations requires protective measures to prevent arcing across isolation joints, both for lightning and AC fault current. These protective measures require the installation of a suitable over-voltage protective device across isolation joints. This regulation also incorporates “by reference” the US National Electrical Code, further requiring compliance to electrical product safety standards. Similar requirements exist around the world to mitigate over-voltage affecting safety at isolated joints, either under health and safety regulations, or regarding product use in hazardous locations.

COMMON OVER VOLTAGE PROTECTION DEVICES

Numerous devices are used by the cathodic protection industry for over-voltage protection of isolation joints. Some have very defined purposes and limitations and should be applied as specified by the manufacturer. The more common devices are described below.

Solid State Decouplers and Over Voltage Protectors

Solid state over-voltage protectors use high power solid state electronic switching components to create a switch between two terminals connected across the isolation joint. Under normal conditions, this switch remains open, thus maintaining electrical isolation across the joint. When the differential voltage across the isolation joint exceeds a prescribed voltage threshold, which would occur during a fault or lightning event, the switch closes virtually instantaneously, collapsing the voltage differential across the joint, thus preventing arcing and protecting it from damage. Immediately following the over-voltage event, the device then automatically switches back into the OFF state to isolate the cathodic protection system.

Solid state decouplers, in addition to protecting the joint from AC faults and lightning, provide a continuous conduction path for steady state AC, which may be induced onto the pipeline from nearby power transmission lines, to pass through the device and across the joint at all times.

By shorting this induced AC current across the isolation joint, a decoupler reduces AC voltage on the pipeline and prevents the AC voltage from triggering the solid state switch. Examples of an over-voltage protector and a decoupler installed on isolation joints are shown in Figures 4 and 5.

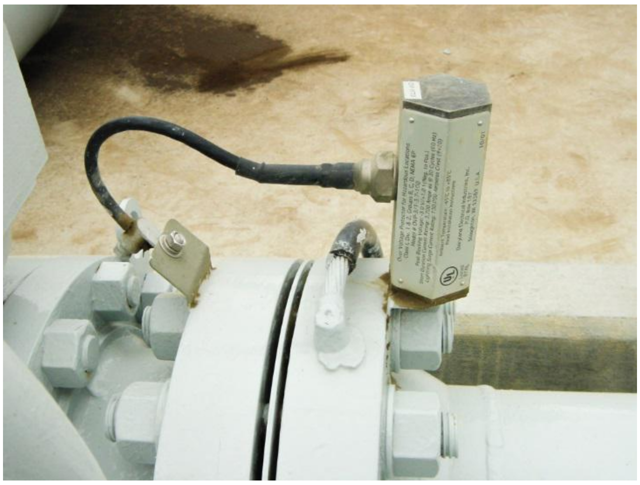

Figure 4. Solid State Over-Voltage Protector

Figure 5. Solid State Decoupler

Polarization Cells

The polarization cell is an electrochemical switch comprised of pairs of stainless steel or nickel plates immersed in a solution of potassium hydroxide. It responds to low voltage DC current by polarizing the plates and reducing the flow of DC current. It passes higher voltage DC, steady state AC, AC faults and lightning current.

Since the introduction of solid state devices in the 1980's, polarization cells have become much less common due to their need for regular maintenance of fluid levels, large package size, and the fact that when they fail, they create an open circuit, which creates a potential safety hazard.

Spark Gap Devices

Spark Gap devices, also referred to as gapped arresters, are commonly used to protect isolation joints from damage due to lightning. An example is shown in Figure 6. When the voltage across the terminals reaches a designated level, an arc bridges the product's two electrodes and passes current. Typically, up to 1000V of AC or DC and up to several thousand volts for lightning is required before the device goes into conduction.

Spark gap devices are relatively low cost and easy to install. However, they have several limitations. They cannot typically carry AC fault current for any significant length of time before failing. When they fail, they create an open circuit, leaving the joint without any over-voltage protection until the device is replaced. Their break-over voltage is so high that dangerously high voltages can exist on the pipeline. In addition, they cannot mitigate induced AC on pipelines.

Table 1 compares the most significant features of the common devices used for over voltage protection on isolated joints.

