FARWEST CORROSION CONTROL COMPANY

BENEATH THE SURFACE

TIPS, EXPLANATIONS AND INFORMATION ON
CORROSION CONTROL & CATHODIC PROTECTION

Farwest Corrosion Control Company

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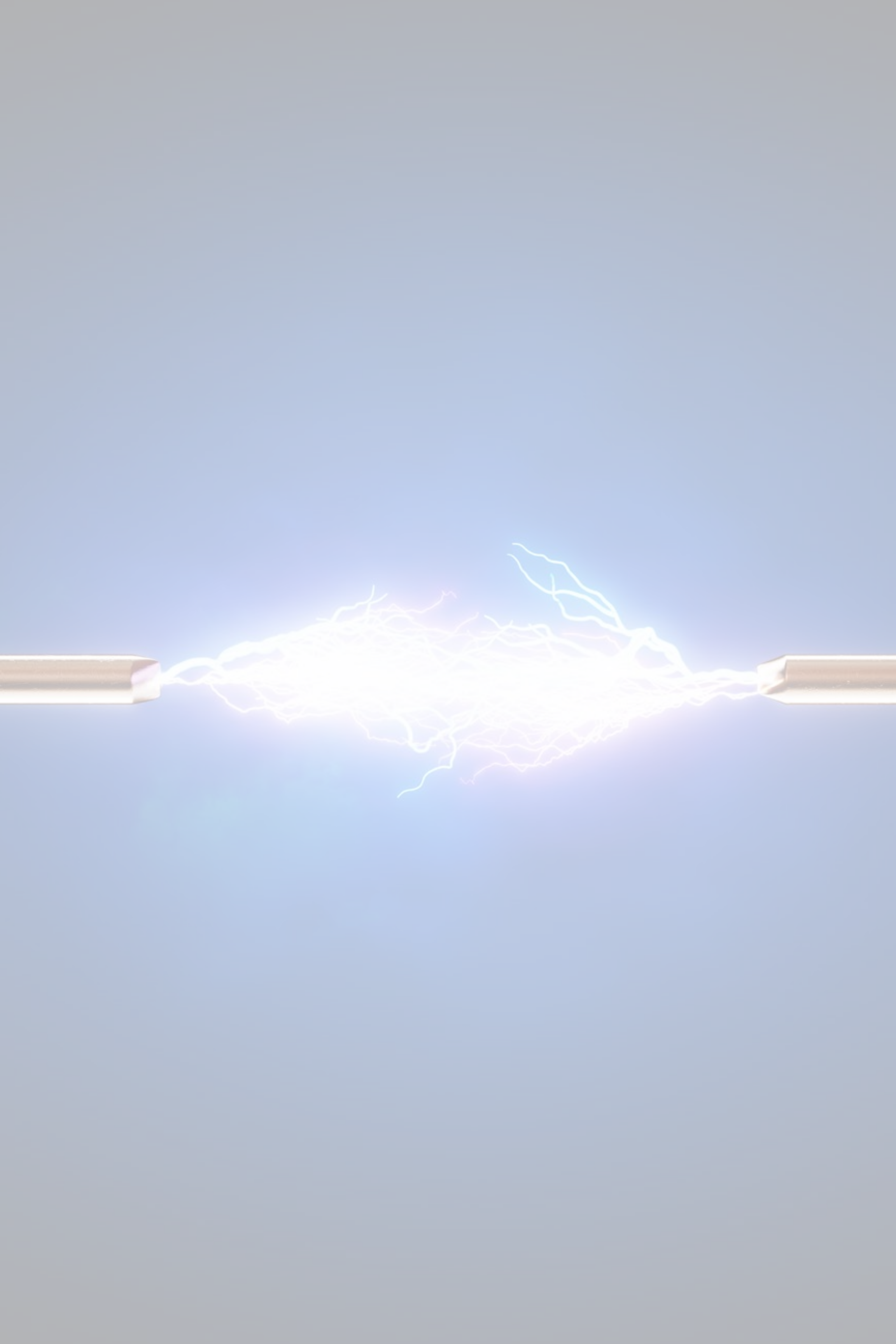

FARWEST CORROSION CONTROL COMPANY

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INTEGRITY | SERVICE | QUALITY

Complete Cathodic Protection & Corrosion Control Solutions

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FOREWORD

Valued Customers and Colleagues,

The protection systems that lie beneath the surface and out of sight are vital in safeguarding our essential infrastructures. Corrosion has long threatened the integrity, safety and durability of our engineered environments. Farwest Corrosion Control has addressed this challenge head-on for nearly seven decades.

Inspired by the writings of our corrosion professionals over the years, "Beneath The Surface" publication consolidates these resources. Many professionals have found our expertise invaluable, often saving them from costly trial and error. Thus, we've compiled these articles to share our cumulative experience.

Guided by MORPH, our Corrosion-fighting Fighting Superhero, this publication covers Cathodic Protection Basics, intricacies of Pipes & Pipelines and dives deep into topics like Rectifiers & Power Supplies, Anodes, Coatings and Electrical Connections. Regardless of your level of expertise, each section promises useful and insightful information to assist in the battle against corrosion.

Our commitment to producing "Beneath the Surface" stems from the belief that shared knowledge is the most powerful. We view it as our responsibility, as well as our pleasure, to offer these insights to the corrosion control community.

We hope "Beneath the Surface" serves as a valuable tool in your professional toolkit. At Farwest Corrosion Control, our pride lies in our daily contributions to the industries we serve and the solutions we provide. We trust this effort showcases our shared dedication and commitment to excellence.

Sincerely,

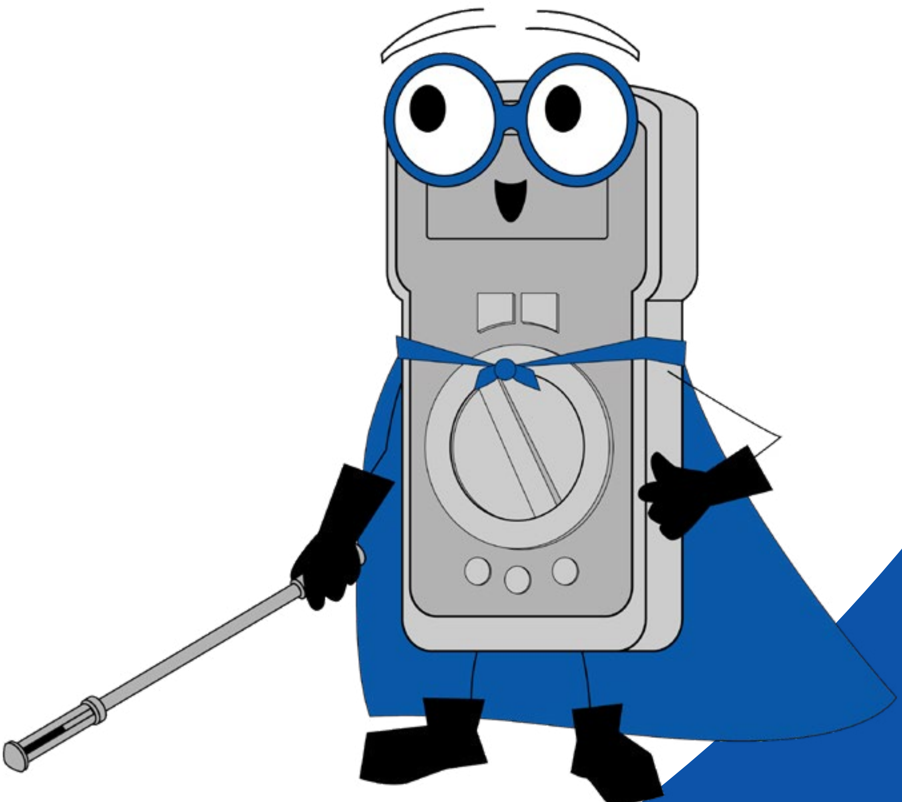
The Farwest Team


EAST
EAST


FARWEST
CORROSION
CONTROL
COMPANY
CAT
CATERPILLAR

CATHODIC PROTECTION BASICS

Get ready to embark on an adventure into the world of Cathodic Protection! With me, Morph, as your guide, we'll unravel the mysteries of the WHY, the magic of the WHAT and the ingenious methods of the HOW. Buckle up as we explore the technology that safeguards our underground and underwater infrastructures.



What is Cathodic Protection?

THE CATHODIC PROTECTION SYSTEM

Cathodic Protection (CP) is a proven method to mitigate corrosion on buried and submerged steel structures. CP is an “electro-chemical” process. Therefore, any CP design will include elements that require some form of electrical energy along with consideration for the chemical and physical properties of the metals within the CP system.

The DC current required to protect a structure depends on the bare metal exposed, that is why pipelines and structures are coated with an epoxy or other relevant coating. This will result in less DC current required to protect the pipeline or structure from corrosion. Over time, as changes occur, CP systems must keep up with current demand. A typical CP system design will take advantage of these properties to be effective.

Structures Protected by Cathodic Protection

To provide CP current to any metallic structure, the structure must be submerged in an "electrolyte," such as soil or water. Without the electrolyte, there is no way to pass electrical current from anodes to the structure to be protected.

A CP circuit consists of the following:

- Anodes (positive in the electrical circuit)
- Structure (negative in the electrical circuit)
- Electrolyte (soil or water in which to pass the electrical current)
- Power (a rectifier or the power generated between differential metals like magnesium and steel)

Types of structures that are commonly protected with CP include pipelines, storage tanks, oil field vessels, offshore structures, marine vessels and more.

Types of CP Systems

GALVANIC SYSTEM

This is where two dissimilar metals are connected in an electrolyte. The “anode” (or corroding electrode) is the more electro-negative metal in an electrical circuit, and the “cathode” (or corroding electrode) will receive Cathodic Protection current from the anode. A typical galvanic anode used in CP is manufactured of magnesium, zinc and aluminum alloys.

IMPRESSED CURRENT SYSTEM

This is where a DC power supply provides the necessary voltage to power a buried or submerged anode, which can be made of graphite (technically not a metal), high silicon cast iron (HSCI), platinum or mixed metal oxide (MMO).

In all CP systems, the anode discharges an amount of DC that is current collected on the structure to be protected. When adjusted for maximum effect, all sections of the structure receive a portion of the DC current, and the entire structure becomes cathodic. In designing a CP system, it is important to understand the physical and electrical properties of the metals that make up the CP system. In either type of CP system, the choice of anode material will be a major factor, as well as the anode size and quanity.

In a Galvanic CP system, the technology can be as simple as connecting a single galvanic anode directly to the structure to be protected. Often this interconnect is through a copper wire between the anode and structure, or the anode can be connected directly to the structure by bolting or welding.

The Impressed Current CP system will require an anode(s) and interconnect wiring between the power supply and the anode(s). The power supply provides DC power to the system and will require an external AC power source.

Sacrificial anode systems are usually installed when the pipeline or structure has a good coating because the demand for CP current is minimal.

There are many considerations in the design of a proper CP System. The choice between galvanic or impressed current will depend on information gathered in the CP design effort.

Impressed Cable-to-Anode Connections

Every impressed current anode Farwest builds is measured for the electrical resistance of the anode-to-cable connection.

This information is kept as a permanent record for seven years, to confirm and ensure that the connection is secure.

If, for instance, the connection is poor - the interface between the anode and the cable is loose - the electrical resistance of that interface will increase – and the connection will be faulty. Therefore, we take precautions to ensure our connection is very secure (tight) and the electrical resistance of that connection is extremely low, ensuring the performance of the system.

The measurement process: (some details have been omitted for simplification):

- Confirm the electrical resistance of the cable just before attachment to the anode
- Confirm the electrical resistance of the anode-to-cable connection
- Compare the two readings and subtract the first reading from the second reading. This value represents the difference between the connection and the wire alone, which is the resistance of the completed connection.

Note: *Our threshold value for the completed connection is less than 0.004 ohms or 4.0 milliohms. If the completed connection falls below this threshold, the connection is proper, and the anode is considered complete and shipped to the customer. If, on a rare occasion, the resistance does not meet the threshold, we repeat the connection process and measure again.*

Materials Used in Corrosion Control

METALS

Many materials have been developed to mitigate corrosion in buried and submerged metals (pipelines, storage tanks, etc.) corrosion. Developing corrosion-resistant materials, i.e., plastic composites, epoxies, urethanes and the like, has significantly contributed to the industry. For many applications, the “non-metallic” products replace the metal or are applied to the metal as protective coatings. Despite this, metals and their unique properties are still major players in the corrosion control industry.

In certain applications, specific metals are selected for their physical resistance to corrosion. Popular choices include copper and copper-based materials (brass and bronzes), stainless steels and nickel alloys. Less cost-effective but very corrosion-resistant are titanium, platinum and the “king” of corrosion-resistant metals, gold.

LOOKING BACK

One metal that changed the world and was a major contributor to many industries is steel. Developed in the 1740s, steel is an alloy of iron. Originally very expensive with small production quantities, steel became a major player in the mid-1800s when a process was developed to produce steel economically and on a large scale. Steel production continued to evolve into the early 20th century with the Siemens-Martin process. While refined, this leading steel-making process is still used today.

The availability of inexpensive steel allowed larger bridges, railroads, skyscrapers and ships, and automobile improvements. In addition, many other products improved greatly thanks to steel, which includes better and stronger pipelines. However, despite all its great physical properties, steel is quite vulnerable to corrosion.

Types of Metals Used in Impressed Current Systems

Types of Metals Used in Impressed Current Systems

Component	Metal	Consideration	Reason
Power Supply	Copper wire from AC power source	Current Requirement and physical length.	Determine if the cable can handle the current rating and the voltage drop acceptable.
Anode Junction Box	Copper buss bar, brass hardware and numerous mechanical connections	Brass has a relatively high resistance to corrosion.	Determine if individual components are properly sized to handle the maximum expected current. Mechanical connections can be a source of high resistance and localized heating.
Anode Material	HSCI, Graphite Platinum, MMO	Anode current density, physical size, weight and quantity.	Determine if anodes are within current density limits and capable of providing the required current for the specified system design life.
Anode Cable	Copper Wires	Current requirement and physical length.	Determine if the cable can handle the current rating and the voltage drop acceptable.
Pipeline	Steel	Cross-sectional area to determine linear resistance and expected voltage drop. The pipeline coating system will have a great influence on the required current density per unit area.	Because steel is a poor electrical conductor, the negative return current will create a voltage drop in the pipeline. This will have a direct impact on the attenuation of the potential profile.

Types of Metals and Their Properties

METAL CONDUCTIVITY

All metals can conduct electricity, but certain metals are more conductive, the most common being copper. Copper is highly conductive, which is why it has been used in electrical wiring since the telegraph. Interestingly, brass, which typically contains approximately 60% copper, is far less conductive because it comprises additional materials that lower its conductivity.

Although used in many common electrical applications, copper is NOT the most conductive metal. Pure silver is the most conductive metal but is considerably more expensive than copper. Therefore, the increase in conductivity is usually not worth the added cost.

A common misconception is that pure gold is the best conductor of electricity. While gold does have a relatively high conductive rating, it is less conductive than copper. Gold is used extensively in computers and other high-end electronics. The gold is usually a thin coating (plating) over the copper connectors. The purpose of the gold plating is to provide stable (corrosion-resistant) and reliable electrical contact.

Understanding the relative difference in the electrical conductivity of metals is important when designing electrical systems, i.e., CP systems. These systems can carry relatively large electrical currents and are sensitive to series voltage drops. Often not considered is the linear voltage drop in steel pipelines. This must be taken into account to ensure an effective CP system.

The following chart shows the relative conductivity of various metals.

Note that copper is the baseline reference and that a 100% rating does not indicate zero resistance.

The differences in electrical conductivity vary considerably depending on the metal. Therefore, it is very important to avoid making assumptions about the electrical conductivity of a metal.

The Relative Conductivity of Various Metals

Metal	% Conductivity	Typical Application
Silver (Pure)	105%	Switch contacts and jewelry
Copper (Reference*)	100%	Electrical wires and cables, plumbing and roofing
Gold (Pure)	70%	Switch contacts and alloyed for jewelry
Aluminum	61%	Lightweight, electrical conductor and heat sinks; Custom alloys designed for galvanic CP anodes
Brass	28%	Easily machined and good corrosion resistance; Typically, 60% copper & 40% zinc.
Zinc	27%	Applied as a corrosion inhibitor (galvanizing); Custom alloys designed for galvanic CP anodes
Nickle	22%	Very corrosion-resistant, hard and strong
Iron (Pure)	17%	Cast iron, machinery castings and parts, pipelines
Tin	15%	Provides corrosion resistance when plated on steel
Phosphor Bronze	15%	Outstanding corrosion resistance for marine applications; a copper-tin alloy
Steel	15%	Structural, formable, weldable, unlimited applications; Most popular material for pipelines
Platinum	15%	Jewelry, plated or clad to metallic substrates for high-performance CP anodes
Lead (Pure)	7%	Heavy corrosion resistance, used in batteries and solder
Cast Iron	7%	Machinery castings and parts, pipelines
Stainless Steel	5%	Outstanding corrosion resistance for marine applications
Nichrome Wire	1.5%	Used as a heating element in electrical heating devices

Basics of Induced AC on Pipelines

Induced AC (Alternating Current) is a common problem when buried pipelines are installed in a common corridor or near energized high-power transmission lines.

There are two main concerns with induced AC on metallic pipelines:

- Induced voltages can present a shock hazard to technicians who physically touch the pipeline or metallic devices connected to the pipeline.
- Induced AC is known to be the direct cause of soil-side corrosion on buried pipelines.

AC power on a pipeline is a result of two methods:

- Inductive refers to an indirect electrical coupling from the electromagnetic field generated by high-power transmission lines, resulting in voltages induced on the pipeline.
- Conductive refers to a direct resistive coupling between a power system and the pipeline. Typically, this would include a power line-to-ground, creating ground fault currents, or a lightning strike that travels to the pipeline through the earth.

INDUCED AC VOLTAGE

The magnitude of the induced AC voltage or “power” depends on many variables:

- The relative positioning and alignment of the pipeline and power lines
- The length that the pipeline parallels the power lines
- The power demand on the power lines
- The balance between phases of the power system
- Soil resistivity as low soil resistivity provides a good path to earth
- The dielectric strength and quality of the pipeline coating (A well-coated pipeline is more susceptible to induced voltages than a bare pipeline.)
- Like DC corrosion, AC corrosion is normally concentrated at coating flaws (also named holidays).
- Abnormal Operating Conditions in the form of a local or direct lightning strike as well as a downed power line (These can result in a very high, i.e.,> 1000 volts, induced or direct conductive coupling.)

Basics of Induced AC on Pipelines

Induced voltages are proportional to the magnitude of current on the power lines. Therefore, the AC pipeline-to-soil potentials will be notably higher during the hottest summer months because of higher power demand.

Induced AC on a pipeline can vary significantly in a 24-hour period.nTypically, the maximum power demand is between 2 pm to 7 pm, with the highest on Tuesday, Wednesday and Thursday. Therefore, it is reasonable to deduce that variable-induced power events will occur at all the locations tested. To provide a better understanding of the range of induced voltages, a data logger can be used to capture AC voltage trends.

During routine pipeline surveys, AC pipe-to-soil potentials should be measured any time the pipeline is in or near an AC power corridor. The method for measuring an AC pipeline-to-soil potential is identical to measuring a DC pipeline-to-soil potential, except that your digital multimeter is set to the AC voltage function.

HOW MUCH AC IS TOO MUCH?

NACE SPO177-2007 addresses many issues and effects of induced AC and lightning on metallic structures and corrosion control systems. Section 5: Personnel Protection, Subsection 5.2: "15 VAC (RMS) open circuit or a source current capacity of 8 mA (milliamps) or more are considered to constitute a possible shock hazard."

INDUCED VOLTAGE/CURRENT CONCERNS

How dangerous the induced voltage/current is a function of how much power is available. There is a series of tests that must be performed to determine actual power and the possibility of personnel shock hazards. This topic will be addressed in a future tip.

In addition to the staff safety issues, there is also the concern of how much, if any, corrosion may be occurring on the pipeline. Corrosion caused by induced AC continues to be a controversial subject. In recent years, it has been determined that AC corrosion of cathodically protected pipelines can and does occur.

Basics Of Induced AC On Pipelines

AC CURRENT DENSITIES

The corrosion that can occur from induced AC is not necessarily proportional to the induced voltage. The concern is the magnitude of AC current density that is induced onto the pipeline, which is expressed as follows:

- Less than 20 Am2 = No induced AC corrosion
- Greater than 20 Am2 but less than 100 Am2 = Corrosion is unpredictable and influenced by many environmental factors
- Greater than 100 Am2 = AC corrosion is likely to occur

AC corrosion is like DC corrosion in that the AC discharges at coating flaws or “holidays.” Better coatings, i.e., smaller and fewer coating holidays, yield smaller areas of bare metal in contact with the earth, resulting in higher current densities per unit area of steel. Other contributing factors to the AC corrosion rate are low soil resistivity soils, porosity and geometric factors in the interface between the soil and the coating holiday.

Monitoring the current density and available power, rather than just AC voltages, is key to assessing the AC current-related corrosion risk.

AC MITIGATION

Providing worker safety is the number one priority. To do so, the pipeline operator must provide a dedicated, low resistance-to-earth ground, essential to ensure that the induced AC voltages are reduced to safe levels. Historically, galvanic anodes (magnesium or zinc) were connected directly to the pipe to provide an electrical path to ground. This allowed the AC to be reduced without imposing any load on the CP system. With the development of the solid-state decoupler that passes AC while providing DC isolation, the problem with depressed Cathodic Protection potentials can be eliminated.

Basics Of Induced AC On Pipelines

Therefore, any grounding electrode material, including newer linear grounding electrode systems specifically designed for AC mitigation, can be used.

An AC mitigation system design may include any or all of the following:

- Gradient control equipment to provide personnel safety against step and touch voltages
- An AC mitigation or grounding electrode system
- AC solid state decouplers
- AC current density monitoring equipment

Pipeline operators must monitor for induced AC and take necessary actions to provide the required mitigation to protect their expensive assets and, more importantly, all personnel working on or near the pipeline.

Vent Pipe for Impressed Current CP Systems

Vent pipes are used in Cathodic Protection anode wells to evacuate chlorine gas from the anode well and into the atmosphere. Impressed current anodes and a natural by-product of the anodic process generate the gas. A vent pipe is essentially a PVC water pipe perforated with small holes around the circumference of the pipe. These holes allow the gas to move from the anode well into the pipe, where it rises naturally and escapes. The most common vent pipe size is 2" in diameter.