Table 1: Common Devices Used for Over Voltage Protection

Product	AC Rated?	Lightning Rated?	Fail-Safe for AC, Lightning?	Limitations
Solid-State Decoupling Devices	Y	Y	Y	
Solid-State Over-Voltage Protectors	Y	Y	Y	Not used with induced AC present
Polarization Cells	Y	Y	N	Liquid loss, maintenance
Spark Gaps	N	Y	N	High voltage allowed before lightning conduction

DEVICE RATINGS

Over voltage protection products must be selected with careful examination of their electrical characteristics relative to the intended purpose in order to assure proper application. The key device ratings are described below.

AC Fault Current

Select a product AC-rms current rating that is above the expected site value. Where induced AC voltage on a pipeline has been modeled, use the modeled value for isolated joint protection as well. For cases where the fault current is not known, a 3.7kA AC-rms rated product is most often appropriate, unless other site conditions indicate that this value should be altered. The conductor or other attachment method used must also be rated for this AC fault current.

By design, solid state devices have the ability and ratings to handle AC fault current, with published and tested rating data to assure long-lasting performance. Devices such as gapped arresters do not have published AC fault ratings (or have minimal ratings) as they are not intended for such faults, yet AC conditions on pipelines are common.

Threshold Voltage

This voltage, measured between the product terminals, determines when the product changes from blocking DC to full conduction (switches ON) to provide over-voltage protection. Typical choices for most solid state protection devices are -3V to +1V (asymmetrical), which would be used for connections between cathodically protected and grounded/unprotected systems, or -2V to +2V (symmetrical) for connection between systems with a similar DC voltage, such as between two different CP systems. Some choose the -2/+2V models for simplicity, since the symmetrical nature prevents an installation with reversed polarity.

On solid state devices, the maximum voltage that can occur across the terminals during an AC fault is just above the threshold voltage. For lightning surge conditions, this maximum voltage is approximately 100V. This assures that over-voltages will be clamped to low levels during faults or lightning events, providing a significant advantage for personnel safety and for applications such as isolated joint protection. In comparison, the voltage allowed across a gapped arrester will reach hundreds to low thousands of volts prior to conduction, exposing personnel and equipment to this voltage until the device conducts.

Steady-State AC Current

Where induced AC voltage is present, such as isolated joints on pipelines in a common corridor with energized power lines, electric and magnetic fields can cause unwanted voltage to appear on the pipeline. For these applications, it is important to utilize over protection devices that can accommodate steady state AC. Solid state decouplers should be used instead of solid state over-voltage protectors. Otherwise the device will likely fully conduct and affect cathodic protection levels. When in doubt about the level of induced AC voltage present, or for any cross-country pipelines that may have nearby paralleled power lines in the future, the best approach is to apply a solid state decoupler.

Typical levels of induced AC current on pipelines do not exceed 45 Arms. However applications do exist with as high as 80 Arms of steady state current. Most solid state decouplers are rated up to 45 Arms with options to handle higher currents. To determine the steady-state AC current rating needed for a site, measure the current in a temporary bond across the isolated joint or from pipe to ground, as appropriate, and select a decoupler rating that exceeds this value.

Lightning current

Lightning represents a significant challenge to electrically isolated CP systems, and is quite different from AC waveforms. Significant differences include a very fast rate-of-rise of the signal, a high peak amplitude, and rapid decay. There are different wave shapes used to define lightning, with varying rise and decay times. A typical current waveform is 8x20μs, as shown in Figure 6, with an 8 microsecond rise time, and a decay to one-half of peak in 20 microseconds. The high rate-of-rise has an especially notable effect as the current flows through the inductance of the conduction path. Inductance opposes radical changes in current in a system, and as a result, causes a large instantaneous voltage to appear. This is an effect that does not appear with AC signals to any notable degree. Most over voltage protection products have a lightning current capability of 75kA to 100kA peak.

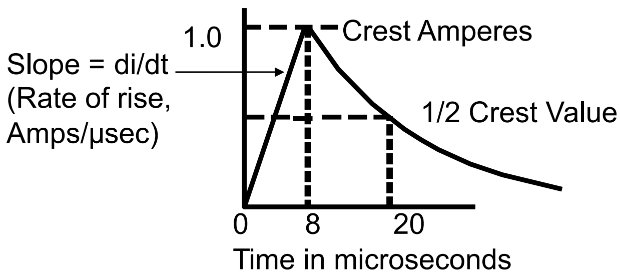

Figure 6. Standard 8x20μs Lightning Waveform

Hazardous Location Classification

Many user sites are formally classified as hazardous locations, according to various standards. Other sites may commonly have explosive vapors or gases present, but haven't been identified as a "hazardous location" due to unfamiliarity with the classification requirements. If a site is classified or otherwise treated as a hazardous location, then an over voltage protection product certified for this environment should be used.

Fail-Safe Construction

If exposed to fault current values beyond their ratings, over voltage protection devices should always fail safely and un-eventfully in the shorted mode (fail as a dead-short), bonding the two points together for safety. This assures that over-voltage conditions will be addressed – whether the product is working or failed.

Solid state devices are the only over-voltage protection devices that are considered “fail-safe.” A gapped arrester has an open gap, which will always remain an open gap. If the arrester were to fail, it would be as an open circuit. After failure, an arrester provides no over-voltage protection and a potential safety hazard is created, as voltage can rise to unsafe levels. Similarly, when polarization cells fail, either from fluid evaporation or tank rupture, they fail as an open circuit and cease to provide safety grounding.

INSTALLATION AND APPLICATION GUIDELINES

Connections

Connection across the joint: Joint insulation can only be confidently protected from over-voltage conditions by connection of a protective product directly across the joint. Often, clients propose to connect a device from one side of an isolated joint to a grounding system, assuming that this will prevent flashover of the insulation. However, for reasons related to conduction path length (see discussion below), protection is not guaranteed.

Connections in parallel: Where multiple isolation joints are in parallel, all joints should be protected. For closely spaced measurement tubing insulators, a single device can protect all, if best practices are used. For large pipelines with isolators in parallel at a manifold, it is generally best to individually protect each.

Pipe to ground connections: While isolators should be protected by device connection directly across them, this does not automatically reference either side to ground. One side of the joint will have cathodic protection, while the other side may be unprotected and grounded, unprotected and not grounded, or also cathodically protected. If this second side also has CP, and the isolator is sited at a facility, then an additional device is needed to reference the pipeline to the facility grounding system. The device connected from pipe to ground can be attached to either side of the isolated joint, as long as a second decoupler connects across the joint, thus referencing each side to the other and to ground.

If at a facility, with CP on one side of a joint and the other side bonded to the facility grounding system, then a second decoupler is not needed – the piping is already safely grounded. For the situation where the station piping is not referenced to ground, this is an unsafe arrangement that should be addressed by installing a bonding conductor or decoupler to ground, as appropriate.

Also at a facility, there may be a series of two isolated joints between the main pipeline and the site grounding system. This requires protection using over-voltage protection devices across both isolated joints to reference each pipe segment to each other and to ground.

Lead length: A primary concern for lightning protection

One very important installation guideline, independent of which product is selected to provide over-voltage protection, is as follows: when the primary concern is over-voltage protection from lightning, it is extremely important that the device be connected across the isolated joint with the shortest possible conductors for optimum protection. When lightning current flows in a conductor, the inherent inductance of the conductor develops a large voltage, which appears between the two connection points. If this voltage is in excess of the insulation or coating strength, arcing will occur. This voltage can be up to 3kV per foot (10kV per meter), depending on the lightning waveform, and it adds directly to the voltage drop that is developed across the terminals of the protective device selected. Solid State devices have very low and safe threshold voltage settings, so under lightning conditions the resulting voltage across an isolated joint is almost exclusively the inductive voltage drop due to the fast-rising lightning waveform.
To address these potential hazards due to lightning, all over-voltage protection devices should be installed with no more than about 6” to 8” (150 to 200 mm) of conductor length for optimum protection. Conductor length is not of concern if only providing over-voltage protection for AC voltage because the rate of rise of current under AC fault conditions does not produce a significant voltage drop in the leads.

Common Application Mistakes

The variety in the type of devices available, coupled with a lack of industry understanding of electrical principles has led to many misapplications that the author has observed over a period of years in typical pipeline installations. Key areas of misapplication have included:

- Devices that do not mitigate induced AC being applied to pipelines with steady-state AC present. Some devices will respond by conducting all current, and therefore affect CP.
- Locating spark gap devices in areas subject to AC faults, with magnitudes adequate to cause device failure.
- Device application with excessive conductor length, negating over-voltage protection between the connection points when addressing lightning.

CONCLUSIONS

Appropriately rated over-voltage protection products can protect pipelines against both lightning and AC fault current, while at the same time maintaining cathodic protection of isolated pipeline joints. Proper device selection and installation location are key, and adjacent pipelines and facilities should be examined to establish a thorough protection scheme.