Loresco makes a product called "All Vent," a water pipe. Rather than holes, Loresco uses very tiny slots that allow the gas to escape. The slots are so small that they do not allow coke breeze, such as Loresco SC-3, into the pipe but are big enough for the gas to pass through.

Chlorine gas is not good for the CP process or the CP materials, the vent pipe is an inexpensive but important part of the anode well. The build-up of chlorine gas in an anode well sometimes referred to as "gas blockage," can lead to premature failure of the well.

Also noteworthy is that the vent pipe exit point, installed above ground, needs to be positioned so that the corrosive gas does not migrate into the anode junction box or any other nearby structure.

Preventing Corrosion of CP Equipment

THE USE OF CATHODIC PROTECTION

Cathodic Protection prevents corrosion of pipelines, storage tanks, and other critical buried or submerged infrastructure assets that support our daily lives. When used effectively, Cathodic Protection (CP) and coatings are the best methods for preventing subsurface corrosion.

When CP is employed, some steps should be taken to prevent the corrosion of the above-ground CP equipment used to protect the subsurface infrastructure. If the degradation of the equipment is not prevented, the CP system may not last as it was designed.

A deep anode well is utilized in many impressed current Cathodic Protection (ICCP) systems. A deep anode well system consists of a vertically drilled borehole, typically 8 to 12 inches in diameter, and the depth can vary from 50 feet to over 500 feet. The anodes are lowered into the hole to the specified depth and surrounded or "backfilled" with calcined petroleum coke breeze (carbon) to provide good electrical contact with the soil.

A vent pipe is installed into the deep anode well during the loading of the anodes and coke breeze. A vent pipe is typically made of 2" SCH 80 PVC pipe, vented with holes or slots. At the surface, the PVC vent is finished in the shape of a "U" to keep rainwater from entering the vent.

When anodes discharge DC current, oxygen is generated. This oxygen combines with chlorides in the soil or water and is then converted to chlorine gas. In some cases, the gas will diffuse into the surrounding soil, but where the anodes are in dense soil or mud, the gas does not diffuse into the earth.
As the gas is not electrically conductive, and once enough gas builds up around the anodes, the anode system can no longer generate DC current, which is commonly known as "gas blockage." To prevent this problem, a vent pipe is routinely installed to route the chlorine gas to the surface of the well.

Preventing Corrosion of CP Equipment

CORROSION CAUSED BY VENTED GAS

A mistake often made is installing the vent pipe near or upwind of the above-ground CP equipment, such as a rectifier, junction box and remote monitor. The escaping chlorine gas, which is corrosive, can then permeate this equipment, causing damage to rectifier components, junction box connections, bare cable and steel enclosures.

Therefore, it is best to provide some distance between the vent pipe and the CP equipment to prevent the potential for chlorine attack.

SEALING OF CONDUITS

When anode cables from a deep well anode system are routed into an anode junction box, sealing the electrical conduit that carries the anode cables into the junction box is a good practice. The reason is that there is a potential for water or chlorine egress into the junction box, causing corrosion of the components, such as the bare cable ends, the cable connectors, buss bar and shunts. Sealing the conduit with a commercially available sealing compound or foam, specially made for this purpose, helps prevent water or gas intrusion and premature failure of the electrical components.

ELECTRICAL CABINETS

Rectifiers, junction boxes, pull boxes and other electrical equipment often utilize metallic enclosures. If not properly designed for the application, these enclosures may deteriorate prematurely, which is unsightly at best. Choosing the best material for the application is key and, if done correctly, will keep the effects of atmospheric corrosion at bay.

The most common rectifier enclosure material is hot-dipped galvanized steel, which is very sturdy and reasonably good at resisting corrosion for many years. However, if the cabinet is in a humid region or near the ocean, this may cause the cabinet to deteriorate more rapidly. If this is the case, another material choice, such as aluminum, which is also much lighter, or stainless steel, may be prudent. Cabinet coatings can also help prevent atmospheric corrosion of rectifier cabinets. Powder coating, anodizing or other specialty coatings, depending on the cabinet material, can also help to prevent corrosion.

Preventing Corrosion of CP Equipment

There are a variety of cabinet choices for anode junction boxes. This includes galvanized steel, powder-coated steel, aluminum, stainless steel and non-metallic choices. Proper selection of the appropriate cabinet materials is important in this case, too.

OTHER CONSIDERATIONS

Other material choices are required for other electrical equipment used for CP system installation. Electrical conduit is available in PVC, galvanized steel, aluminum and PVC-coated steel. The best choice depends on the application, the environment and code requirements, if any. There are also decisions to be made for proper cabling, cabinet support structures, electrical fittings and more.

Choosing the proper material for the application and system requirements is important and should be considered carefully for an effective and lasting CP system design.

Reference Electrodes For CP

In the Cathodic Protection (CP) industry, we are required to use several types of reference electrodes to measure the voltage differential between the structure being evaluated and the reference electrode. The types and configurations vary, and the details here refer to both portable and stationary reference electrodes.

TECHNICAL OVERVIEW

In almost all cases, the reference electrode is used as a zero-reference point concerning the structure under test. The voltage differential between the structure under test and the reference electrode is commonly called a "structure-to-electrolyte potential" and the electrolyte is usually soil or water.

A typical example of measuring a structure-to-electrolyte potential would be where a reference electrode is placed in the soil or water (the electrolyte surrounding the structure) and connected through a test wire to one terminal of a voltmeter. The other terminal of the voltmeter is connected directly to the structure. This creates a bimetallic or galvanic "cell" between the reference electrode and the structure through the electrolyte. In this electrical circuit, the structure is one electrode, and the reference electrode is the other electrode. Hence, the reference electrode is often called a "Half Cell."

Because the reference electrode is considered a stable (zero) reference voltage, any changes measured in the structure-to-electrolyte potential must occur on the structure (voltage or IR drop in the soil is not considered and is a subject for another time).

The characteristic potential of a reference electrode is determined by the metallic element from which the reference is built. There are many types and configurations of reference electrodes, but for most CP applications, four types are commonly used. These include:

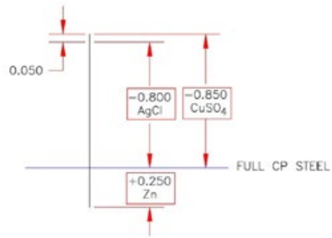
- Copper-Copper Sulfate (CuCuSO4) used in soil and freshwater applications.
- Silver-Silver Chloride (AgAgCl) used in seawater, high saline water and mud.
- Zinc (Zn) used in soil, seawater, high saline water and mud.
- Iron or Steel, often referred to as a "coupon," fabricated from the same metal of the protected structure.
    - This can be used to emulate a "native or natural potential" coupon when it is not connected to the structure.
    - Or it can be used as a "protected potential" coupon when electrically connected to the cathodically protected structure.
    - Coupons are often used as a "zero voltage" reference electrode in high temperature or severe environments that might destroy a conventional referenc electrode.

Reference Electrodes For CP

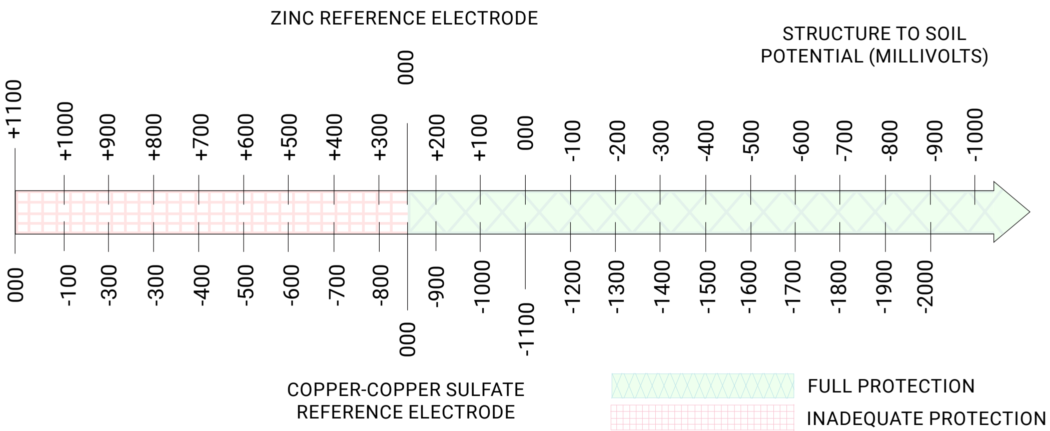
WHAT VOLTAGE LEVEL EQUALS FULL PROTECTION?
It is important, if not critical, to know the type of reference electrode used during structure testing. Different reference electrodes have different relative potentials that represent full protection of a structure. In the information below, you can see this relationship.

The voltage values for each referenced electrode type to achieve full protection of steel is:

- CuCuSO4 = Negative 0.850 Volts (-0.850)
- AgAgCl = Negative 0.800 Volts (-0.800)
- Zn = Positive 0.250 Volts (+0.250)



When using a zinc reference electrode, pay particular attention to the polarity of the reading. As you can see in the chart below, a protected potential of +0.250 Volts represents complete protection when using a zinc reference electrode. As the Cathodic Protection level increases, the voltage reading decreases. With a potential change of -0.250 Volts, the potential reading will be zero volts. Any further polarization due to Cathodic Protection will become a negative voltage. The illustration below shows the relative voltage differential between Zn and CuCuSO4.



Reference Electrodes For CP

There are external Influences that will affect the accuracy of the reference electrode.

These include:

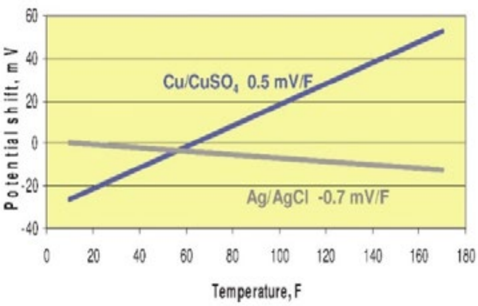
- Temperature (see below for explanation)
- Light
- Electrolyte concentration
- Electrolyte contamination or electrode polarization

TEMPERATURE EFFECT

Temperature variations can affect the voltage reading taken per the example below:

- Potential at 90 Degrees F. = -0.865 Volts
- Potential at 40 Degrees F. = -0.840 Volts

Portable reference electrodes can be maintained at a relatively constant temperature. However, stationary reference electrodes are subject to the temperature of the environment. Be mindful of this when measuring or attempting to check the calibration or accuracy of a stationary or in situ reference electrode.



Graph with Permission
Electro-Chemical Devices

LIGHT EFFECT

Copper salts and silver salts are photo (light) sensitive. As a result, exposure to light will change their relative zero point. Experiments have demonstrated that in the case of a CuCuSO4 reference electrode, a difference of as much as -0.520 Volts (-52mV) can occur on a reference electrode that transitions from total darkness to bright sunlight (clear summer solstice). This means the measured potential would be 52 mV lower in the sunlight than in the dark. Reference electrode manufacturers recognize this characteristic, and as a result, they have eliminated the clear reference electrode tubes or the tubes with a clear or view window. If you are using a reference electrode with a clear or view window, it is advised that you cover the window with dark tape.

ELECTROLYTE CONCENTRATION

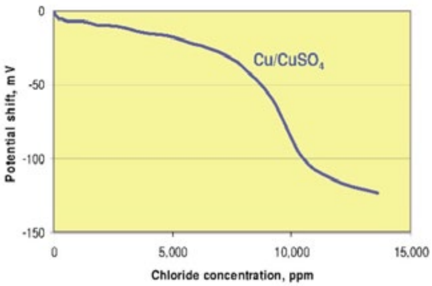
Electrolyte concentration should be considered when selecting a reference electrode for field measurements. Both CuCuS04 and AgAgCl electrodes can be affected by electrolyte concentration.

- CuCuSO4 electrodes can become contaminated in high chloride environments. This contamination will affect their accuracy. See below for additional information
- AgAgCl electrodes require relatively high concentrations of chlorides to function properly.

Reference Electrodes For CP

CONTAMINATION EFFECTS

Contamination of the electrode's internal electrolyte can affect the characteristic potential of the electrode because the electrode is now in a conflicting chemical environment. Once contaminated, the potential of the electrode can be significantly affected (see graph below). In practice, this will be a problem if the electrode is subjected to high concentrations of contaminants. CuCuSO4 electrodes are particularly sensitive to chloride contamination.



Graph with Permission
Electro-Chemical Devices

When using a CuCuSO4 electrode in brackish or seawater, the chlorides migrating back through the porous electrode plug will eventually result in an inaccurate or compromised electrode. When contaminated, the electrode's CuCuSO4 solution turns to a cloudy or milky blue.

You can use a CuCuSO4 electrode in seawater or brackish water/mud if no other solutions are available. In this instance, it is important that the electrode's liquid level be filled to a maximum to minimize air within the electrode. This will reduce the number of chlorides migrating back through the porous plug and contaminating the CuCuSO4 solution. Also, you should only use the electrode in shallow (<25 ft.) water and minimize the time the electrode is immersed. If the CuSO4 solution becomes contaminated, disassemble the electrode and flush and clean the components with distilled water. Once clean, renew the CuSO4 solution by mixing CuSO4 crystals and distilled water. The porous ceramic plug should be discarded and replaced with a new one, as the ceramic will be contaminated.

CHECKING ACCURACY OF A CuCuSO4 REFERENCE ELECTRODE

As discussed, many factors can affect the accuracy of a reference electrode, so you should monitor your electrodes for accuracy. Electrode manufacturers do this using a laboratory-grade Calomel reference electrode or a standard hydrogen electrode. Both are quite expensive, and Calomel electrodes are not legal in all states because they contain mercury.

Portable CuCuSO4 reference electrodes are the most popular choice in the CP industry. Many companies use a brand new and properly serviced CuCuSO4 reference electrode as their "gold standard" by which all other electrodes will be compared. This standard electrode will never be used for fieldwork, which minimizes the possibility of contamination or other scenarios that may compromise the standard portable electrode. But how do you know if this reference electrode is indeed accurate?

Reference Electrodes For CP

Farwest has conducted a series of comparative tests to evaluate the practicality of this method. Using three new reference electrodes from three different manufacturers, making a total of nine electrodes under test. The reference electrodes were properly serviced before testing. The test consisted of taking two reference electrodes and contacting the moistened ceramic plug together while measuring the millivolt (mV) differential between the two electrodes. In a perfect world, the differential measurement would be zero volts. However, it was found that the overall minimum to maximum differential between different manufacturers was 19 mV. And the differential voltage among individual manufacturers was:

- Manufacturer “A,” 12 mV
- Manufacturer “B,” 5 mV
- Manufacturer “C,” 3mV

In a typical CP field survey, if the “measured” potential was within 10mV from the “actual” potential, this differential would represent less than a 2% error in most cases. This would have a minimal effect of skewing the overall survey results or the ability to properly evaluate the CP system's performance. However, this differential becomes more important during a close interval survey (CIS) when having multiple reference electrodes close to a zero potential differential is important.

Suggestion: *As a minimum, you should have three reference electrodes available to you that exhibit minimal voltage differential. Choose one primary electrode for field work and routinely retest the group of electrodes so you can determine when it is time to retire or recondition the primary electrode.*

CARE & MAINTENANCE OF REFERENCE ELECTRODES

To help maintain a portable CuCuSO4 reference electrode:

- Keep the plastic cap on the ceramic, porous tip when the electrode is not in use.
- Be sure the CuCuS04 solution remains bright blue (not milky) and has an adequate liquid level. A milky appearance of the CuCuSO4 solution indicates that the solution is contaminated.
- Always carry new CuCuSO4 crystals and distilled water to clean and recharge your portable reference electrode.

The porosity and relative durability of ceramic tips vary between manufacturers. If you are fortunate, you will get a reference electrode that does not leak the CuCuSO4 solution even with the cap off. Either way, keep your reference away from sensitive metallic components, i.e., meters, precision tools, etc., as the CuCuSO4 solution is very corrosive.

Reference Electrodes For CP

Reconditioning a CuCuSO4 reference electrode:

- Clean all internal electrode components with distilled water.
- Remove oxidation or contamination from the copper rod with either a Scotch Bright pad or "garnet sandpaper." Never use aluminum oxide sandpaper or any type of steel wool or wire brush, as this will contaminate the copper rod.
- Check, clean or replace O-ring seals to prevent leaks.
- Recharge the electrode with new CuCuSO4 crystals to approximately 50% before adding water.
- Use only distilled water or approved premixed CuCuSO4 solution.

Post-survey maintenance on a portable AgAgCl reference electrode would include rinsing the electrode with fresh, potable water to flush out any residual salts or chlorides. When clean, allow the electrode to air-dry and store it in a clean plastic bag.

ALTERNATE TYPES OF CuCuSO4 REFERENCE ELECTRODES

Alternative reference electrode technologies that eliminate the need for much of the maintenance described above are available. The new technology provides components that are contained in a sealed unit that incorporates a non-porous, ionically conducting end plug. This electrode is calibrated at the factory and shipped with a Certificate of Calibration.

Electrodes are used to measure the “potential” (voltage) of a structure such as a pipeline, tank, etc.

Portable copper-copper reference electrodes require proper placement and regular maintenance to maintain the integrity of readings taken when using the electrode.

PLACEMENT

A buried, permanent or stationary CuCuS04 reference electrode should be placed in close proximity to the structure to be measured. The closer the electrode is to the structure, the less "IR" error there is when a potential reading is taken through that reference electrode.

Reference Electrodes For CP

Close proximity can mean within a few inches or as close as "practical". If a pipeline is buried 40 ft. below the surface, it may not be practical to get the electrode within inches of the structure. Yet, in most cases, closer is better.

Other installation considerations include:
- Reference electrodes should be buried below the frost line - they should not be frozen.
- Like a magnesium anode, the electrode and surrounding soil should be wetted.
- Native soil, not sand, should be used when backfilling the electrode.

Always remove any plastic bag from around the electrode before installation. Otherwise, the electrode will not work.

MAINTAINING OR REJUVENATING PORTABLE CuCuSO4 REFERENCE ELECTRODES
Maintenance should be done on a periodic basis depending on how often the electrode is used or the conditions in which it is used. A good rule of thumb for rejuvenating an electrode is when the copper sulfate liquid inside the electrode becomes “milky” as the color should be a very bright blue.

1. Open the reference electrode by unscrewing the plastic end cap where the copper rod is mounted.

2. Properly dispose of the liquid copper sulfate.

   Note*: This liquid is hazardous. Proper safety measures should be employed including the use of safety glasses and disposable gloves.*

3. Clean the internal copper rod with a non-metallic abrasive, such as sandpaper or a scouring pad. This will remove any patina or impurities from the rod.

   Note*: NEVER use metallic abrasives to clean the rod, such as an emery cloth, as it will contaminate the copper rod.*

4. Add new, pure copper sulfate crystals to the interior of the reference electrode by removing the end cap of the electrode. Fill the electrode cavity to approximately one-third to half full.

Reference Electrodes For CP

5. Add clean, distilled water to the interior of the electrode filling the electrode to almost full.

   Note: NEVER use tap water for this purpose.

6. Replace the plastic end cap by threading it back onto the electrode body.

7. Ensure the ceramic tip of the electrode is clean and in good condition. A cracked ceramic tip should be replaced with a new tip to avoid excessive electrolyte leakage.

Understanding CP Test Stations

THE PURPOSE OF A CP TEST STATION

The primary purpose of a Cathodic Protection (CP) test station is to provide an access point to terminate cables from a buried structure (pipeline) to take electrical measurements or readings on that structure.

Because it is impractical to excavate the structure every time a measurement must be taken, a test station is used by connecting cables to obtain CP measurements.

In its most basic form, a test station is simply an enclosure (above or at grade) with cable connecting points that allow cables from a buried structure, such as a pipeline, to be terminated. This electrical access to the structure will enable technicians to perform necessary CP tests. In addition to structure access, a test station can allow a technician to monitor other CP components, such as an anode, a stationary reference electrode, or a CP coupon.

CAPABILITIES AND ADVANCEMENTS

In some cases, more than one structure may be monitored from a single test station, requiring more cables and cable terminations. Alternatively, multiple cable connections can be affixed to the same structure, in this case, a pipeline, to determine if a buried pipeline isolator is functional. The test station design will still include an enclosure with cable connecting points, even with added complexity.

While a test station has a relatively simple job, Cathodic Protection designers have altered the basic design to include other internal testing components, including current measurement shunts, on/off switches, bond jumpers and more. The basic enclosure and cable terminations are the core, even in the more advanced test stations.

LEAD WIRES

When installing test lead wires on a buried structure, installing two lead wires (instead of one) is best. This allows for options if a lead wire becomes broken or disconnected from the pipe. The installation cost of reinstalling a test wire (digging into the ground to expose the structure) is significantly higher than installing multiple wires during installation.

Understanding CP Test Stations

Cable size will vary by specification. #12 AWG (solid or stranded) is typically the smallest cable used for test station lead wires. Cable insulation can vary and include RHH/RHW and HMWPE for direct burial.

THE DIFFERENCE BETWEEN A SHUNT AND A BOND STRAP

A shunt measures the current output of an anode or similar. It is installed across two isolated terminals of a test station. Having a known resistance value, a shunt is used for converting the voltage drop across the shunt to a DC current value using Ohm's Law.

A bond strap is a piece of metal (nickel-plated brass) used to bond or connect two isolated terminals of a test station but does not provide the ability to read the voltage drop (like a shunt).

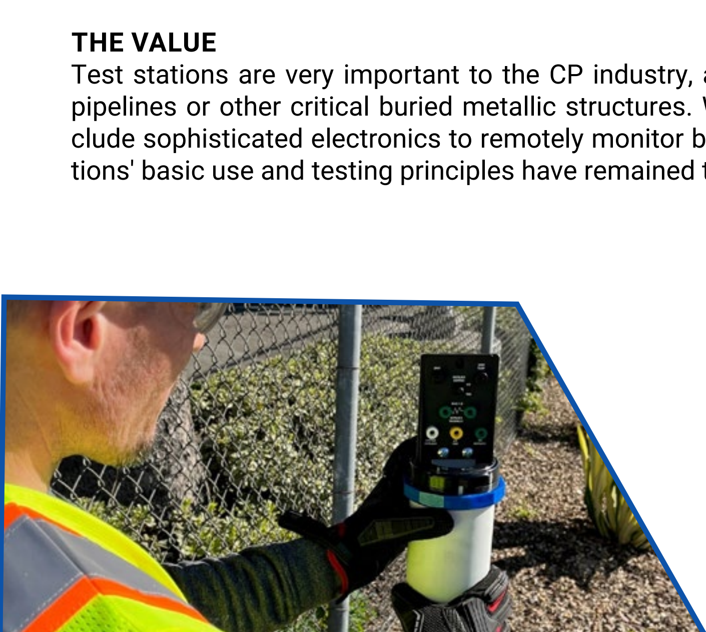
THE HISTORY

The first test station enclosures were invented in the mid-1900s and made from metallic alloys. These enclosures were designed for aboveground service and included a non-metallic panel for cable terminations. Concrete "valve boxes" were also used for at-grade test stations employing a non-metallic panel board with cable terminations. Later, metallic test station bodies were designed for at-grade use.

In the later 1900s, plastic compounds evolved, and non-metallic test stations entered the CP market. These aboveground test stations were made from polycarbonate, a very durable plastic compound still used today. Later, the same polycarbonate materials were used for buried or at-grade versions.

THE VALUE

Test stations are very important to the CP industry, allowing technicians to monitor pipelines or other critical buried metallic structures. While they have evolved and include sophisticated electronics to remotely monitor buried structures, CP testing stations' basic use and testing principles have remained the same.



Testing Pipeline CP Systems for Broken Test Wires

Corrosion technicians conduct routine operational status checks on Cathodic Protection (CP) Systems to ensure that the system provides adequate protection levels. Many common systems can include multiple 2-wire, magnesium anode test stations (one wire for the anode and another for measuring Pipe-to-Soil (P/S) potentials) with simple 2-wire P/S test stations between the anode test stations. Normal potential readings should be between -0.950 and -1.150 volts with respect to a CuSO4 reference electrode along the pipeline.

CHECKING TEST EQUIPMENT AND TEST STATIONS

When an unusually low reading occurs at one of the test stations, the first step is to ensure that the test equipment and the test station are not the source of the issue. The following are the first checks to make:

- Verify that you removed the plastic protective cap from the reference cell. (It happens.)
- Verify that you have adequately wetted the soil to obtain proper reference electrode contact-to-earth.

  Note*: Digging down 2 or 3 inches and wetting the soil can make a difference.*
- Check to ensure that your meter test leads are not broken. Put your meter on the “Ohms” function and short the test leads together. The meter should read less than 1 ohm and be stable if the leads are good.
- Ensure that the connection point(s) within the test station is clean, tight and free from corrosion.

INDICATORS OF A DEFECTIVE OR BROKEN TEST WIRE

Once you are confident that the test equipment and test station are serviceable, the next step is to find the indicators of a defective or broken test wire. These include:

- *Lower than the expected potential and likely unstable or drifting readings.*
- *This is the most common situation.* If a pipeline test lead wire is broken, you are, in effect, reading the open circuit potential (OCP) of the end of the broken wire with respect to your reference electrode.
- *In addition, besides low readings, a higher-than-expected potential can indicate a broken test wire.* This is rare but can be found in a 1-wire magnesium anode test station. The high reading exists because the test wire to the pipeline is broken. Because the test wire is still connected to the magnesium anode through the test station, you are now reading the OCP of the magnesium anode. In this case, you need to disconnect the anode and perform an “applied current” test, detailed below, to confirm that the test wire is indeed broken.
- *Zero current output from a magnesium anode (maybe).* This can occur even with serviceable test wires if the pipeline is the exact same potential as the anode.

Testing Pipeline CP Systems for Broken Test Wires

TEST METHODS

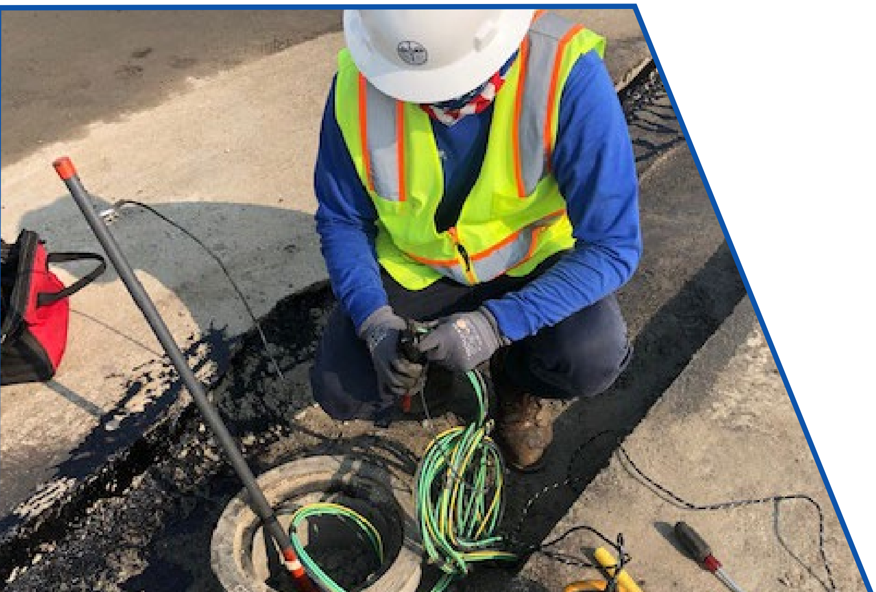
- *In a 2-wire test station, the quickest way to test conductor continuity is to measure the voltage between the test wires.* With two good test wires, the voltage should be zero.
- *The anode should be disconnected before measuring the voltage between the test wires.* If there is a voltage differential or the reading is unstable, one of the test wires is likely defective. If there were any measurable anode current, it would be safe to conclude that the anode wire is in good condition.
- *In some instances where only one test wire exists, a modified version of the above test may be possible.* Extend a separate test wire between the suspect test wire and a contact point that is electrically continuous with the pipeline, i.e., an above-ground valve. Measure the voltage differential between the two points of contact. If the test wire is good, the voltage should be "zero" or within a few mV of "zero." If a large or variable voltage differential exists, this confirms that a test wire is broken.
- *Another option is to use a simple Ohmmeter test*. Set your meter function switch to "Ohms" on the lowest scale. Connect the meter test leads between the test lead to be tested and a contact point that is electrically continuous with the pipeline. Read and record the value in ohms. A good test wire could read less than 1 ohm to as much as 20 ohms but should be stable. This method will always include the resistance of the wire on your test reel. Therefore, it will be necessary to measure the resistance of the test reel wire and subtract that value from the total measured resistance.
- *Using an "applied current" to the suspect test wire from a temporary ground anode can be a very effective test.* Use a 9-volt battery and a small probe rod (resistivity pin, screwdriver, etc.).
  - Drive the probe rod a few inches into the ground. Do not be concerned with the location, as this is not critical. Set up the meter and the reference electrode to measure the pipe-to-soil potential on the suspect wire. Place the reference electrode about six inches from the probe rod. Record the reading value from the meter.
  - Connect the probe rod to the positive of the battery. Briefly (1 to 2 seconds), connect the negative of the battery to the suspect test wire. During the application of the current, regardless of the condition of the test wire, you will observe a significant change in the potential of the wire and may read a potential as high as 8 volts. This high potential is due to IR drop because the reference electrode is close to the probe rod. As you disconnect the current, watch the potential change. If the potential immediately returns to the original reading, this indicates a good test wire. If the potential slowly changes or is unstable, you can be certain it is a broken test lead.

Testing Pipeline CP Systems for Broken Test Wires

Why this test works:

- If the test wire is good, the amount of current generated from the small probe rod (likely less than 1 mA) will have little effect on a large, buried structure.
- If the test wire is broken, there is only a very small surface area contacting the earth. Therefore, the small amount of current will have a very large effect on the potential of the exposed end of the broken wire and quickly polarize it.

The time and effort required to test a suspected broken test wire can be minimized if all test stations are specified to have a minimum of two test wires connected to the protected structure.



Using the Four Point Resistance Meter

In Cathodic Protection (CP), a Four Point (Pin) Soil Resistance Meter (FPSRM) is used to measure the resistivity of the soil in the field or in a soil box.

THE METER
The meters are basically an ohmmeter, albeit a special one. As the name implies, the meter has four points (pins) to obtain the needed resistance values.

OPERATION
Powered by internal batteries, a current is circulated between the C1 & C2 current terminals while measuring the voltage/potential drop between the P1 & P2 potential terminals. Using Ohm's Law (R=E/I), the internal electronics are calibrated to provide a direct reading in ohms. Typically, these meters can accurately measure resistances from 0.01 ohms to 1.1 megohms.

These models differ from a standard ohmmeter, such as a Fluke 87 or similar, which cannot be used to obtain soil resistance measurements. This is because:

- The FPSRM uses a reversing polarity (modified square wave) current output with a frequency of 97Hz. This cancels out any electrode polarization of the soil pins that would result if a straight DC current source was used, i.e., a typical ohmmeter or digital multimeter (DMM).

- A DMM uses only two test leads to carry both the test current and measure the voltage drop. The resistance of the test leads and any contact resistance in the connections will be added to the final reading displayed. Therefore, the reading from a typical DMM can have a significant error when measuring resistances below 10Ω.

USES OF THE FPSRM
The most common uses of a soil resistivity meter include:

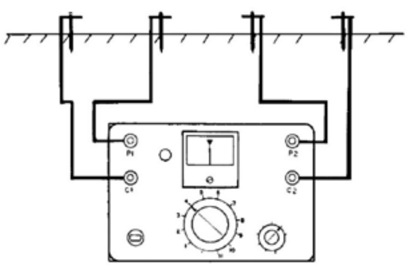
- Determining the average soil resistivity to a specific soil depth.
- Measuring the resistance-to-earth of a buried electrode, such as an anode or ground rod.
- Determining the resistivity of a soil sample or water sample when utilizing a "soil box."
- Measuring the resistance between two buried electrodes, such as two ground rods or two anodes.
- Measuring the electrical resistance of a length of pipe or cable.

Using the Four Point Resistance Meter

In corrosion control, the most common use of the FPSRM is for measuring soil resistivities in the field using the "Wenner Four-pin Method." The "Wenner" method consists of driving four metallic pins into the soil. The distance between each pin is equal to the depth of the soil to be measured. The following will provide the best results:

- The pins should be equal distance apart and in a straight line.
- Avoid installing the pins near any underground metallic structures. At a minimum, the pins should be installed at an offset and perpendicular to any known buried metallic structures or pipelines.
- If the soil is dry, wetting the soil around the driven pins may help. Specifically, the C1 & C2 pins are the most important pins for moisture.
- Each soil pin shall have a dedicated wire to interconnect the pin to the appropriate connecting post on the meter.
- Note and record the surface soil conditions, i.e., dry, damp, and previous weather conditions (recent rain, etc.). This information will be helpful in evaluating the overall resistivity profile.

Driven Soil Pin



MEASURING AND CALCULATING SOIL RESISTIVITY (4-PIN WENNER METHOD)
Following the manufacturer's recommended operating procedures, manipulate the main knob of the meter to indicate a "Null" reading. Record the resistance (ohm) value and the multiplication factor, i.e., Null dial reading = 4.6Ω and the ohms "multiply by factor" = 1.0. Therefore, the total resistance measured = 4.6Ω.

Note*: This is not the soil resistivity.*

To calculate the soil resistivity for a pin spacing of 10 feet, use the following formula:
SR = 191.5 x D x R – Where:

- SR = Average resistivity in ohm-cm to depth in feet
- D = Distance between pins in feet
- R = Resistance in ohms as measured on the meter

Using the Four Point Resistance Meter

Using the example above: 191.5 X D (10 ft.) X R (4.6Ω)

SR= 191.5 10 X 4.6 = 8,809 ohm-cm

The soil resistivity values measured using the four-pin resistivity method vary greatly between depths. It is important to remember that the soil resistivity measured is a weighted average of the soils from the surface to that depth.

SPACING EVEN FEET	MULTIPLIER	SPACING FEET–INCHES	MULTIPLIER
1	191.5	2'7"	500
2	383.0	5'3"	1000
3	574.5	7'10"	1500
4	766.0	10'5"	2000
5	957.5	13'1"	2500
10	1915.0	15'8"	3000
15	2872.5	18'3"	3500
20	3830.0	20'10"	4000
25	4787.5	23'6"	4500

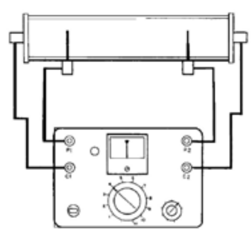
Note: *The table to the left shows two sets of pin spacings. The column to the right shows distances that use multipliers that are easier to work within the field.*

TESTING WITH A SOIL BOX

Soil samples obtained in the field can be tested in a "Soil Box." An advantage to using a soil box is that results are precisely the value of the soil as tested. It is important to note the relative moisture content of the sample, as any soil that is dry will yield a high resistivity value. The soil box allows you to add moisture (distilled water) to the sample and compare the soil characteristics between dry and saturated. Soils with high parts per million chemical elements will show a significant drop in resistivity when saturated. This gives the CP technician an indication of the "worst case condition," i.e., low resistivity usually equates to high corrosivity.

FACTS ABOUT SOIL RESISTIVITY TESTING

- Obtaining soil samples in the field can be challenging, as a field technician will not usually have the necessary equipment to obtain a proper soil sample. Taking a sample with a shovel will NOT be representative of the soil at depth and will provide erroneous readings. Therefore, it is best to obtain soil samples from soil borings.
- On construction sites where engineered soils or cut-and-fill techniques are used, it is important to ensure that the samples you receive are representative of the soils that would be in contact with the pipeline or structure.



- On new pipeline installations, backfill material is often imported, such as sand or slurry. This must be considered when developing an anode design. If possible, specify that CP anodes are to be installed in undisturbed native soil. Installing anodes in sand or slurry will likely reduce the current output of the anodes due to the relatively higher resistivity of the sand or slurry environment.

Using the Four Point Resistance Meter

- Be selective with the soil that you put in the soil box. Remove large clumps or rocks from the soil sample.
- Soil samples must be compacted in the soil box. Non-compacted soil will yield a much higher resistivity.
- You must fill the soil box completely to the top of the box to obtain an accurate reading.
- Make note of the type and color of the soil, i.e., clay, sand, loam, etc.
- Always note the relative moisture content of the "as received" sample, i.e., dry, trace of moisture, damp, wet, saturated.
- To obtain a “minimum resistivity,” it is necessary to add distilled water to the soil sample in the box. When adding distilled water to saturate the sample, note how well the water is absorbed. If the soil is reluctant to saturate the soil, you will have to wait for the water to migrate through the sample. If necessary, add more water to the sample so it becomes fully saturated. In some cases, you may have to allow the sample to soak overnight to obtain full saturation. If you test the resistivity periodically through the saturation process, you will see that the resistivity will continue to drop to a point where it stabilizes.
- Most soil boxes manufactured today have a 1:1 multiplier and use a “mini” version of a 4-pin method. Some of the older soil boxes (made by Agra) had 2:1 and even a 10:1 multiplier. These older boxes were built with two end plates and no potential pins, which is not ideal. Be sure and understand the type of soil box in use and the correct measurement process.

ADVANTAGES OF TESTING ACTUAL SOIL SAMPLES IN A SOIL BOX

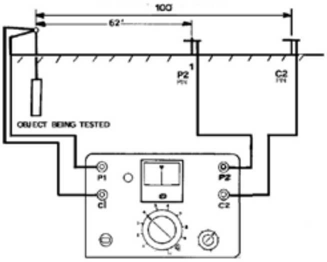
- The reading obtained is the actual value of the soil at the depth and condition found in the field. There is no “averaging” of the reading.
- The ability to obtain a saturated value compared to the “as received” value helps better understand the soil characteristics.
- Soil samples can be lab tested for many other chemical properties if required.

RESISTANCE-TO-EARTH OF A SINGLE ELECTRODE

(Known as the “3 pin method” or “Fall off potential method”)

This method (often referred to as an “Electro-Log”) is typically used during the installation of a single anode or multiple anodes in a deep well anode bed.

Using the Four Point Resistance Meter



Note the pin spacing and ratio. The potential pin is 62% of the total distance between the anode under test and the C2 pin. The 100 feet shown would be typical for a 20 feet deep electrode. It is important to have adequate pin spacing from the electrode under test not to influence the reading.

Once the pins are in place, the reading will be "Ohms to Earth" of the electrode being tested.

MISUSE OF THE FPSRM

What is wrong with these diagrams?

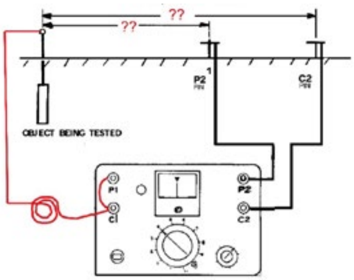


Figure A

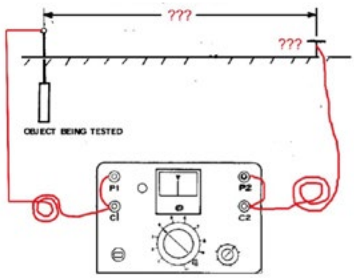


Figure B

FIGURE A & B = Test leads should NOT be on spools as indicated in the drawing. The "square wave" current output of the FPSRM will generate an inductive reactance that will add to the actual resistance being measured. This can result in a significant error and must be avoided.

FIGURE A & B = Interconnecting C1 & P1 as well as C2 & P2 with a short buss wire is often done to minimize or simplify the field wiring setup. However, the resistance of the test cable going to the anode or ground pin will add to the actual resistance of the electrode(s) under test

TESTING CABLE RESISTANCE

This method can provide very accurate results if performed properly. It is important that the cable under test is NOT coiled or on a spool.

Using the Four Point Resistance Meter

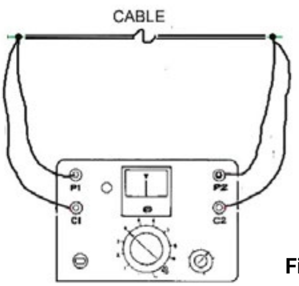


Figure C

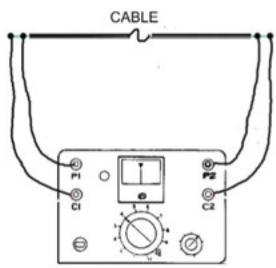


Figure D

FIGURE C – The improper method to be avoided. Even though there are four individual test leads, the figure shows the test leads "stacked" or connected to a common point on the cable under test. Any contact resistance between the test wires to the cable will add to the actual cable resistance.

FIGURE D – This shows the proper method of connecting the test leads to the cable under test. Separate C1 & C2 are positioned on the outside of P1 & P2. The actual cable resistance is the length of cable between P1 & P2.

Note: *When measuring cable resistance with the FPSRM, the cable should not be on a spool or coil. The square wave current output of the FPSRM will generate an inductive reactance that will degrade the accuracy of the test.*

SUMMARY

The four-pin soil resistance meter is a versatile tool for accurately measuring soil resistivity, electrode-to-earth resistance values, the resistance of non-coiled cables as well as pipeline lengths. As with any technical instrument, knowing how to properly operate the device and why you use a certain technique or test method is important. Understanding the limitations of the instrument and improper test methods will avoid obtaining erroneous data.

How to Use CP Shunts

Many Cathodic Protection (CP) technicians struggle with correctly reading and interpreting shunt measurements or readings.

SHUNTS AND HOW TO USE THEM PROPERLY

A shunt is a calibrated resistor with a known value. In Cathodic Protection, shunts are used for many applications. Some uses include:

- Measure the current output of an anode (galvanic or impressed current)
- Verify the accuracy of rectifier panel mounted ammeters
- Measure the current in pipeline resistance bond connections

The primary advantage of having a shunt in a circuit is to measure the current flow without disconnecting the circuit to install a portable ammeter. Clamp-on ammeters can be used in some instances. However, most are unable to accurately read current values of less than 200 milliamps (0.2 amps).

Shunts come in many sizes and ratings, ranging from less than one ampere to thousands of Amperes with varying resistance values. With the proper shunt in a circuit, you can determine the magnitude of current flow by using a typical digital multimeter (DMM).

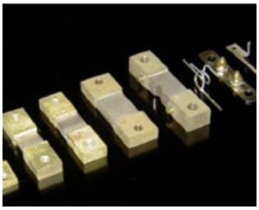
Following are examples of commonly used shunts for Cathodic Protection:

Holloway Type “SS,” 0.001 Ω with a 25-ampere rating. This shunt is very popular for use in impressed current anode junction boxes.

Holloway Type “RS,” 0.01 Ω with a 6-ampere rating. The RS is used in both impressed current and galvanic anode applications.

Note: *Not all shunts have the resistance value inscribed on the shunt. The Holloway RS is one example of that.*

How to Use CP Shunts



The five-shunt shown on the left is typically used in CP rectifiers. The shunt would be connected to the front panel ammeter.

The shunts to the left are popular in post-mounted test stations. They are color-coded to depict their resistance value.
Red = 0.1 Ω
Yellow = 0.01 Ω
Orange = 0.001 Ω

Note: *All shunts will have 4 points of connection. Two positions to connect into the current circuit and two positions to be used to measure the voltage or millivolt value across the shunt.*

When measuring the voltage drop across a shunt to determine current, it is imperative that you know the resistance value of the shunt and understand Ohm's Law. In all cases, when measuring shunts for current values, the formula to use is I = V / R.

- I = The current value you need to know
- V = The voltage drop across the shunt test points (usually measured in millivolts)
- R = The known resistance of the shunt in ohms Ω

Note: *The shunts used in the CP industry typically have very low resistance values, such as 0.001 Ω, 0.01 Ω and 0.1 Ω.*

Measurement Example 1: Shunt Resistance value is 0.001 Ω.
- With your meter setting on DC millivolts, you measure 5.3 millivolts (0.0053 volts) across the shunt.
- The resistance of the shunt is 0.001 Ω
- Therefore, the equation is 0.0053 / 0.001 = 5.3 Amperes

The benefit of using this shunt is that the value you read in millivolts on your meter is a direct conversion to Amperes.

How to Use CP Shunts

Measurement Example 2: Shunt resistance is 0.01 Ω

- With your meter setting on DC millivolts, you measure 5.3 millivolts (0.0053 volts)
- The resistance of the shunt is 0.01 Ω
- Therefore, the equation is 0.0053 / 0.001 = 0.53 Amperes

Another way to think about this shunt is that the value of 10 millivolts on your meter will equal 1.0 Amperes. Therefore, with your meter on millivolts, the reading is 5.3, so simply move the decimal point one position to the left to determine the current in Amperes.

Important Note: *The meter reading of 5.3 millivolts was the same in the above measurement examples. However, the actual current was a factor of 10 differential. Therefore, the technician must know the resistance value of the shunt.*

Using Portable Interrupters

Installation Options & Issues

INTERRUPTERS
An “interrupter” is a switch installed on Cathodic Protection (CP) rectifiers to switch the rectifier OFF and ON in a timed cycle. The interrupter switch can be a conventional mechanical (metallic contact) switch or an electronic, solid-state switch. The purpose of the Interrupter is to enable the CP technician to measure pipe-to-soil potentials in both an ON (CP current applied) & OFF (CP current interrupted) condition. Referred to as an “interrupted survey, " the survey results reveal the effectiveness of the CP system within the influence range of the CP rectifier.

Interrupters can be included in a rectifier during manufacture. This is rare, as it is a special option many people do not know is available. As a result, most rectifiers do not have a built-in interrupter. Therefore, to conduct an interrupted survey, connecting a portable interrupter to the rectifier is necessary.

Portable interrupters are available from many manufacturers. The type, rating and technology of the interrupters vary. It is important to select an interrupter that has a suitable current rating for the application. Additionally, if multiple interrupters are required along the pipeline, the interrupters must be capable of synchronization.

Regardless of the type of portable interrupter, there are options for how it can be connected to the rectifier to provide the necessary interruption cycle.

CONNECTING A PORTABLE INTERRUPTER TO A CP RECTIFIER
The following are three options to connect an interrupter to a rectifier. (Refer to Figure 1 for clarification.) Each method has advantages and disadvantages as they may have some effect on survey results. Depending on the type of structure protected, some of the conditions noted may not apply.

Option 1 - Interrupter Installed in the AC Input to the Rectifier.

Advantages
- Low switching currents in the primary of the transformer, typically less than 10 Amperes. An interrupter with a low current rating would be capable of interrupting a rectifier with a high DC current rating.

Using Portable Interrupters

Disadvantages

- Requires the technician to manage connections with high AC input voltages.
- In-rush AC current can trip the AC input breaker.
    - In-rush current can be experienced when turning ON the switch to the main panel circuit breaker. When this happens, you may hear a low pitch "bong," or the breaker will trip immediately.
    - The magnitude of the in-rush current is dependent on when the switch is closed relative to the input AC sine wave. Note that the AC voltage varies from zero to a maximum of 120 times a second. If the breaker is closed when the AC voltage is at or near zero, there will be minimal in-rush current as the voltage ramps up on the sine wave. If the switch is closed at or near the maximum voltage on the sine wave, high voltage hits the transformer creating a high in-rush current.
    - Depending on the rating of the breaker, it may or may not trip. So, it is possible to set up the interrupter on the AC input side, and initially, everything may look good. However, the circuit breaker can trip during the survey, which is highly inconvenient.
- When the transformer is switched OFF, the collapsing magnetic field will cause a voltage spike in the rectifier output. Often referred to as "anodic spiking," this can cause inconsistent pipe-to-soil potential readings.
- If the pipeline under survey has induced AC voltages, these induced voltages will pass through the rectifier stack and be converted to DC during the OFF cycle. The rectified DC will be impressed onto the pipeline during the OFF cycle, resulting in "false high OFF" pipe-to-soil potential.

Option 2 – Interrupter Switch is Installed in the AC Secondary of the Main Transformer.

A popular technique to accomplish this is to remove one of the coarse or fine rectifier tap link bars, then connect the interrupter in place of the tap link bar. This technique directs the AC secondary current through the interrupter.

Advantages

- No in-rush current issues, as the main transformer is already running. There is no concern regarding the AC input circuit breaker tripping.
- Convenient as it only requires removing a tap link bar and connecting the interrupter to the rectifier tap studs.
- AC current will have less arcing on the interrupter contacts than DC current.
- No anodic spiking.

Using Portable Interrupters

Disadvantages

- Interrupter must have a current rating equal to the output of the rectifier.
- As in Option 1, if the pipeline under survey has induced AC voltages, these induced voltages will pass through the rectifier stack and be converted to DC during the OFF cycle. The rectified DC will be impressed onto the pipeline during the OFF cycle, resulting in “false high OFF” pipe-to-soil potential.
- Rectifier may indicate a lower DC current output due to added resistance of interrupter equipment.

Option 3 – Interrupter is Installed in the DC Output of the Rectifier.

Advantages

- No in-rush current issues.
- No false high “OFF” readings due to induced AC.
- No anodic spiking.

Disadvantages

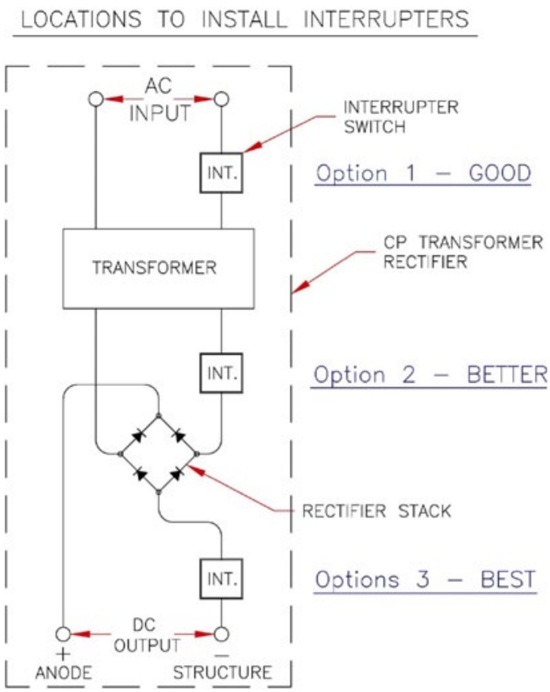
- Interrupter must have a current rating equal to the output of the rectifier.
- Rectifier may indicate a lower DC current output due to added resistance of interrupter equipment.
- Managing the large DC output cable may be an inconvenience.

FINAL COMMENTS

Interrupting a conventional transformer rectifier has its challenges. There are better ways to interrupt a CP rectifier. Some conventional transformer rectifiers are manufactured with a “hybrid” rectifier stack - a stack with two conventional diodes and two SCRs (Silicon Controlled Rectifiers). The hybrid stacks are usually found on constant current and constant potential controlled rectifiers. This technology allows the rectifier to be interrupted using a simple, low current relay to interrupt the gate control current to the SCRs. Therefore, it is possible to interrupt a rectifier, even one rated at 500+ Amperes, with an interrupter relay that only needs to switch 5 milliamps.

Using Portable Interrupters

Figure 1



Note: *A new generation of CP power supplies that use "switch-mode" technology is available. These power supplies can be more user-friendly and are designed to be interrupted with a low current external relay. They can also be interrupted with an external input voltage, i.e., the output of a portable interrupter that was intended to drive a large high-current relay. When interrupting a conventional rectifier with a hybrid stack or switch-mode CP power supplies, all the disadvantages noted in Options 1 through 3 above will be eliminated.*

CP Systems for Water Tanks

Many factors go into determining what type of system is best to protect a particular tank, including the size of the tank, the efficiency of the coating, other bare structures inside the tank, water resistivity and more, especially the coating system.

The best course of action is to determine what type of system exists, if it is working correctly, and what should be done in the future.

IMPRESSED CURRENT CP SYSTEMS
This system uses anodes and a separate DC power supply (CP rectifier) to generate current from anodes to protect the tank's interior. When the rectifier isn't working, the anodes sit dormant until the rectifier is either repaired or replaced.

Components in this system can include cable, reference electrodes and assorted hardware. Impressed current CP systems are typically used where more DC current is required to protect the structure. This can be the case in water tanks when the coating is in poor condition, and there is more bare metal to protect. This is called CP current demand.

GALVANIC (OR SACRIFICIAL) CP SYSTEMS
This system uses magnesium anodes. All the other major components are similar to an impressed current CP system (except the rectifier, which is not needed).

Sacrificial anode systems generate a limited amount of unregulated current to protect the structure (without a power supply). Once installed, this system provides as much current as possible for as long as possible.

Basic Electricity

THE BASICS

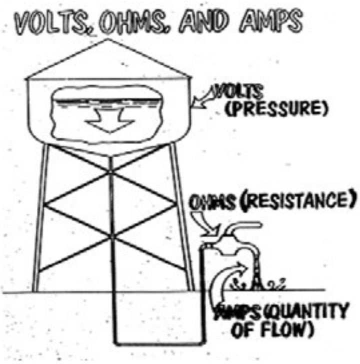
Because we cannot physically see volts, amperes or resistance, a comparison to something familiar, like a water/hydraulic circuit, will be used to demonstrate the relationship.

Value	Water Circuit	Electrical Circuit
Pressure	Pounds per square Inch (PSI)	Voltage (Volts)
Flow	Gallons per hour (GPH)	Current (Amperes or Amps)
Resistance to Flow	Pipe size or friction loss	Resistance (Ohms)

The three circuit values shown in both water and electrical circuits can be directly compared for cause and effect.

Using the water tank example to the left:

With high pressure/high water level and low resistance (the water valve is open all the way), we can obtain a large current or water flow.



The same high pressure with a high resistance or friction loss (the water valve is nearly closed) will result in a lesser current or water flow.

A smaller pressure (lower water level) in either of the preceding instances will result in a correspondingly lower water flow.

Basic Electricity

Ohm's Law defines the following electrical phrases and symbols:

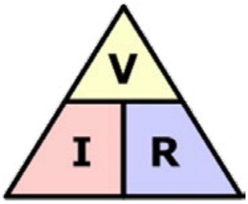
- Volts (V) = Electromotive Force
- Amperes (I) = Current Flow
- Ohms (R) = Resistance to flow of current with the "Omega" symbol (Ω)

If any of the above values are found in an electrical circuit, the third can be calculated using Ohm's Law. Using the symbols V, I & R, the formula is:

- V= IR or Volts = Current x Resistance
- I = V/R or Current = Volts /Ohms
- R= V/I or Resistance = Voltage/Current

If two of the above values are found in an electrical circuit, the third can be calculated using Ohm's Law. Using the symbols V, I & R, the formula is:

- V= IR or Volts = Current x Resistance
- I = V/R or Current = Volts /Ohms
- R= V/I or Resistance = Voltage/Current



Use the diagram to the right to understand the formula: Put your finger on what you want to know; the remaining symbols reveal the formula you will use.

Example:
To calculate the current flow in a circuit, use the formula I = V/R

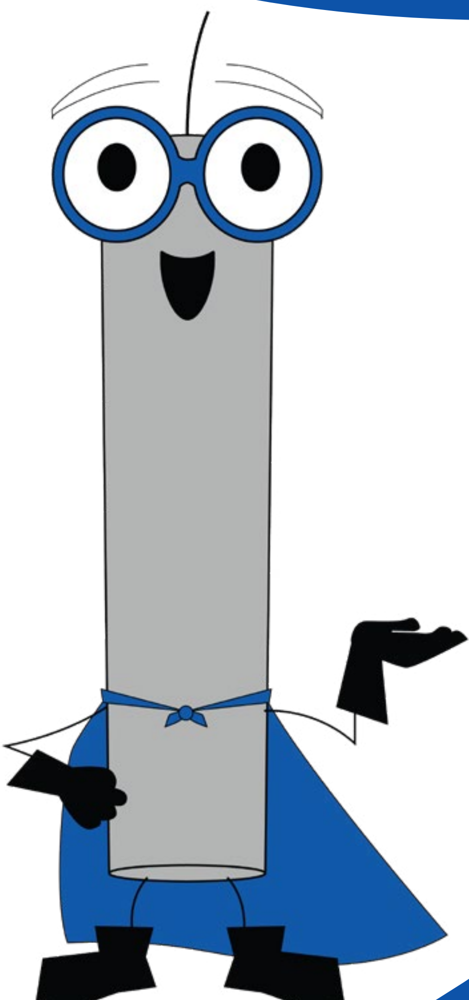
- Measure voltage with a portable meter = 10.0 volts
- The resistance of the circuit is known and has a value of 2.0 Ohms (Ω)≠
- Therefore, the equation is 10.0 V/ 2.0 Ω = 5.0 Amperes

Important Note: *It is always best to use all whole unit numbers, i.e., volts, amps & ohms, rather than mixing the values, i.e., millivolts and Amperes, in the same calculation.* For reference:

- Volt = 1000 millivolts
- Ampere = 1000 milliamps
- Ohm = 1000 milliohms

ANODES

Anodes are the superheroes of Cathodic Protection. Some are sturdy, like high silicon cast iron, others are flexible, like MMO and there's always the trusty zinc, magnesium and aluminum sacrificial anodes. Let's explore their exciting universe and discover where and when we unleash their superpowers!



Types of Anodes - Linear

A "linear" anode is long and usually designed to provide a relatively small amount of DC current over the length of the anode. In some cases, linear anodes are added to an existing CP system to increase needed current in areas where protection levels are not as they should be. In this case, additional current is supplied from the linear anode in addition to the current supplied from other CP anodes.

Linear anodes can also be used beneath the floor of storage tanks. In this case, the anode material is installed in a circular or similar pattern under the tank bottom to get equal current distribution over a small, restricted area. And, since these anodes are relatively "skinny," they fit beneath the tank bottom with relative ease.

Examples of linear anodes include magnesium and zinc sacrificial ribbons and a variety of impressed current anodes that all do similar jobs but have special nuisances for different applications.

Types of Anodes - Platinum

There are many shapes and configurations for platinum anodes. This includes wire, rods, tubes, mesh, sheets, discs, etc. Platinum anodes are made of a substrate (base) material, such as niobium or titanium, with a very thin layer of platinum bonded to the substrate.

Types of substrates typically used:

- Niobium with copper core - Niobium is an excellent substrate as it is resistant to electrical breakdown. However, it is a poor conductor and very expensive. A copper core is used to reduce the /cost and improve electrical conductivity. A platinum anode layer (measured in microinches) is bonded to the niobium substrate. The platinum is the part of the anode assembly that produces CP current. Niobium is available in 20% or 40%. 40% is usually used in anode diameters of 1/16" to 3/4" diameter.
- Titanium - Not used as commonly, titanium is subject to electrical breakdown in DC voltages exceeding approximately 8 volts. While structurally strong, titanium is not as expensive as niobium but is also a poor electrical conductor. The platinum layer is applied in the same manner as with niobium.

While platinum is an excellent anode material, the cost can be very high. However, it only takes microinches to be effective and is most often used in fresh or seawater applications, not soil. Platinum can be applied to selected areas of a substrate. This is usually done in probe anodes when there is no need to coat the entire anode rod with platinum. In other cases, such as small-diameter wires, the whole length of the wire is coated with a layer of platinum.

There are many ways to connect a cable to a platinized anode, but the method depends on the configuration or shape of the anode.

Types of Anodes - Sacrificial

THERE ARE THREE TYPES OF SACRIFICIAL ANODES

MAGNESIUM ALLOY

- Voltage potential ranging from -1.55 to -1.80 (standard or high potential) and a consumption rate of 17 lbs/amp year.
- Magnesium anodes have a higher "driving voltage" and can produce more DC current than zinc or aluminum anodes of a similar size. However, there are conditions where that amount of DC current is not required, such as seawater, where a lower potential anode (zinc or aluminum) will provide adequate amounts of DC current.

ALUMINUM ALLOY

- Voltage potential of -1.10 and a consumption rate of 7 lbs/amp year.

ZINC ALLOY

- Voltage potential of -1.10 and a consumption rate of 26 lbs/amp year.
- Zinc and aluminum have similar driving voltages (-1.1). However, based on their respective consumption rates, aluminum is three (3) times more efficient (lasts longer) while providing the same driving potential and resultant current.
- On the other hand, zinc anodes will "passivate" or stop working in temperatures over 120° F. Therefore, zinc anodes may not be a good choice for oil field vessels where high temperatures are routinely encountered.

Affects of Weight & Length of Magnesium Anodes

THE WEIGHT & LENGTH OF MAGNESIUM ANODES AFFECTS CP SYSTEM LIFE & PERFORMANCE

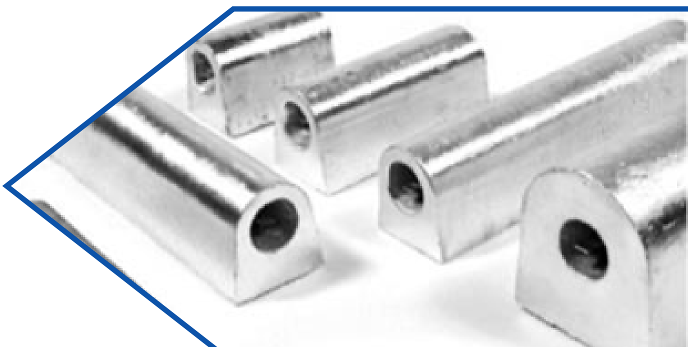
Key Facts

- Longer anodes produce more current than shorter anodes. Anode resistance-to-earth is primarily controlled by the anode length.
- Doubling the diameter of the anode will increase the volume (weight) by a factor of 4; yet, will only increase the current output approximately 15%.
- Greater anode weight (volume) increases the anode or system life.
- Surface area of the anode is not as important as some people believe.
- High potential anodes will always generate more current than a standard potential anode given the same resistance-to-earth.

Myths

Almost a Myth - System life can be calculated by using the published deterioration rate of 17 lbs. per ampere year. This is a good start, but anodes, as they consume, will become physically smaller, therefore producing less current. For that reason, we always include a “utility factor” when calculating anode life. If basic calculations require 100 lbs. of anode material, specify a minimum of 130 lbs. of anode material, a 1.3 to 1 utility factor.

Full Myth - Installing two anodes will double the current output. Not true. In most instances, it will be less than double. The distance between the anodes will affect how much total DC current the system can provide. The farther apart the anodes are spaced from each other, the better.



Affects of Weight & Length of Magnesium Anodes

The chart demonstrates the effect of various physical anode sizes to current output & service life.

Anode Characteristics Comparison

Diameter - In.	Length - in.	Res-to-Earth in 1000 Ω-cm Soil	Calc. Current Output Amps.
1	30	9.4Ω	0.080
2	30	7.9Ω	0.095
3	30	7.1Ω	0.106
4	30	6.4Ω	0.117
1	60	5.4Ω	0.139
2	60	4.7Ω	0.160
3	60	4.3Ω	0.174
4	60	4.0Ω	0.188

Note*: The lower the Res-to-Earth, the higher the current output achieved by the anode.*

Example 1
1” X 60” anode can generate **0.139 amps**
2” X 30” anode can generate **0.095 amps**

Note*: The 1” anode is half the weight and twice the length of the 2” anode, yet they have identical surface areas.*

Example 2
1” X 60” anode can generate **0.139 amps**
4” X 30” anode can generate **0.117 amps**

Note*: The 1” anode generates more current and has 1/8 the volume (weight)with half the surface area of the 4” anode.*

Affects of Weight & Length of Magnesium Anodes

THE WEIGHT & LENGTH OF MAGNESIUM ANODES AFFECTS CP SYSTEM LIFE & PERFORMANCE

Key Facts

- Longer anodes produce more current than shorter anodes. Anode resistance-to-earth is primarily controlled by the anodes length.
- Doubling the diameter of the anode will increase the volume (weight) by a factor of 4; yet, will only increase the current output approximately 15%.
- Greater anode weight (volume) increases the anode or system life.

- Surface area of the anode is not as important as some people believe.
- High potential anodes will always generate more current than a standard potential anode given the same resistance-to-earth.

Myths

Almost a Myth - System life can be calculated by using the published deterioration rate of 17 lbs. per ampere year. This is a good start, but anodes, as they consume, will become physically smaller, therefore producing less current. For that reason, we always include a "utility factor" when calculating anode life. If basic calculations require 100 lbs. of anode material, specify a minimum of 130 lbs. of anode material, a 1.3 to 1 utility factor.

Full Myth - Installing two anodes will double the current output. Not true. In most instances, it will be less than double. The distance between the anodes will affect how much total DC current the system can provide. The farther apart the anodes are spaced from each other, the better.

Determining the Number of Anodes Needed to Protect a Pipeline

While anode manufacturers provide suggestions, a sound Cathodic Protection (CP) solution requires an engineer to make a determination.

To provide an accurate answer, the following information is needed:

- Structure size (length, diameter, and height
- Coating performance details
- Service environment (freshwater, seawater, soil, etc.)
- Operating temperature
- Desired CP system service life

Installing Anodes in Tanks or Vessels

CURRENT CONSIDERATIONS
The DC current does not 'travel' around corners or through walls. Depending on the type of vessel, there may be "baffles" or walls inside the vessel. If an anode is installed in one compartment, the DC current will not likely reach another compartment within the same vessel.

As an analogy, you can install an air conditioner unit in the bedroom, but the cool air will not likely provide much of a benefit in the kitchen. Such is the case with Cathodic Protection current.

DC current travels the path of least resistance and may have little or no positive influence on locations in a vessel separated by walls or similar structures.

THE TANK BOTTOM
When an exterior of a tank bottom requires Cathodic Protection, several issues must be considered.

ON THE GROUND
When the bottom of a tank is sitting directly on the ground, anodes can be installed around the circumference of the tank. Current from those anodes will protect the tank bottom because there are no dielectric barriers. CP current can reach and will protect the bottom of the tank.

POLYETHYLENE MEMBRANE
If a polyethylene membrane (for leak control) is below the steel tank bottom, anodes installed outside of that membrane cannot pass CP current through the membrane to protect the bottom. The membrane acts as a dielectric insulator. The only CP system that will work is one that is between the membrane and the tank bottom.

OILED SAND BASE
If the tank is installed on top of an oiled sand base, the oil acts as a dielectric barrier similar to the membrane preventing the CP current from passing through the oiled sand to protect the steel bottom.

SECONDARY (ADDITIONAL) TANK BOTTOM
When the bottom of a tank has failed, a new steel bottom is sometimes installed above an old, leaky bottom. Sand is usually placed between the old, leaky bottom and the new bottom to form a cushion for the new bottom. In this case, the old steel acts as a barrier while still electrically connected to the new bottom.

Installing Anodes in the Ground

HOW DEEP TO INSTALL ANODES
As a general rule, bury the anode at least to the depth of the structure to be protected, or deeper if possible. The deeper the anode, the more likely the soil will remain moist, suitable for anode performance.

DISTANCE FROM STRUCTURE
Anodes are typically buried at least three (3) feet, and more is usually better. Positioning the anode farther from the structure allows better current distribution.

POSITION OF ANODE
Whether vertical or horizontal, the anode will perform the same.

DISTANCE BETWEEN ANODES IN A DISTRIBUTED BED
When installing multiple anodes in a "distributed bed," they should be placed ten (10) feet apart. This is because anodes work better when set farther apart. When positioned closer, they tend to "fight" each other, thereby reducing anode output.

BACKFILLING ANODES – NATIVE SOIL VS. SAND
Native soil should be used to bury the anode. Sand is a high-resistance backfill.

Installing Anodes in the Ground

INSTALLING PREPACKAGED MAGNESIUM ANODES

When installing prepackaged magnesium anodes in the ground, the anode should be "wetted" before backfilling. Rather than submerging the anode in water, spraying a generous amount (5 gallons at least) of water around the anode after it's positioned in the hole or excavation is best. This will allow water to soak into the anode backfill and surrounding soil. Adding water lowers the circuit resistance of the anode installation. Reducing the circuit resistance allows the anode to produce more current.

ANODES IN LAND OR WATER

Anodes installed in free-flowing water perform better than anodes covered in mud or silt. The reason is that water of any kind is less resistive than mud or silt despite there being mud or silt in the water. With less resistance, anodes can provide a greater amount of protective current.

When protecting underwater structures, there are times when anodes are installed at the bottom of the body of water (ocean, bay, lake, river, etc.). Since there is usually a layer of mud or silt on the bottom, the anodes sink into that layer or are covered by mud or silt over time. When that happens, the anode current output is reduced.

If the anodes cannot be kept above the mud/silt layer, then other methods are used to increase anode current output. These methods include increasing the number of anodes or using longer (more surface area) anodes to increase output.

PIPES & PIPELINES

Next on our journey, we'll dive into the intricate maze of Pipelines. Hidden beneath our cities, suburbs and rural landscapes, these unseen arteries weave a complex web that allows us to live our daily lives in comfort. Demanding our care and protection, every pipeline and many other steel structures have a unique and fascinating story. Join me as we uncover the mysteries of the submerged!

PIPES AND PIPELINES

Pipes – OD or ID? How to Take an Accurate Pipe Measurement

Accurate communication is key to minimizing errors in system designs and material supply.

Take pipes, Cathodic Protection (CP) systems are designed for many different types and sizes of pipe. In the design, it is common to specify certain types and sizes of pipe fittings, such as an insulated pipe union, to produce an effective and efficient CP system. To accurately measure and order pipes and accessories, it is important to follow ANSI Pipe Schedule Standards.

Pipe Measurement Miscommunication Example

CONVERSATION 1:
Customer calls the supplier to order insulated pipe unions. Supplier confirms stock and asks for size. Customer 'measures' the pipe and orders 2" unions.

CONVERSATION 2: ONE WEEK LATER
Customer calls the supplier to report that the fittings are too large.

WHAT HAPPENED?
In this case, the customer measured the outside diameter of the pipe and ordered based on a 2" pipe. The actual outer diameter (OD) of a 2" pipe is 2.375", while the inside diameter (ID) is more likely 2". The customer measuring the pipe was thinking of actual inch values instead of the actual ANSI nominal pipe size. It is difficult to accurately measure a round pipe by holding a tape measure across it. 2" would be very close to the actual OD of a 1 ½" (nominal) pipe size, not a 2" pipe. Therefore, 2" nominal fittings would be too large for the pipe measured.

This issue occurs in many industries and can result in project problems.

Pipes – OD or ID? How to Take an Accurate Pipe Measurement

HOW TO MEASURE

The best way to measure the OD of a pipeline is to wrap a measuring tape around the pipe to measure the pipe's circumference. Then, divide the circumference by 3.1416 to obtain the actual OD of the pipe.

Once you have that number, you must look up the "nominal" pipe size on the ANSI Pipe Schedule Table (below) to determine the actual ANSI pipe size.

HISTORY OF PIPE SIZING

Pipe sizes can be confusing because today's terminology relates to historical dimensions.

Around 1930, the pipe industry standardized sizes for pipes. At the time, all pipes had an ID (inside diameter) that was the same as the designated pipe size, i.e., a 2" pipe actually had an ID of 2". Yet, this pipe's OD (outside diameter) was 2.375". Given the metallurgy technology of the time, this was the dimension required for a standard low-pressure pipe.

As time progressed, there was a need for higher-pressure pipe. Rather than increase the OD, the decision was made to maintain the same OD and increase the wall thickness, which reduced the ID. With this scheme, all the threaded fittings of a given size pipe would be compatible. In time, the metallurgy improved, allowing manufacturers to build pipes with thinner wall thickness while retaining the pressure rating. The consequences of the evolution in pipe technology resulted in pipe sizes that are now a name rather than a descriptive term. In fact, the term "nominal," which is the current way of defining pipe sizes, means "in name only."

Today, the OD is fixed for a given pipe size, and the ID will vary depending on the wall thickness of the pipe. Therefore, a higher-pressure rated pipe will have a heavier wall thickness, represented by Schedule Rating. The higher the Schedule, the heavier the pipe's wall thickness and pressure rating. For example, a 2" Schedule 80 pipe has a thicker wall and, therefore, a smaller inside diameter as compared to a 2" Schedule 40 pipe. Interestingly, all of the above confusion is non-existent in pipes that are 14" and above.

(cont.)

Pipes – OD or ID, How to Take an Accurate Pipe Measurement?

ANSI (AMERICA NATIONAL STANDARDS INSTITUTE) PIPE SCHEDULE TABLE

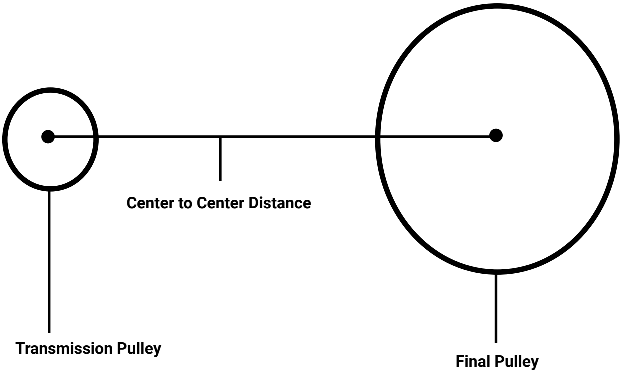
NOM.	O.D.	LEGEND	5	10	20	30	40	STD	60	80	XH	100	120	140	160	XXH
1/8"	.405"	AVG	.035	.049			.068	.068		.095	.095					
		LBS/FT	.1384	.1865			.2450	.2450		.3148	.3148					
1/4"	.540"	AVG	.049	.065			.088	.088		.119	.119					
		LBS/FT	.2572	.3301			.4252	.4252		.5356	.5356					
3/8"	.675"	AVG	.049	.065			.091	.091		.126	.126					
		LBS/FT	.3279	.4239			.5681	.5681		.7395	.7395					
1/2"	.840"	AVG	.065	.083			.109	.109		.147	.147				.188	.294
		LBS/FT	.5385	.6717			.8518	.8518		1.089	1.089				1.310	1.716
3/4"	1.050"	AVG	.065	.083			.113	.113		.154	.154				.219	.308
		LBS/FT	.6844	.8580			1.132	1.132		1.475	1.475				1.945	2.443
1"	1.315"	AVG	.065	.109			.133	.133		.179	.179				.250	.358
		LBS/FT	.8686	1.405			1.681	1.681		2.174	2.174				2.846	3.662
1-1/4"	1.660"	AVG	.065	.109			.140	.140		.191	.191				.250	.382
		LBS/FT	1.108	1.807			2.275	2.275		2.999	2.999				3.768	5.219
1-1/2"	1.900"	AVG	.065	.109			.145	.145		.200	.200				.281	.400
		LBS/FT	1.275	2.087			2.720	2.720		3.635	3.635				4.863	6.414
2"	2.375"	AVG	.065	.109			.154	.154		.218	.218				.344	.436
		LBS/FT	1.605	2.640			3.656	3.656		5.027	5.027				7.469	9.037
2-1/2"	2.875"	AVG	.083	.120			.203	.203		.276	.276				.375	.552
		LBS/FT	2.477	3.534			5.798	5.798		7.668	7.668				10.02	13.71
3"	3.500"	AVG	.083	.120			.216	.216		.300	.300				.438	.600
		LBS/FT	3.032	4.336			7.583	7.583		10.26	10.26				14.34	18.60
3-1/2"	4.000"	AVG	.083	.120			.226	.226		.318	.318					.636
		LBS/FT	3.475	4.977			9.118	9.118		12.52	12.52					22.87
4"	4.500"	AVG	.083	.120			.237	.237	.281	.337	.337		.438		.531	.674
		LBS/FT	3.919	5.619			10.80	10.80	12.67	15.00	15.00		19.02		22.53	27.57
4-1/2"	5.000"	AVG						.247			.355					.710
		LBS/FT						12.55			17.63					32.56
5"	5.563"	AVG	.109	.134			.258	.258		.375	.375		.500		.625	.750
		LBS/FT	6.355	7.777			14.63	14.63		20.80	20.80		27.06		32.99	38.59
6"	6.625"	AVG	.109	.134			.280	.280		.432	.432		.562		.719	.864
		LBS/FT	7.593	9.298			18.99	18.99		28.60	28.60		36.43		45.39	53.21
7"	7.625"	AVG						.301			.500					.875
		LBS/FT						23.57			38.08					63.14
8"	8.625"	AVG	.109	.148	.250	.277	.322	.322	.406	.500	.500	.594	.719	.812	.906	.875
		LBS/FT	9.923	13.41	22.38	24.72	28.58	28.58	35.67	43.43	43.43	51.00	60.77	67.82	74.76	72.49
9"	9.625"	AVG						.342			.500					
		LBS/FT						33.94			48.77					
10"	10.750"	AVG	.134	.165	.250	.307	.365	.365	.500	.594	.500	.719	.844	1.000	1.125	
		LBS/FT	15.21	18.67	28.06	34.27	40.52	40.52	54.79	64.49	54.79	77.10	89.38	104.2	115.8	
11"	11.750"	AVG						.375			.500					
		LBS/FT						45.60			60.13					
12"	12.750"	AVG	.165	.180	.250	.330	.406	.375	.562	.688	.500	.844	1.000	1.125	1.312	
		LBS/FT	22.20	24.19	33.41	43.81	53.57	49.61	73.22	88.71	65.48	107.4	125.6	139.8	160.4	
14"	14.000"	AVG		.250	.312	.375	.438	.375	.594	.750	.500	.938	1.094	1.250	1.406	
		LBS/FT		36.75	45.65	54.62	63.50	54.62	85.13	106.23	72.16	131.0	150.9	170.4	189.3	
16"	16.000"	AVG		.250	.312	.375	.500	.375	.656	.844	.500	1.031	1.219	1.438	1.594	
		LBS/FT		42.09	52.32	62.64	82.85	62.64	107.6	136.7	82.85	165.0	192.6	223.9	245.5	
18"	18.000"	AVG		.250	.312	.438	.562	.375	.750	.938	.500	1.156	1.375	1.562	1.781	
		LBS/FT		47.44	58.99	82.23	104.8	70.65	138.3	171.1	93.54	208.2	244.4	274.5	308.8	
20"	20.000"	AVG		.250	.375	.500	.594	.375	.812	1.031	.500	1.281	1.500	1.750	1.968	
		LBS/FT		52.78	78.67	104.2	123.2	78.67	166.6	209.1	104.3	256.3	296.6	341.4	379.4	
22"	22.000"	AVG		.250	.375	.500		.375	.875	1.125	.500	1.375	1.625	1.875	2.125	
		LBS/FT		58.13	86.69	114.9		86.69	197.6	251.0	114.9	303.2	353.9	403.4	451.5	
24"	24.000"	AVG		.250	.375	.562	.688	.375	.969	1.219	.500	1.531	1.812	2.062	2.344	
		LBS/FT		63.47	94.71	140.8	171.5	94.71	238.6	296.9	125.6	367.5	429.8	483.6	542.6	

Center-to-Center Dimension

The term used for measuring the distance between two circles, holes, or other round objects, is center-to-center. This is the dimension or distance from the center of one circle to the center of a second circle.

For example: If a customer wants multiple conduit openings at the bottom of an anode junction box, we need to know the center-to-center dimension of those openings to ensure the conduit holes are in the correct position. In addition, we need to know the conduit size to provide the appropriate opening for the conduit.

The same methodology is used for other needs, such as the distance between two pulleys, gears, columns and more. As the diameter of circles can vary, the center ocation is used as the constant when measuring between two or more circles.



Protecting Miles of Underground Pipelines with Anodes & Coatings

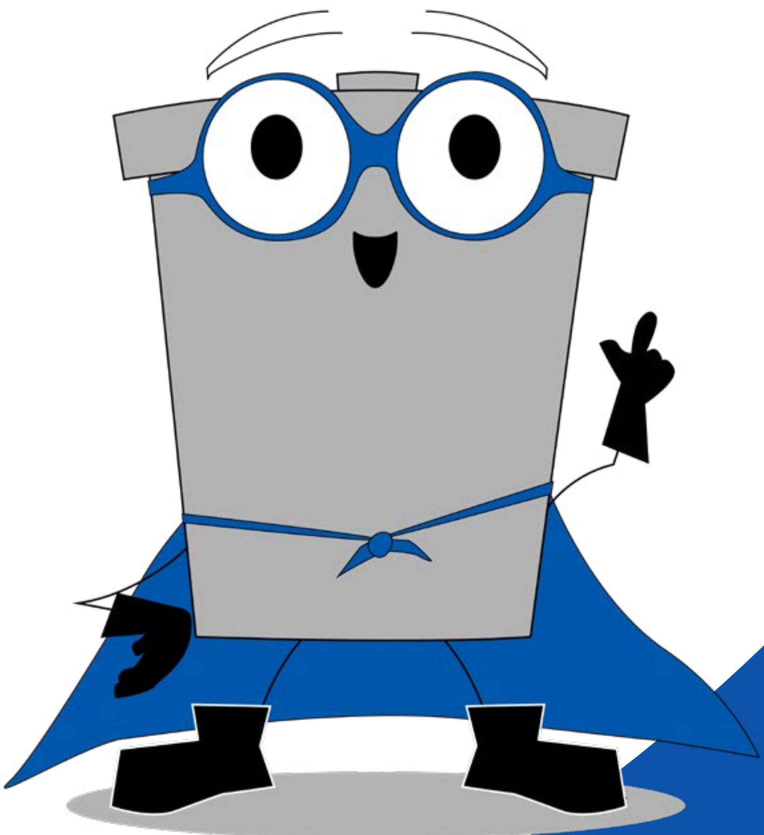
When Cathodic Protection (CP) is applied to a pipeline or other metallic structure, only the bare metal exposed to soil or water is protected by CP. Metal covered by a coating is effectively shielded from the soil or water so corrosion cannot occur.

If a pipeline is extremely well coated with one of today's "modern" coatings (like FBE/ fusion bonded epoxy), there is very little bare metal to be protected. Since there is so little bare metal, the need for protective CP current is minimal. As a result, magnesium anodes are an ideal solution for adequate protection.

Another important consideration is the effective electrical isolation of the pipeline. The well-coated pipeline MUST be electrically isolated from all other metallic structures. Without effective isolation, more metal is exposed, and the current requirement increases. As a result, the likelihood of using a few magnesium anodes diminishes.

RECTIFIERS & POWER SUPPLIES

Charge up your curiosity and join me in the powerful world of Rectifiers & Power Supplies! These unsung heroes of Cathodic Protection work tirelessly, converting energy and directing DC power with precision. Whether protecting pipelines, tanks, or offshore, their role is as fascinating as vital. Join me as we illuminate the magic behind these power players!



Diagnosing and Repairing a Broken Rectifier

Common rectifier problems are often misdiagnosed. Despite zero output current while the rectifier indicates some level of output voltage, it is likely that the rectifier is in working order. A broken or "open" cable or connection in the positive (anode) circuit and/or the negative (structure) output circuit could be the problem.

UNDERSTANDING RECTIFIERS

Most Cathodic Protection (CP) rectifiers produced today are extremely reliable. Yet, like any manmade device, failures can and will occur. In some instances, CP rectifiers will continue to operate despite component failure.

Most CP rectifiers in service today are air-cooled, single-phase transformer units. While they may appear complicated to provide the needed DC current for Cathodic Protection to a steel structure, there are only two components required to have a fully functional rectifier:

- Step-down transformer - to reduce the incoming AC power to a lower, usable voltage
- Diode or rectifier stack - four diodes configured into a "full-wave bridge" rectifier stack

In most CP rectifiers, there will be circuit breakers, surge suppressors, meters, component frames, panels and an enclosure. Understanding the purpose and function can help a CP technician properly maintain and troubleshoot the rectifier.

The more components in a rectifier, the greater the chance of a failure. Some failures completely disable the rectifier, while other failures have little or no effect on the actual capability of the unit to produce current. An example would be a defective meter or broken meter switch.

RECTIFIER FAILURE

For example, an operator has a rectifier operating at 20 volts and 20 amps for an extended time. Suddenly, the unit begins operating at 10 volts and 10 amps. While not completely broken, it is not operating as normal.

Two conditions (below) can cause this issue. Changes to the tap settings or reconfiguring the transformer primary AC input will not fix the problem.

Diagnosing and Repairing a Broken Rectifier

POSSIBLE CAUSES

- The AC input voltage has reduced by 50% (unlikely). Checking the AC input voltage to the rectifier would eliminate this unlikely situation.
- One of the four rectifier stack diodes has failed in an “open” condition (most likely). The rectifier still operates but in a “half-wave” condition, thus only producing half the voltage output and half the current output.

Troubleshooting the diode stack will not be covered in this tip. However, there is an easy way to confirm that there is an open diode. Simply measure the output frequency in Hertz (Hz). (Wait! This is a DC rectifier so it should not have an output frequency, shouldn’t it?). Actually, the typical full-wave bridge does not provide true DC output. Instead, it is a “unidirectional cycling voltage.” Therefore, it has an “AC component” to the DC output.

See the waveforms below. A normally operating rectifier will have an output frequency of 120 Hz. In the case of an open diode, the output frequency will be only 60 Hz. Most digital multimeters (DMM), as well as clamp-on ammeters, can measure frequency in Hz.

When using a DMM to test this possibility, set the meter to measure “DC volts” and connect the test leads across the output lugs of the rectifier. Press the Hz button to read the output frequency of the rectifier.

When using a DC clamp-on instrument, measure the output in DC amps. At the same time, press the Hz button or switch the meter to the Hz function and read the output frequency.

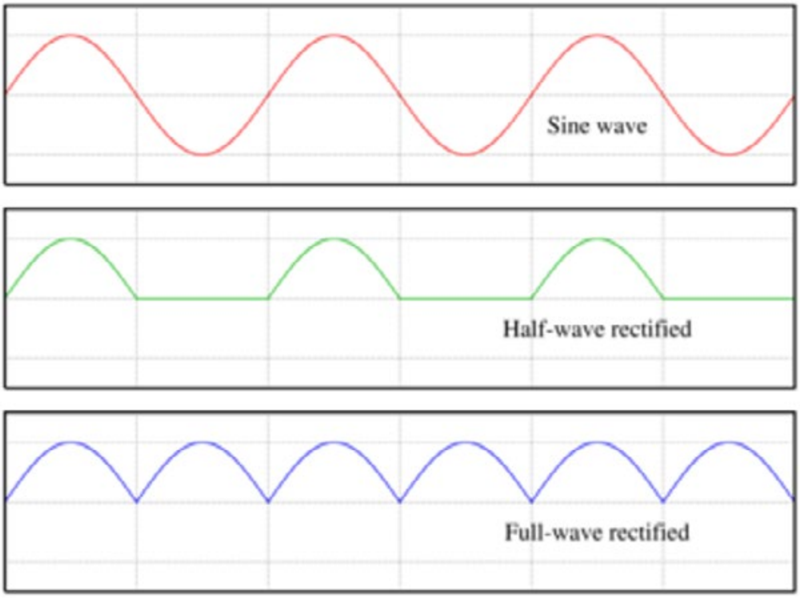
Correcting this issue will require replacing one or possibly two diode(s). With this fix, your rectifier will fully function again.

Diagnosing and Repairing a Broken Rectifier

60 Hz AC

60 Hz half wave

120 Hz full wave



DETERMINING THE SOURCE OF THE PROBLEM
Failures in the DC output circuit are rare. When they do happen, they can occur suddenly. One day the system works fine, and you have an open circuit the next. The following are checkpoints:

- With a portable multimeter, confirm that there is some level of output voltage. Rectifier meters can "stick," providing incorrect information.
- Check the millivolt drop on the rectifier current shunt. The ammeter could be defective while everything else is okay.

If the output voltage is confirmed and the millivolt reading on the rectifier shunt is zero, there is an open circuit in the anode and/or structure circuit. Conduct the following checks:

- Check all mechanical cable connections on both the positive (anode) and negative (structure cables) to ensure they are tight. Loose connections can eventually become an open circuit.
- Check the area for evidence of any excavation, specifically in the vicinity of the underground CP cables. A backhoe or other excavator can unknowingly destroy both cables.

Diagnosing and Repairing a Broken Rectifier

- *Look for evidence of gophers or moles in the area. These critters love to chew* on underground cable insulation. Any compromise in the cable insulation on an underground positive (anode) cable will result in a cable failure in just a matter of days. The bare copper acts as a local anode, and failure is imminent.

There are many physical configurations of CP systems. Variations in the location of the anode bed, the type of anode construction (deep well or shallow), and the method of connection to the structure must be considered when selecting a testing method.

TEST METHOD 1
This test method applies to a CP system that includes a deep well anode system, anode junction box and an above-ground appurtenance, electrically common with the protected structure. For this example, we will assume that the indicated voltage output of the Rectifier is about 10 Volts.

- With the rectifier “ON,” measure the DC voltage between points A & C and B & D.
- If the positive (anode) cable is broken, the readings would be:
    - A & C – Approximately 9 Volts
    - B & D - 0 Volts
- If the structure cable is broken, the readings would be:
    - A & C - 0 Volts
    - B & D – Approximately 9 Volts
- If both cables are broken, you will likely obtain many voltage readings that do not make sense. Therefore, Methods 2 & 3 will help.

TEST METHOD 2
In this instance, no above-ground connection points exist for either anode or structure cables.

- Switch “OFF” the rectifier.
- Find or establish an electrically isolated temporary test electrode/anode. This can be any number of structures, including a chain link fence, barbwire fence with metal posts, a metal signpost or similar. If these are not available, you can drive a metallic test rod into the soil, like the one depicted in the drawing.

Diagnosing and Repairing a Broken Rectifier

- Important Note: *The test rod should be driven to a depth of at least 18" to 24" to be effective.*
- To test the anode cable, connect a test cable between points A & E.
- While watching the rectifier ammeter, switch "ON" the rectifier. Watch for any amount of current output. Note that it will be a small amount. If any current output is indicated, this confirms that the anode (positive) cable is broken and the structure (negative) cable is okay.

If the test results indicate zero current output when the temporary anode/electrode is connected, it can mean:

- The structure cable is broken OR
- Both the anode and the structure cables are broken. You must now test the structure (negative) cable.
- Connect a test cable between points B & E.
- While watching the rectifier ammeter, switch "ON" the rectifier.
- If any current output is indicated, this confirms that the structure (negative) cable is broken, and the anode (positive) cable is okay.

TEST METHOD 3

If the above tests indicate that both the positive and negative cables are broken, conduct the following test:

- Switch "OFF" the rectifier.
- Connect a test cable between points A & E.
- Connect a test cable between point B and the rectifier enclosure ground lug (not indicated on the drawing).
- While watching the rectifier ammeter, switch "ON" the rectifier. You will be looking for any amount of current output. In this case, if any current output is indicated, this confirms that the anode (positive) cable AND the structure (negative) cables are both broken.

(cont.)

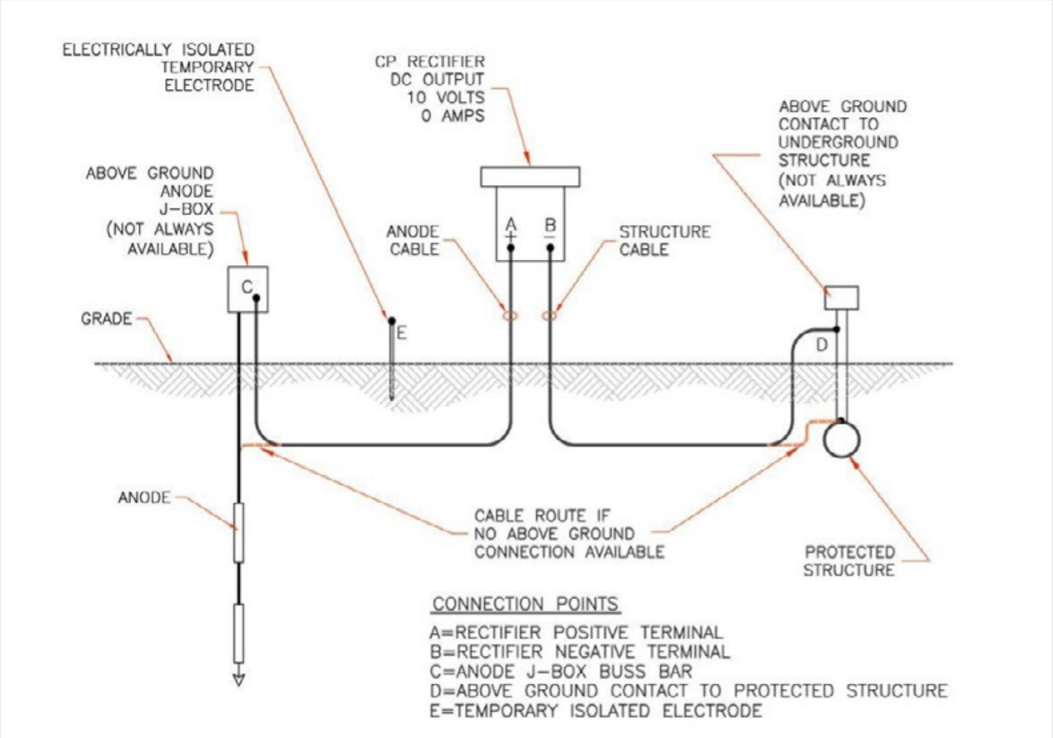


FIGURE 1

Overcoming Rectifier Adjustment Issues

IMPROPER RECTIFIER SIZING

SITUATION
A new, deep well anode CP system and a standard, air-cooled CP rectifier were installed on a pipeline. Before installation, current requirement tests were conducted. Test results indicated that rectifier output of 36 to 40 DC Amperes would be required to achieve proper protection levels.

HARDWARE DESCRIPTION

- 450' deep anode well with 20 cast iron anodes in coke breeze
- New CP rectifier with a DC output rating of 50 volts and 50 Amperes with a "standard" voltage adjustment tap configuration of 3 Coarse and 6 Fine settings
- AC input rating of the rectifier is 115/230 volts, 1 phase, 60 Hz

SYSTEM START-UP/ENERGIZING THE RECTIFIER

- Installation - Checked the entire CP system to ensure proper installation techniques.
- Power - Confirmed that AC power is available to the rectifier.
- Tap Settings – Confirmed that the tap setting was set to Coarse 1 and Fine 1.

INITIAL RECTIFIER START-UP RESULTS
When attempting to achieve the target range of 36 to 40 amps, the following occurred:

- Tap setting C1-F3 provided current output of 33 amps (not enough current)
- The next setting, C1-F4, provided current output of 45 amps (too high)

DIAGNOSIS
The anode well and cabling had a very low total resistance (less than 0.25 ohms), which is common. This is good for CP efficiency but can be a problem.

Overcoming Rectifier Adjustment Issues

A 50V-50A rated rectifier with the standard 3 Coarse and 6 Fine tap settings (total of 18 steps) yields approximately 2.8 volts differential between each tap change. With a 0.25-ohm circuit resistance, the current output change between tap settings is approximately 11 amps.

Options

OPTION 1 (NOT RECOMMENDED)
Install a resistor to the DC output to increase the system circuit resistance.
Likely Result: With a relatively high current requirement, installing a series resister is inefficient and will consume 50 to 60 watts of (wasted) power. The resistor would require a separate enclosure. With materials and labor, this modification would be a costly (multi-thousand dollar) 'Band-Aid.'

OPTION 2
Remove and replace the rectifier with one that has the proper output voltage rating. In addition, it would be advisable to increase the number of Coarse and Fine taps.
Likely Result: In this case, a 12V-50A rectifier with 5 Coarse and 5 Fine taps would provide 25 steps of adjustment. This would provide approximately 0.5 volts and 2.0 amps between tap settings.

OPTION 3
Reconfigure the existing rectifier to a 25V-50A rectifier in less than 5 minutes.
Likely Result: If the existing rectifier is manufactured with a dual AC input voltage rating of 115/230, you are in luck. Simply reconfigure the primary AC input voltage links to operate the rectifier on 230 VAC AND reconfigure (if required) the actual AC input power to provide 115 VAC.

Note: *Not recommended for rectifiers that contain electronic control boards i.e., constant current, constant potential or any other electronic control features.*

The rectifier is now only receiving half the input voltage than before. Therefore, the total DC output voltage would also be half of the rated output of the rectifier.

Explanation: With this option, the rectifier will operate like a 25V–50A unit. This change now provides approximately 1.4 volts between and 5.6 amps per tap setting change. With the taps set at C2 & F1, the output would be about 39 amps.

Even with the reconfigured 25-volt output rating, the rectifier still has a large current change between taps. If the pipeline had a low current requirement, it still might have been a problem, even with the reconfiguration. As mentioned in Option 2, a 12-volt output rating with additional taps would have been a better selection and application.

Overcoming Rectifier Adjustment Issues

Option 3 will not damage the rectifier. Unlike a motor that would be damaged with the low input voltage, a CP rectifier transformer is simply a voltage conversion device. Because the reconfigured rectifier can only put out half of its rated power, the maximum rated current of the transformer primary will not be exceeded.

ROOT CAUSE OF IMPROPER RECTIFIER SIZING

The issue discussed here occurs when the CP designer does not know the final system circuit resistance required. Therefore, to be safe, the designer will order a rectifier with a conservatively high DC voltage output rating.

The best way to ensure the proper rectifier output rating is specified is to conduct on-site field tests after installing the anode system. A qualified CP Technician is needed to conduct the tests after installing the deep well anode system. The downside of this method is that the completion of the project is now on hold until the proper rectifier can be built, delivered and installed, which might take up to 12 weeks. This is often considered unacceptable because it extends the project and ultimately increases the project costs.

To avoid project delays waiting on a rectifier to be built, many CP operators will purchase and store rectifiers for future CP installation projects. To “standardize” their inventory, they purchase a single output rating, typically 50V-50A. In this case, the “one size fits all” approach did not work.

CONCLUSION

A proper CP design requires many considerations. Guessing can be costly and frustrating. As illustrated above, proper testing is recommended. Conferring with a CP expert can also help. In the case of the rectifier, ordering a model with a high number of tap adjustments is always a good idea, and the 25-step example is a good start.

New CP power supplies are now available that can overcome these output issues. The Farwest DCPro is an advanced CP power supply that can provide as many as 500 ‘steps’ of current adjustment. With the DCPro, you can order a 50V-50A output rating, have it shipped in a matter of days and eliminate all the adjustment issues discussed.

Checking/Testing CP Rectifier Diodes

Cathodic Protection Power Supply or Rectifier problems can cause Cathodic Protection (CP) system failures 58% of the time. When troubleshooting a failed CP rectifier, the most common problem occurs with the rectifier stack. (Rectifier failure causes: Rectifier Diode Stack – 85%; Meters, Breakers, Fuses – 12%; Transformers, Chokes – 3%).

STACK TYPES

Conventional transformer-type rectifiers have a single-phase, full-wave silicon stack with manual tap control. Selenium stacks require a different test method.

DIODE FUNCTIONS

A diode is essentially an electronic “check valve.” This value allows current to flow in one direction and block it from the opposite direction. The symbol is the common symbol for a diode. As shown here, the current can flow from left to right but is blocked from right to left.

HOW TO TEST A DIODE OUTSIDE OF A RECTIFIER

Most Digital Multimeters (DMM) will have a “diode test” mode. It may share a space on the dial with another function. In the diode test function, the meter will provide a small, fixed amount of current through the diode being tested. The displayed value on the DMM is the voltage drop across the diode.

- Ensure the rectifier power is “OFF,” and all safety precautions and proper PPE are utilized.
- It is critical that the diode be isolated from the circuit to avoid parallel conductive paths. This may require disconnecting one end of the diode from the circuit. Methods specific to testing rectifier diodes are discussed below to elimate the need to physically disconnect the diode.
- Connect the DMM test leads on both sides of the diode and record the measurement displayed on the DMM. Then, reverse the test leads and record the measurement displayed again.
- A good diode will read from 0.450 to 0.800 volts “drop” in one direction and “open circuit” in the opposite direction. “OL” is the typical DMM display for open circuit conditions.
- When a diode fails, it will either fail in a shorted or open circuit condition.
- A “shorted” diode will display 0.000 volts in both directions.
- An “open” diode will display “OL” in both directions.

Checking/Testing CP Rectifier Diodes

TESTING DIODES IN A CP RECTIFIER FROM THE FRONT PANEL

Individual diodes can be tested from the rectifier front panel. This is a good option because physical access to the diode stack (as discussed above) can be challenging. In most air-cooled rectifiers, the diode stack assembly is located low and to the rear of the enclosure. With oil-cooled rectifiers, the diode stack is submerged in oil and rarely accessible without pulling the component rack up and out of the oil, which can be messy.

PREPARATION FOR TESTING

The diodes to be tested must be isolated from other circuit components. With a CP rectifier, this would include the main transformer, the anode or the structure circuits. The steps for isolating these components include:

- Verify that AC power to the rectifier is "OFF" and that power is locked and tagged out.
- Remove one of the voltage adjust tap link bars (coarse or fine) on the front panel to isolate the transformer.
- Disconnect either the positive or negative output cable from the output lug.
- Ensure that the AC secondary breaker is "ON." If a fuse is utilized instead of a circuit breaker, ensure that the fuse is installed and in working order (not "blown").

TESTING THE DIODES

Set the DMM to the "diode test" function. Ensure that your test lead cables are in good operating condition.

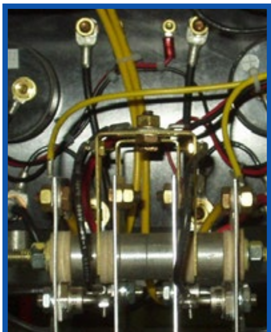
Refer to the test diagram and chart (below). A letter identifies each individual diode, as well as the test points:

- Diodes - A thru D
- Test Points - E thru H.

To test diode "A":

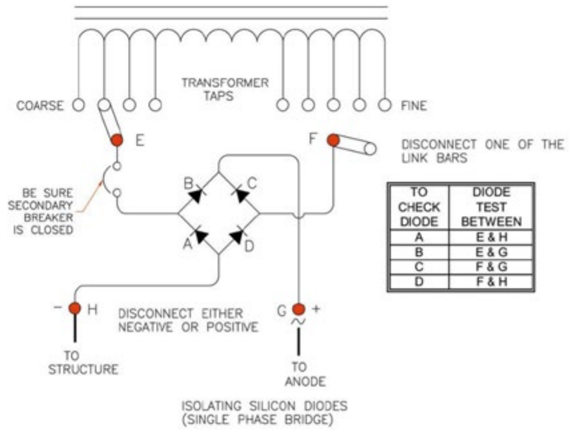
- Make contact to test points E & H with the DMM test leads. Read the DMM display and note the values.
- Reverse the test lead polarity on test points E & H.
  Read the display and note the values.

Diode "A" is in working order (good) when the reading is between 0.450 - 0.800 in one polarity and OL (open circuit) in the other polarity. A shorted diode will read 0.000 in both directions.



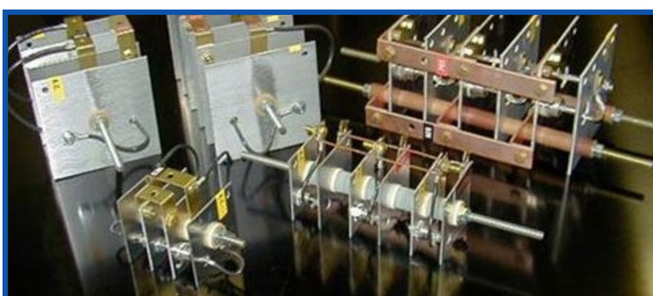
Checking/Testing CP Rectifier Diodes

To test diodes B, C & D, reference the chart below.



This method allows the testing of each diode without needing to access the physical component directly. This is a real benefit when troubleshooting crowded air-cooled or messy oil-immersed rectifiers.

CAUTION! Most silicon stacks will have surge arrestors installed in parallel with the AC input and DC output of the stack. The arrestor may be mounted directly on the stack or separately on the side of the stack. If this is the case and your tests indicate two shorted (bad) or more diodes, it is possible that the diodes are in working order (good), but the surge suppressor is shorted. At this point, you have no choice but to find a way to access the physical components for individual diode testing.



Selecting The Proper Rectifier Output Rating

OUTPUT VOLTAGE RATINGS

The DC output “ratings” for Cathodic Protection (CP) rectifiers refer to the DC output voltage and current capacity of the rectifier. Output voltage ratings are typically between 5 and 125 volts, while current ratings range between 5 and 400 Amperes.

CHOOSING THE CORRECT RATING

All CP rectifiers must have adjustable output ranges to provide DC current to the structure requiring protection. For instance, a rectifier with an output rating of 50 volts and 50 amps can be adjusted to operate at a much lower output, such as 5 volts and 2 amps. While possible, this is not ideal and is like having a car designed to travel at 200 MPH when you need to only travel at 5 MPH—obviously not a good match and certainly a waste of money.

While technicians may be required to specify the voltage and current output rating of a rectifier, many have no knowledge of the actual, site-specific requirements for the CP system. To properly specify a rectifier’s output rating, the following information is required:

- The actual DC current requirement for the pipeline or structure that is to be protected
- The resistance-to-earth of the impressed anode system (bed) that is to be powered by the rectifier.
- The length and size of the DC cables that will be used to connect the rectifier to the structure and anodes

Note: *The size and length of the cable will play a large part in determining voltage needs.*

- The available AC input power at the project site
    - Is the input voltage 120, 240, 480 volts, or something different?
    - Is the provided power single or three-phase?

The CP technician can calculate the appropriate rectifier output range with this information. When selecting this output range, it should be somewhat conservative and allow a for higher range in case of field changes. If it is determined that 20 volts, 10 amp output is required for the job, upsizing this by 20% may be prudent in case operating parameters change over time. This could include changes in anode bed resistance, coating performance, or adding more steel to the protected structure.

Selecting The Proper Rectifier Output Rating

Most CP rectifiers are manually adjustable, with a finite number of available output adjustments. Depending on the manufacturer, the standard number of rectifier tap adjustments includes 3 coarse and 6 fine settings. This provides a total of only 18 steps of adjustment over the rated voltage range. If the rectifier output range is too high for the application, control is limited, and you may not be able to adjust the rectifier to the exact output setting needed. Therefore, when ordering a manually controlled rectifier, it is wise to order a greater number of tap settings to allow more precise adjustment options in the field.

Rectifier Cabinets

WHAT TYPE OF RECTIFIER COOLING IS BEST? AIR OR OIL?

Cathodic Protection (CP) rectifiers generate heat due to the loss of energy as a result of converting AC power to DC. This is caused by the relative inefficiency of the internal components, such as the transformer and diodes. Therefore, this heat must be moved away from the rectifier components.

AIR-COOLED CABINETS

Air-cooled cabinets use the movement of cooler air across the rectifier components to cool the components. Called convection, warm air rises and escapes through upper cabinet vents and then pulls cool air into the cabinet via the lower cabinet vents. This removes the heat from inside the rectifier cabinet to the outside environment. This is the most common type of cooling used for CP rectifiers. However, as convection draws in outside air, it also brings with it dust and possibly damp, corrosive air that can cause corrosion, thereby aging rectifier components.

OIL-COOLED CABINETS

Oil-cooled cabinets use the movement of transformer oil to cool rectifier components. Similar to air-cooled units, as the oil is heated, it rises and moves across the components. The heat in the oil is then dissipated through the cabinet walls and cooling fins into the atmosphere. The oil also protects the rectifier components from dust and corrosion, so oil-cooled cabinets may be more practical in dusty or humid environments.

Oil-cooled rectifiers can be used in certain hazardous locations because any electrical arcing due to abnormal conditions in the rectifier is suppressed by the oil and is prevented from reaching the atmosphere.

Rectifier Cabinet Material & Finish

RECTIFIER CABINET MATERIALS
Steel is most often used for air-cooled rectifier cabinets due to its relative durability and cost. Aluminum and stainless steel are also available but at a greater cost. Oil-cooled cabinets are almost always (if not always) heavy-gauge steel for durability purposes.

CABINET FINISH
Many standard, air-cooled, steel CP rectifier cabinets utilize a hot-dipped galvanized (zinc) finish, that is very durable, but not extremely attractive. There are more attractive paint or FBE powder coating options that allow for color variations, which may be a need in city settings.

Aluminum cabinets are available in raw aluminum (not recommended), painted or FBE powder coated, and/or anodized.

Stainless steel cabinets are typically provided in raw metal due to the protective nature of stainless.

Rectifier Cabinet Mounting

COMMON AIR-COOLED RECTIFIER MOUNTING TECHNIQUES

Most air-cooled rectifier cabinets will mount on a steel pole or wood post, which is common in rural areas. Standard, air-cooled rectifier cabinets typically include a mounting channel that can be bolted to the pole or post, and the channel fits the contour of the pole or post for mounting ease.

This same cabinet configuration can be mounted to a wall or backboard instead of a pole or post. This is less common but is done in locations such as production facilities or similar.

Air-cooled rectifier cabinets can also be fitted with a mounting pedestal. This pedestal frame converts a pole or post mount cabinet to a free-standing cabinet, which is typically mounted to a concrete pad.

ORNAMENTAL MOUNTING

In more populated areas, CP rectifiers can be mounted inside a free-standing cabinet referred to as an "ornamental" or "decorative" cabinet. The standard factory cabinet is no longer required because the rectifier sub-frame mounts inside the ornamental cabinet. In addition, other components, such as a shunt panel or remote monitor can be included inside the cabinet, making for a nicer project appearance.

Farwest designed and offers the POWERHOUSEplus line of ornamental, air-cooled cabinets, which is a multifunction cabinet solution providing an AC input breaker, a power company watt-hour meter location, and an AC convenience outlet. The cabinet provides room for a CP rectifier, shunt board and a remote monitor. This configuration provides an orderly rectifier installation.

OIL-COOLED CABINET MOUNTING

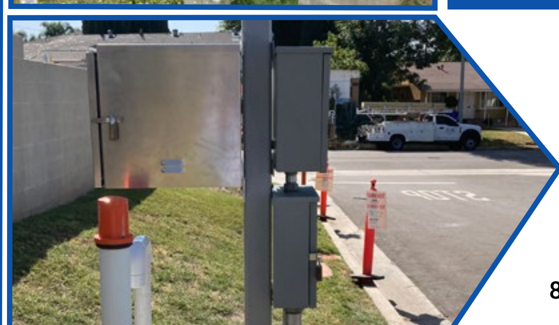
Oil-cooled cabinets are usually mounted to the ground in some fashion, typically on a concrete pad. Depending on the size of the cabinet, rectifier pads can be quite large and may require the use of a reinforcing bar or other structural support within the concrete. In some locations, a containment system may be required in the case of an unlikely transformer oil leak.

Solar Powered CP Solutions

Solar energy can be used to power impressed current Cathodic Protection systems. By converting light energy to DC power, the power source utilized for CP, a solar power supply can be designed for stand-alone power in remote locations.

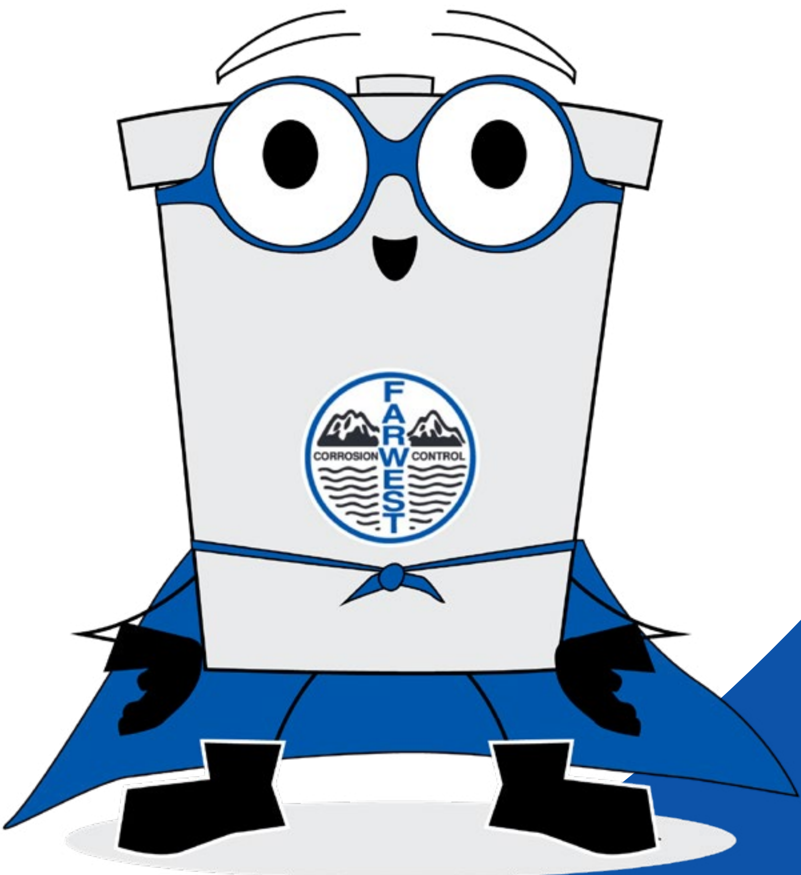
Depending on the amount of DC power required, the size of the solar power supply can range from a single solar panel to many panels arranged in an "array." The only limitation to power output is available space and cost.

In addition to anodes, coke breeze, cable and other components of a CP system, a solar-powered CP system will include the solar array, an output controller or regulator, batteries, a battery box and wiring.



ELECTRICAL CONNECTIONS

From vital junction boxes to electrical ratings, every element is an engineering wonder, and let's not overlook cable insulation, our silent sentinel.



Understanding Electrical Connections in CP

Poor or defective Cathodic Protection electrical connections can cause issues in anode systems, rectifiers, test lead cables, test station connections and more. Many of these issues can be avoided.

TYPES OF ELECTRICAL CONNECTIONS
An electrical connection can be defined as connecting two or more metallic conductors together to establish continuity between the individual conductors. The purpose of an electrical connection is to establish low electrical "contact resistance" between the conductors. There are two types of Cathodic Protection electrical connections. Each uses a different method to achieve the proper connection.

METALLURGICAL CONNECTIONS
A metallurgical connection is very strong and reliable. Aside from extreme corrosion issues, poor design or an improperly built connection, metallurgical connections are permanent and immune to progressive increase in contact resistance. Types of metallurgical connections include:

- Soldering – A process to join two or more metal conductors by melting a filler metal (solder) into the joint between the two conductor metals. Solder has a relatively low melting point and is used on many electronic or electrical components.
- Brazing – This process is like soldering, except higher temperatures are employed. The filler metal used also has a lower melting point than the conductors being joined.
- Exothermic Welding – A welding process that employs molten metal to join conductors. This process uses an exothermic reaction of a thermite composition to heat the metal. The chemical reaction that produces the heat is an aluminothermic reaction between aluminum powder and a metal oxide.
- Welding – A process of fusion by melting both metals together, not usually associated with electrical connections.

MECHANICAL CONNECTIONS
A mechanical connection occurs when two or more conductors are in direct physical contact. The configurations and methods used to establish this physical contact are endless. When done properly, they are very reliable. These connections must be protected against corrosion, or they will fail prematurely.

Understanding Electrical Connections in CP

A familiar mechanical connection is a power cord from an electronic device, appliance, or power tool that plugs into an electrical wall outlet. This mechanical connection requires physical pressure to be exerted between the metallic contacts to function properly.

In CP, there are many types of electrical connections. These include crimps, wire nuts, split bolts, ring terminals and more. For a good mechanical connection to occur, the conductors for the connection must be clean (free of any oxides, debris, corrosion, etc.). The term, “bright, shiny metal”, applies here. The conductors must fit together properly and have good contact pressure between all the conductors. A good or proper connection has low contact resistance and does NOT generate heat when electrical current is applied.

A bad or poor connection occurs when a mechanical connection is dirty and or loose. Any dirt, oxide or similar contaminant prevents proper electrical contact between the metallic conductors and increases the “contact resistance” of the connection. Even a clean connection will not work well if the conductors are “loose” or when there is not enough pressure in the connection.

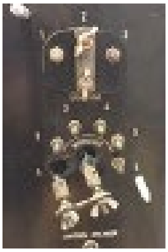
A compromised or poor connection, and in instances where relatively high currents are required, can “heat” the connection. How hot the connection gets is an actual ohmic value of the contact resistance and the magnitude of current in the circuit. To exacerbate the condition, the more heat generated will cause the contact resistance to increase, thereby creating more heat. This regenerative process can result in a total failure of the electrical device.

THE RESULTS
A poor or bad electrical connection can result in:

- Failure of a rectifier due to loose adjustment taps or other connections
- Failure of a CP system due to loose connections in a junction box or rectifier
- Failure of cable splices
- High resistance connections in a bond or resistor box

Methods to detect possible connection problems in a high-current circuit can include:

- Color or surface appearance changes (darkens)
- Abnormally elevated temperature



Understanding Electrical Connections in CP

Note*: Just because a connection is tight does not guarantee that it has low contact resistance. This occurs in CP rectifiers very often and is extremely costly.*

No matter the connection type, there is a technique and process to making a good electrical connection. When done correctly, the connection will last for years. To achieve this, maintenance may be needed depending on the connection, the amount of current and the environment, along with measures to protect the splice or connection, such as splice kits, anti-corrosion coatings or similar.

Making Good Electrical Connections

Whether an electrical connection is made by crimp, split bolt, clamp, Cadweld, braze, silver soldier, or any other means, ensuring the connection is secure and protected from the elements is important.

Good electrical connections are required between:

- A sacrificial anode wire and the structure to be protected
- A sacrificial marine or water anode and the structure to be protected
- Two or more cables to be spliced together
- An anode core, such as with Plattline ribbon and a cable or structure
- A cable attached to a structure via thermite welding (Cadweld)

Determining good electrical connections:

- The surfaces of the connectors should be clean and dry.
- The electrical resistance should be as low as possible. This means the connection must be as mechanically secure as possible. Two cables spliced together should not have any movement between them. An anode bolted to a structure should not have any movement once bolted. 'Secure weld' or 'crimp' means the same thing. A "loose" connection means more resistance. More resistance can mean heat, which is bad for an electrical connection.
- Once the connection is secure, it must remain secure. Movement at the connection point will cause the connection to loosen over time. Measures to resist that movement should be taken.
- Corrosion at the connection point will cause an otherwise good connection to go bad. Measures must be taken to mitigate corrosion at the connection area. Coatings, splice kits, sealants and more are used to keep moisture from the connection. If this is done correctly, moisture is prevented from migrating to the connection.

How NEMA Electrical Ratings for Enclosures Affect CP Design & Installation

The National Electrical Manufacturers Association (NEMA) has designated electrical enclosures into different categories or types depending on the level of protection required. These enclosure ratings affect a Cathodic Protection (CP) design or installation.

DESIGN PURPOSE

To determine the appropriate rating and enclosure for a CP design, an engineer first considers the purpose. It can include:

- Protection from the external environment (rain, dripping water, water spray, salt air, dirt, dust)
- Security of the internal components from physical damage or unauthorized tampering
- Convenient access to the internal components by the intended user
- Proper enclosure size to contain needed equipment and allow adequate room to work within the enclosure for cable routing, etc.

ENCLOSURE RATINGS

- Type 1 – Indoor use only (to keep out solid objects such as fingers, falling dirt and similar)
- Type 2 - Same as Type 1 and prevents ingress of dripping or lightly splashed water
- Type 3 - Can be used indoors or outdoors and provides the same protections as Type 1 & 2 with additional protection from windblown dust and ingress of water (rain, sleet, snow) - allowing it to be unaffected by the external formation of ice on the enclosure
- Type 3R - Same as Type 3 but does NOT protect from windblown dust (Most air-cooled CP rectifier enclosures comply with this rating)
- Other Type 3 Ratings - 3S, 3X, 3RX, 3SX (only minor differences)
- Type 4 - Same as Type 3 and includes protection from hose-directed water
- Type 4X - Same as Type 4 and adds a level of protection against corrosion via the use of stainless steel, aluminum or non-metallic materials

Note: *Additional NEMA types include 5, 6, 6P, 11, 12, 12K, and 13. Alternatively, types 7, 8, 9 and 10 are used in hazardous locations. A complete listing of NEMA types can be found at: https://en.wikipedia.org/wiki/NEMA_enclosure_types.*

How NEMA Electrical Ratings for Enclosures Affect CP Design & Installation

CLASSIFICATIONS

All enclosures will ultimately be installed in one of two AREA classifications:

- Unclassified Area– Any enclosure type is allowed if it meets the physical and environmental requirements and complies with specific company electrical specifications.
- Classified Area– These are for locations considered "Hazardous" or have a "Hazardous Area Classification." There is typically some product or substance within the physical area that would be flammable or explosive in certain concentrations. This could include flammable gases, liquids, dust and lint.

To define a hazardous area, there are Classes, Divisions and Groups:

CLASS DEFINITION

- Class I - Locations in which flammable vapors and gases may be present
- Class II - Locations in which combustible dust may be found
- Class III - Locations that have easily ignitable fibers or "flyings"

DIVISION DEFINITION

- Division 1 - Ignitable concentration of hazards exist under normal operation conditions and/or where hazards are caused by frequent maintenance or repair work or frequent equipment failure
- Division 2 - Ignitable concentrations of hazards are handled, processed or used, but normally in closed containers or closed systems from which they can only escape through accidental rupture or breakdown of such containers or systems.

GROUP DEFINITION

- Group A - Acetylene
- Group B- Hydrogen, Ethylene Oxide, Propylene Oxide
- Group C - Ethylene, Ethyl Ether
- Group D- Propane, Acetone Benzene Butane, Ethanol

In most refineries and/or process facilities, the most common hazardous area classifications include:

- Class 1 Div.1 Group D - Hazardous area and all enclosures must be "explosion proof"
- Class 1 Div. 2 Group D - NEMA 3R enclosures MAY be permissible

How NEMA Electrical Ratings for Enclosures Affect CP Design & Installation

Area classifications are normally assigned when the facility is designed. A classification within an area can change within a few feet from a classified area to an unclassified area or vice versa. Therefore, knowing where the classified area change occurs is important to ensure that the proper NEMA enclosure rating is specified.

It may seem odd, but there may be occasions where a NEMA 3R-rated enclosure can be used in a Class 1 Div. 2 area. According to National Electrical Code (NEC) Article 501-3, Para (b),(1),c., NEMA 3R-rated enclosures are allowed for the use of "non-incendive" circuits that, under normal conditions, do not release sufficient energy to ignite a specific ignitable atmospheric mixture.

Interpretation of Article 501-3 of the NEC permits general-purpose enclosures in a Class 1 Div. 2 area for some applications if the equipment does not constitute a source of ignition under normal operating conditions. Therefore, a NEMA 3R enclosure for a simple anode shunt box or structure junction box would be permitted, as no spark or incendive equipment exists under normal operations.

In the case of CP rectifiers in Class 1 Div. 2 areas, the rectifier MUST be oil cooled and all conduit fitting MUST be "explosion proof."

As a designer of Cathodic Protection, it is important to know the environment, physical requirements and area classification before specifying an enclosure or rectifier type.

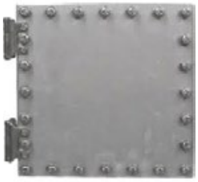
ENCLOSURE EXAMPLES FOR CATHODIC PROTECTION

NEMA 3R ENCLOSURES

How NEMA Electrical Ratings for Enclosures Affect CP Design & Installation

NEMA 4X ENCLOSURE

NEMA EXPLOSION PROOF" ENCLOSURES, NEMA 7,8 & 9



RECTIFIER ENCLOSURE EXAMPLES

NEMA 3R-rated enclosures with air-cooled rectifier.

Note: *This design can only be used in an "unclassified area."*

How NEMA Electrical Ratings for Enclosures Affect CP Design & Installation

NEMA 3R, Oil-cooled rectifier enclosure with 3R enclosure interface.

This design is a good choice for harsh environmental areas, such as marine environments or areas where airborne dust is prevalent.

Note: *This design can only be used in an "unclassified area."*

NEMA 8, Oil-cooled rectifier enclosure with explosion-proof fittings.

Note: *This design is suitable for Class 1 Div. 2 areas. Refer to the above-referenced NEC Article 501-3.*

Junction Boxes

Because electrical components or connections (such as switches) can be ignition sources (if exposed to explosive gasses), they are installed in enclosures that keep those gases away from electrical components. This is typical for refineries, tank farms and other similar process areas.

References such as Class 1, Division 1 or 2, Groups B, C or D indicate explosive areas which require explosive-proof enclosures and/or fittings.

These enclosures are cast metal - no seams to allow gas to enter the enclosure. As a result, they are not easy to open. The door opening is gasketed so gas cannot enter around the door and it is secured, with bolts, for a good seal to the gasket. Threaded conduit access holes can be installed directly into the box so explosion-proof fittings can be threaded into the box.

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Making Effective CP Connections to a Structure

BACKGROUND
During a typical Cathodic Protection (CP) field survey, the CP technician must make effective electrical connections to the structure under test and other metallic components.

Often, the technician will encounter an existing above-ground test station where a conductor (cable) is permanently attached to the structure under test and the other end is terminated to the test station panel. In this case, the connection to the structure is already made and is typically effective.

However, when a ground-level or "flush-mount" test station is encountered, the enclosure may be flooded or may have been at some point, presenting testing challenges. The technician will still need to connect directly to the structure via the test station cables, but connection points or cables are often corroded, and a sound electrical connection may be challenging. If this is the case, a poor structure connection can result in inaccurate CP readings. Therefore, the connections and cables must be cleaned before testing. Cleaning methods include a file, wire brush, sandpaper or similar to clean the connection points.

MAKING GOOD ELECTRICAL CONNECTIONS
A test station is not required when a technician can make a direct electrical connection to the structure under test, such as an above-ground pipe or storage tank. However, some conditions can make it challenging to establish a good electrical connection for CP testing. Rust or corrosion deposits on a steel structure are good electrical insulators and, conversely, poor electrical conductors.

In cases where you need to obtain a CP reading on a rusty structure, it is imperative that you get through the corrosion layers and down to clean metal to obtain an accurate CP measurement.

Making Effective CP Connections to a Structure

Typical tools and techniques include:

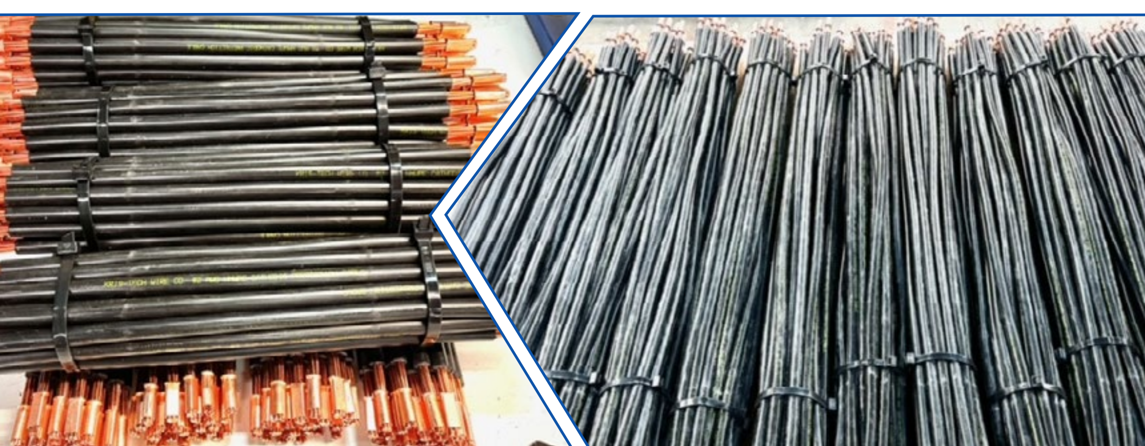
- An “awl” is a tool with a steel shaft with a pointed end used for punching holes in soft materials, such as leather. The point of the awl can usually get through the rust deposit or protective coating. Once contact with the steel structure is made with the awl, the technician can use a test or “alligator” clip to connect the meter test wire to the awl shank.
  - Pros – An inexpensive solution that works well in most situations.
  - Cons – Damages the structure's protective coatings; the tool may dull quickly depending on the metal quality of the awl.
- The corner of a flat or square file can be used to cut through a rust deposit or protective coatings. It is best to use the file on an edge or small-diameter component of the structure, such as a flange. Once the connection to the structure is made with the file, the technician can again use a test or alligator clip to connect the meter test wire to the file in contact with the structure. This is the author’s favorite connection technique.
  - Pros – Effective and inexpensive, a well-made file will last years.
  - Cons - Damages the structure's protective coatings.
- If working in a marine environment, especially on offshore structures, multiple layers of surface corrosion can be encountered, making it a challenge to conduct testing. If the surface of the structure allows, use a pair of locking pliers or Vise Grips to obtain a connection. Do this by tightly clamping the pliers to the structure and then rotating the pliers back and forth to break through the layers of corrosion. When the pliers reach steel, remove the pliers, and clean away the corrosion particles on the pliers and the structure. Once clean, reattach the pliers back to the same clean structure location and clamp the pliers as tightly as possible. Once again, rotate the pliers to obtain a connection to bare metal. When done, leave the pliers locked to the structure and connect the meter test-lead wires to the pliers to get a CP reading.
- To connect a large gauge wire (#10 to # 6 AWG) to a structure for current testing, use the above locking plier method to clean a test location. When clean, clamp the cable to the structure with the jaws of the locking pliers.
- A “C-clamp” with the flat shoe removed from the tool and the threaded end sharpened to a point works well for current testing where you need to make a structure connection for an extended period. To prepare the C-clamp for the cable connection, drill a hole in the body of the clamp, install a bolt in the hole, and connect the cable to the C-clamp using a cable ring or fork terminal.
- There are many magnetic connecting tools available that may work for CP testing. Magnetic connections work best when the structure under test has clean and bright metal at the magnet contact area. Depending on the situation, magnets may have limited applications.

Cable Insulation

Impressed current anode systems (cast iron, graphite and MMO) require the correct cable insulation for the anode.

- HMWPE (High Molecular Weight Polyethylene) is a flexible and durable cable insulation most commonly used for anodes, negative cables, test leads, bonds, etc. A single layer of HMWPE insulation is a good choice, but not very chemically resistant. The insulation can deteriorate when exposed to certain chemicals, such as chlorine gas, causing premature cable failure.
- Kynar/HMWPE - Kynar is the trademarked name for PVDF or polyvinylidene fluoride. For CP, it is used as the first or primary insulation in a dual-insulated cable. The significant benefit of using Kynar is its good resistance to many chemicals, including chlorine. It is more costly than HMWPE, is not all that flexible, and not used for direct burial. The application of HMWPE as a secondary insulation over the Kynar allows this cable to be used in direct burial scenarios.
- Halar/HMWPE – Halar is the trademarked name for ECTFE or ethylene chlorotrifluoroethylene. The inner or primary Halar insulation is a very tough and chemically resistant material that is composed of two separate or dual cable insulations. The outer insulation is HMWPE. This dual cable insulation is almost exclusively used for impressed current anodes. Halar is resistant to even more chemicals, including chlorine, than Kynar, yet the cost is about the same. And like Kynar, it is not flexible and not used for direct burial. The application of HMWPE as secondary insulation allows this cable to be used in direct burial scenarios

  Adding a primary layer of Halar provides a very chemically resistant protective layer to the copper cable. It is a good choice when significant chlorine gas is in contact with an anode cable.



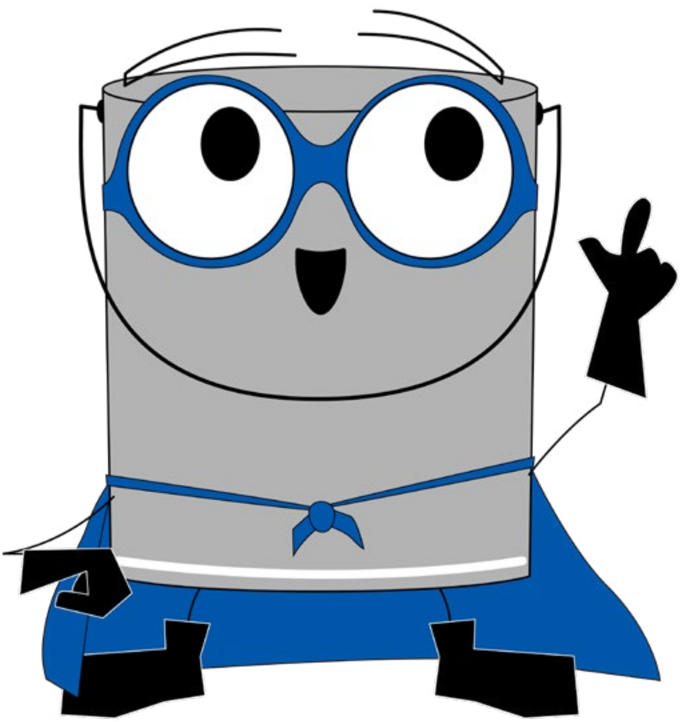
Cable Insulation

In impressed current anode systems, some amount of chlorine gas is produced. The amount of gas produced depends on factors, including the salinity of the soil/water and the level of DC current produced by the anodes. The more DC current generated by the anodes and the higher the salinity, the greater the chlorine produced. While chlorine is vented out of the anode bed, it can still damage HMWPE insulation if found in sufficient quantities.

Determining the type of cable insulation that will perform the best is best left to the experts. If a CP system is designed to provide high current outputs, Halar/HMWPE cable insulation is likely the best choice - just a bit more expensive. If the design is for very low current outputs, then HMWPE may be suitable.

COATINGS

Fasten your seatbelts as we venture into the important and protective realm of Coatings! In the world of Corrosion Protection, coatings are the first line of defense, working silently to ward off corrosion and the relentless elements. From their chemistry to their application, every layer plays a crucial role. Come along as we peel back the layers on an unsung hero that keeps our structures strong!



Removing Coatings from Metallic Structures

When removing a coating from a metallic structure (pipe, tank, etc.) to make a Cadweld connection, using a grinding wheel to prepare the metal is standard practice. A bright, shiny metal surface, devoid of contaminants, is required to make a good connection. Sometimes despite meeting this requirement, problems are getting the Cadweld connection to adhere to the structure.

Some grinding wheels are resin- or vitreous-based meaning the abrasive material in the grinding wheel is bonded together by a resin-based material. When grinding, some of this resin stays on the surface of the structure as an invisible film. This thin resin layer is enough to prevent the Cadweld connection from sticking.

The remedy is to use a non-vitreous or resin-based grinding wheel. A good alternative is securing a Bristle Blaster, which does not use a grinding wheel. Instead, it uses steel pins to remove the coating.

The Importance of Dielectric Coatings on Pipelines

THE ROLE OF DIELECTRIC COATINGS

Dielectric coatings play a crucial role in protecting buried pipelines from various forms of corrosion and degradation. Due to their exposure to soil, moisture and other environmental factors, metallic pipelines are susceptible to corrosion. Dielectric coatings help address these concerns and offer important benefits:

- **Corrosion Prevention**: Coatings are the first line of defense against corrosion. Their primary function is to create a barrier between the metal surface of the pipeline and the surrounding soil. Soil contains various corrosive agents, such as moisture, salts and minerals, which can accelerate the corrosion process. Coatings prevent the contact of those agents with the pipeline, thereby preventing corrosion.

- **Insulation Properties**: Dielectric coatings provide electrical insulation, as the coating is a barrier between the soil and the pipeline. Dielectric coatings help prevent the flow of electrical currents between the pipeline and the surrounding soil, reducing the risk of various forms of corrosion, i.e., differential electrical potentials, stray ground currents from neighboring Cathodic Protection systems or electric rail systems.

- **Chemical Resistance**: Dielectric coatings are typically resistant to a wide range of chemicals, including acids, alkalis and other substances that may be present in the soil. This chemical resistance will shield the pipeline from any ill effects from these chemicals.

- **Durability**: Properly applied dielectric coatings can offer long-term service. They are designed to withstand harsh environmental conditions, i.e., temperature fluctuations and mechanical stresses.

The Importance of Dielectric Coatings on Pipelines

THE IMPORTANCE OF COATINGS

The importance of dielectric coatings on buried pipelines cannot be overstated. Modern coatings provide essential protection against corrosion, extend the operational life of pipelines and reduce maintenance costs. Proper selection and application of a coating system can enhance the long-term integrity, reliability and safety of buried pipelines.

In theory, a pipeline with a 100% effective coating would provide total isolation of the pipeline from the soil, which would result in zero corrosion. However, this is unrealistic due to the inevitable nicks, scratches (called coating holidays) and possibly less than perfectly coated field joints. And all coating will deteriorate over time which is why a Cathodic Protection (CP) system is typically specified to compensate for a “less than perfect coating” and protect the bare surfaces of the pipeline.

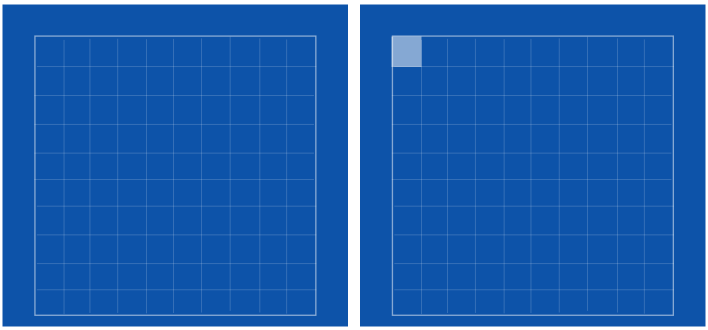
DESIGNING A CP SYSTEM WITH COATING

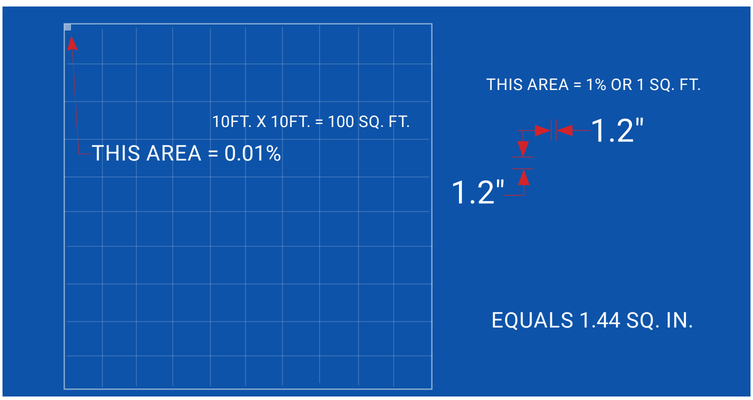
The basis of design for any CP system requires, among other factors, knowledge or a competent estimate of the quality of the coating. In other words, understanding how well the coating is performing and how much bare steel will be exposed to the soil. The CP system designer should collect all available information on the coating system to estimate its efficiency. This is a major factor in calculating the amount of CP current needed to properly protect the pipeline.

Often, the CP designer will be required to consult with others to obtain an assessment of the quality of pipeline coating. This is where the CP design can go amiss.

As an example, consider a 99% efficient coating. Most people might agree that a 99% efficient coating application would be a relatively good effort. However, consider a requirement or specification to coat a structure that is ten feet by ten feet square, or one hundred total square feet. A 99% efficient coating would mean that one full square foot of surface area was missed and is still bare. This is not acceptable and would be very poor for a new coating system.

The Importance of Dielectric Coatings on Pipelines





In the example to the left, a coating that would be 99.9% coverage, still results in the equivalence of a 1.2” square still exposed or bare.

The Importance of Dielectric Coatings on Pipelines

COATING EFFICIENCY

The coating efficiency of the new generation of fusion bonded epoxy (FBE) coatings used on most new pipeline installations can provide very impressive coating efficiencies. It is our experience that through empirical testing, FBE coatings consistently provide efficiencies higher than 99.9%. FBE coatings provide greater long-term stability and performance, which is far superior to older coating types, such as "coal tar" type coatings that had a much lower dielectric strength and would degrade more quickly over time.

No matter the coating type, it is important that prior to backfilling, the entire pipeline is checked for coating imperfections (called holidays) with a high-voltage holiday detector. Conducting this testing and repairing any holidays will help to ensure a much better performance from the designed CP system.

Besides coating efficiency, all coatings have a "dielectric strength," which varies with coating type. This is the ability of the coating to function as an electrical insulator or barrier between the pipeline and the soil. Despite a perfect or 100% efficient coating, a minute amount of CP current can pass through the coating and affect the actual current requirement and the system design life.

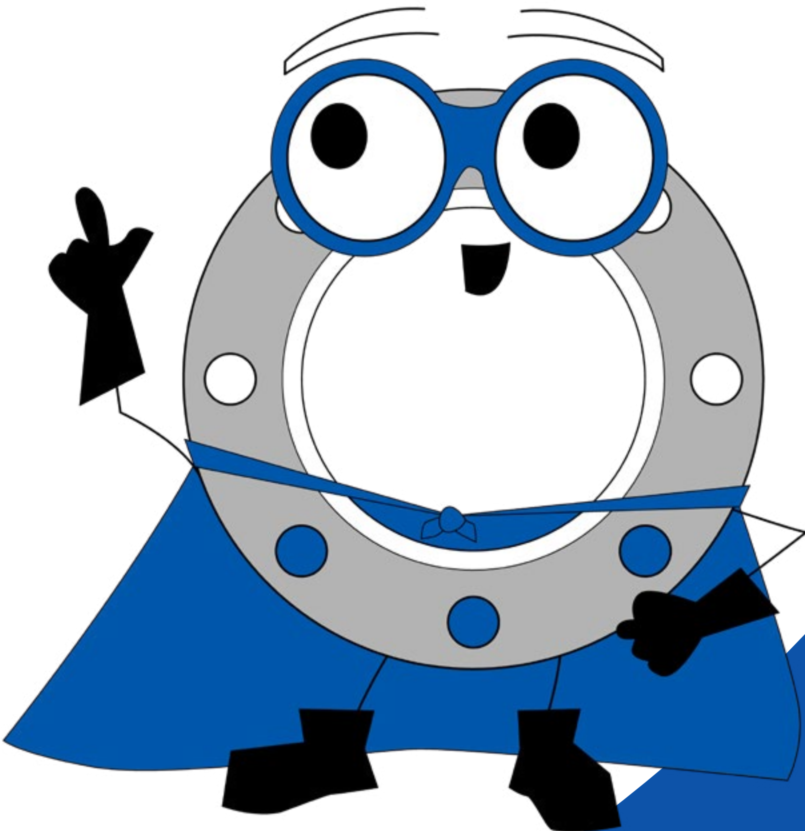
CONDUCTING A CURRENT REQUIREMENT TEST ON AN INSTALLED PIPELINE IS IMPORTANT

Regardless of the coating type or estimated coating efficiency, if the pipeline is already installed, conducting a Cathodic Protection “current requirement” test is an ideal way to determine the actual magnitude of CP current required to protect the pipeline.

A current requirement test consists of setting up a temporary CP system using a portable DC power supply and a temporary anode. A temporary anode can be any buried metal structure, such as a driven rod, chain link or other metal fence, an abandoned pipeline or a well casing - it is critical that the temporary anode be an electrically isolated structure. With the temporary anode and isolated anode selected, the test methodology is the application of a known magnitude of DC current on the pipeline while measuring the pipe-to-soil potential shift. As with all CP testing, the current requirement test and evaluation should be performed by a qualified corrosion professional.

ELECTRICAL ISOLATION

Get ready for a jolt of excitement as we explore Electrical Isolation in Cathodic Protection. Acting as an electrical fortress, isolation products control energy flow, keeping CP current where they are needed. From isolating flanges to monolithic isolating joints, each product has a role to play and is key in effective Cathodic Protection. Join me as we uncover the techniques that form our electrical barriers and ensure Cathodic Protection efficiency and precision.



Flange Isolation Kits

Flange isolation kits are designed to electrically isolate two pieces of pipe at a mechanical flange isolation is achieved by using a flange gasket, isolating sleeves and isolating washers. Combined, these parts eliminate all metal-to-metal contact between the flange faces and bolts.

It is important to install flange isolation kits as recommended by the manufacturer. Doing otherwise can cause harm to some of the components resulting in the flange not being properly isolated. Failure of one simple sleeve or washer will cause a mechanical "short," resulting in a non-isolated section of pipe.

WHEN AN ISOLATION FLANGE KIT DOES NOT WORK

If the pipe carries a highly conductive material, such as salty water, a "bridge" can form inside the pipe over the gasket, effectively shorting the two flange faces together. This is called "high resistance short." It is different from a mechanical short, which is metal-to-metal contact.

The Importance of Electrical Isolation for Buried Pipelines

ELECTRICAL ISOLATION AND PIPELINES

Electrical isolation for buried or submerged pipelines is crucial for Cathodic Protection and the overall operational integrity of the pipeline. Effective electrical isolation can provide many technical advantages for pipeline operators.

Key reasons why electrical isolation is important for these pipelines:

- **Corrosion Prevention**: Corrosion is a significant threat to buried or submerged pipelines, especially in environments that contain elevated levels of dissolved salts. When pipelines are in contact with the surrounding soil or water, a corrosive electrochemical process known as galvanic corrosion can occur. This happens when dissimilar metals are used in the construction of the pipeline or if the pipeline is electrically connected to a foreign structure that has a different structure-to-soil potential, i.e., a copper grounding system, thereby creating a corrosion cell. By providing electrical isolation between the two dissimilar metals, the electrical connection can be broken, minimizing the potential for galvanic corrosion.

- **Cathodic Protection**: Cathodic Protection is a technique used to prevent corrosion on pipelines. Electrical isolation used to isolate sections of pipe allows for effective Cathodic Protection because it prevents the loss of needed CP current to foreign structures or pipelines. This process ensures that the protective CP currents are directed where they are needed, maximizing corrosion prevention efforts.

- **Maintenance and Inspection**: Electrical isolation can provide easier maintenance and inspection of the pipeline. It allows various pipeline sections to be individually monitored, assessed and maintained without interactions with other pipelines.

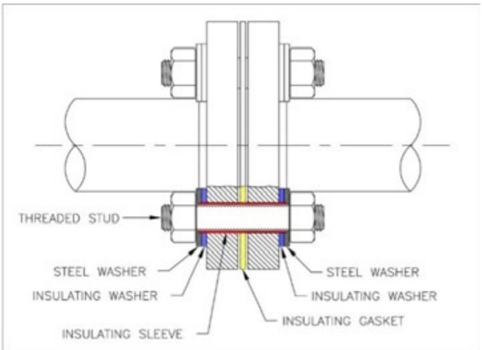
HOW ELECTRICAL ISOLATION WORKS

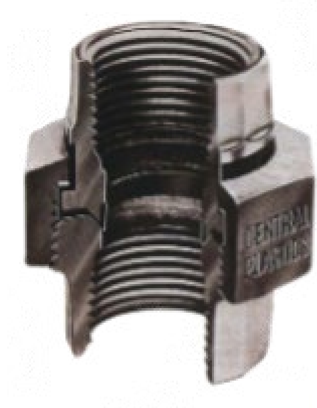
Electrical isolation for buried pipelines is vital for preventing corrosion, ensuring safety, enabling effective Cathodic Protection, facilitating maintenance and promoting pipeline longevity. It is an essential element of pipeline design and operation that contributes to the overall reliability and sustainability of the pipeline system.

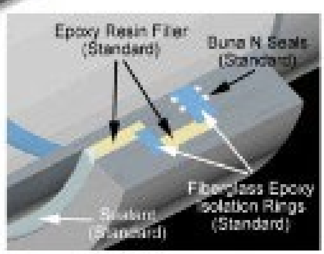
Electrical isolation of pipelines is primarily accomplished by the installation of dielectric isolation fittings. Typical examples of these fittings are isolating flange kits, dielectric isolating unions, isolating couplings and monolithic isolation joints (MIJ).

Below are examples of the several types of dielectric isolation fittings used to electrically isolate pipeline sections.

The Importance of Electrical Isolation for Buried Pipelines







ELECTRICAL SHORTS

Installation of the appropriate dielectric fitting in a pipe system is important to sectionalize and control the amount of pipe to cathodically protect. As important as it is to install the dielectric insulating fittings, ensuring that the pipeline does not inadvertently contact a foreign metallic structure is equally important. This contact with another metal structure is commonly referred to as an "electrical short" or "short." This metal-to-metal contact with foreign structures can be caused by many sources, and shorts can exist either above ground or below ground.

A short to a foreign metallic structure usually results in significantly reducing or nullifying the effectiveness of the installed insulating fittings and the Cathodic Protection system. The following photographs provide examples of electrical shorts on a pipeline.

The Importance of Electrical Isolation for Buried Pipelines

The Importance of Electrical Isolation for Buried Pipelines

ELECTRICAL ISOLATION ISSUES

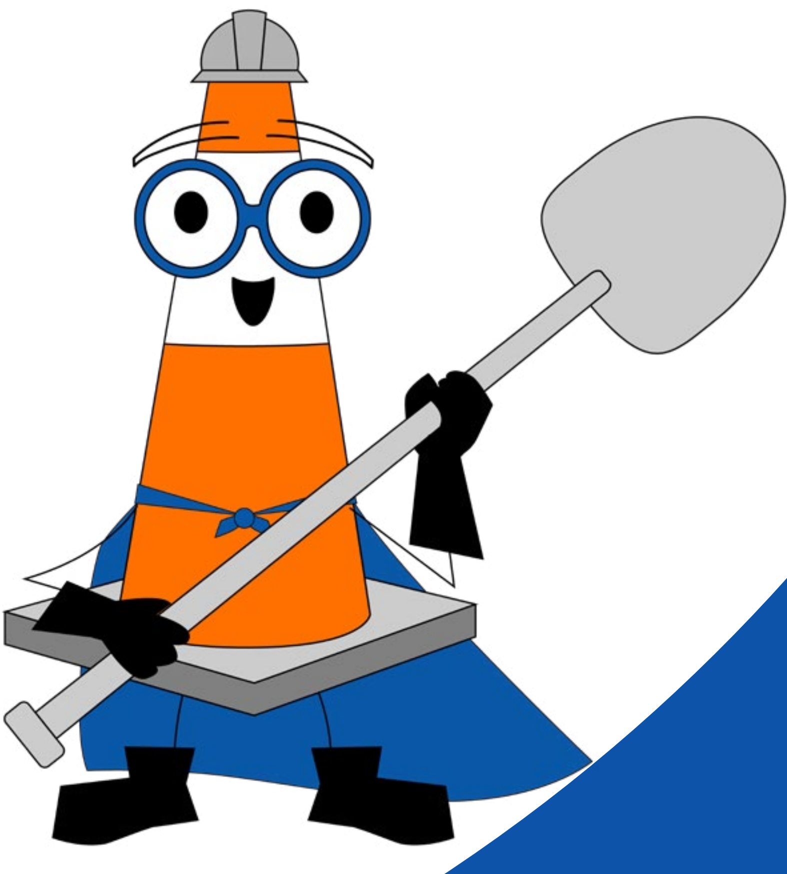
There are many situations and equipment along the pipeline that can cause electrical isolation issues. These include motor-operated valves, pig signals, temperature probes, flow meters, pipeline taps, bridge crossings and more. Careful design and attention to installation procedures are required to ensure that structures such as these are properly isolated, electrically, from the pipeline.

OTHER POSSIBLE ELECTRICAL ISOLATION PROBLEMS

Pipeline pigging can also present problems for electrical isolation. As the pig pushes sediments, oxides or other internal pipeline contaminants (which can be electrically conductive) through the pipeline and across a dielectric isolation flange, these contaminants can electrically bridge or short the Isolating gap in the flange. This can reduce the effectiveness of the isolating flange kit, or in some cases, result in a completely shorted flange. The good news is that there are solutions to this problem, such as a monolithic isolating joint and internally coated pipeline spools (photos shown above).

MISCELLANEOUS

The Mega Rule for Cathodic Protection marks a milestone in pipeline management, offering a guideline for operators. It illuminates the path toward enhanced safety, reliability and compliance in the ever-changing landscape of underground pipeline infrastructures.



The Impact of the Mega Rule on Cathodic Protection

Cathodic Protection is essential for preventing corrosion on underground and submerged metallic structures such as pipelines. The introduction of the Mega Rule by the U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) has far-reaching implications for Cathodic Protection practices, extending federal oversight to an additional 400,000 miles of pipelines and bolstering safety protocols.

The Mega Rule focuses on the maximum operating pressure and integrity management of pipelines near High Consequence Areas (HCA) for onshore gas transmission pipelines. The changes extend federal safety requirements to onshore gas gathering pipelines with large diameters and high operating pressures, regardless of HCA rating. The Mega Rule expands corrosion control requirements for gas transmission pipelines having direct impact on operators and Cathodic Protection practices.

KEY IMPACTS ON PIPELINE OPERATORS

The Mega Rule introduces sweeping changes in pipeline regulations, with specific implications for operators in areas ranging from safety protocols to public engagement. The changes are designed to enhance pipeline safety, reduce the likelihood of pipeline failures and mitigate the potential consequences of such failures. The Mega Rule addresses various aspects of pipeline operations, including integrity management, risk assessment, record-keeping and quality assurance.

- **Enhanced Safety and Oversight**: The Mega Rule mandates the adoption of modern technology and best practices, requiring more frequent and thorough inspections to support safe pipeline operations. The Mega rule expands the regulations to now cover pipelines in rural and less populated areas that were previously exempt, through a more stringent HCA rating process. Comprehensive safety records must be maintained and operators are now subject to more frequent compliance audits.

- **Cost Implications for Operators**: Compliance with the Mega Rule necessitates significant financial outlay, particularly in corrosion and integrity management inspections, technology and training. Older pipelines may need modifications or retrofits to meet the new operating standards, including equipment replacement and technological upgrades. Stricter regulations mean higher penalties for non-compliance, making adherence to the new protocols vital.

- **Timelines for Implementation**: There is a heightened focus on regularly assessing risks and preventative measures, integrating Cathodic Protection practices into broader integrity management strategies. This includes expedited deadlines for compliance during new pipeline installations, interference events and monitoring of both internal and external corrosion. These requirements can involve meticulous planning that could affect short-term operational strategies.

The Impact of the Mega Rule on Cathodic Protection

- **Public Engagement and Environmental Impacts**: The Mega Rule calls for increased transparency and public communication during pipeline planning and upgrades. New provisions now require additional inspections following extreme weather events such as hurricanes, landslides, earthquakes and floods. Environmental considerations for spill prevention and product release are woven into the new regulations.

EXPANDED FOCUS ON CATHODIC PROTECTION

The Mega Rule's impact extends to the specialized field of Cathodic Protection, affecting how corrosion prevention technologies and strategies are implemented and managed.

- **Advanced Monitoring**: The Mega Rule required more robust Cathodic Protection monitoring, integrating advanced technologies for real-time critical data. This includes the use of remote monitoring and data analytics to ensure timely identification of any operational deviations or anomalies that would affect system performance and safety.

- **Strategic Assessments**: Cathodic Protection is now an integral part of overall pipeline integrity assessments, with a focus on immediate corrective actions for identified vulnerabilities. It also expands the need for enhanced surveys such as coating surveys for new pipeline installation and interference testing where potential stray current interference is indicated.

- **Quality Assurance and Documentation**: The Mega Rule places a significant emphasis on documentation and quality assurance. Pipeline operators are required to maintain comprehensive records of Cathodic Protection system design details, installation, operation, and maintenance. This documentation serves as an important resource for regulatory compliance and effective Cathodic Protection management.

- **Comprehensive Risk Assessment**: The Mega Rule calls for an inclusive risk evaluation that ties Cathodic Protection directly to broader pipeline risk assessment. The mandates require a more comprehensive risk assessment approach, considering factors such as soil corrosivity, potential coating defects and Cathodic Protection system performance. This helps operators to prioritize their efforts and allocate resources more effectively.

- **Environmental and Safety Benefits**: Enhanced Cathodic Protection practices, as mandated by the Mega Rule, aim to minimize both the risk of corrosion-related failures and subsequent environmental hazards.

The Impact of the Mega Rule on Cathodic Protection

The Mega Rule represents a paradigm shift in U.S. pipeline regulation, with substantial impacts on Cathodic Protection practices. This change necessitates comprehensive updates in technology, strategic planning and investment, reaffirming the role of Cathodic Protection as a vital tool in pipeline integrity and safety.

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FARWEST CORROSION CONTROL COMPANY

Farwest Corrosion Control Company is an industry pioneer and leader in comprehensive Cathodic Protection and corrosion control services and related products.

Named a Top Ten Corrosion Solution Provider from Manufacturing Technology Insights magazine, Farwest is known for finding solutions to difficult problems through quality products, sound engineering solutions and onsite installation services.

Founded in 1956, the firm is a Minority Business Enterprise headquartered in Downey, CA, with offices and representation nationwide.

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