An Introduction to Cathodic Protection Systems Maintenance

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1. SCHEDULED PREVENTIVE MAINTENANCE

1.1 INTRODUCTION. To comply with environmental regulations, public law, and industry standards, preventive maintenance is required for all installed cathodic protection systems. Maintenance actions in this section are the minimum required.

1.2 CLOSE-INTERVAL CORROSION SURVEY. The close-interval corrosion survey is an interrupted potential survey on impressed current systems and a noninterrupted potential survey on galvanic (sacrificial) systems. The purpose of this survey is to ensure that adequate cathodic protection is maintained over the entire protected structure. It should be thorough and comprehensive to identify problems within the protected structure, or any interference problem on all foreign structures. The interruption cycle must have an ON cycle of minimum duration four times longer than the OFF cycle, and the OFF cycle should not exceed one second. For surveys on galvanic systems, measurement errors must be considered, typically through the application of sound engineering practices which address the location of the reference cell, the protected structure, the anodes, the condition of the coating, the soil resistivity, and the depth of the protected structure. If test stations are installed at each anode, this also can be an interrupted potential survey.

1.2.1 MAINTENANCE INTERVALS. A close-interval survey must be conducted at the following intervals:

- Thirty days after cathodic protection system is installed and properly adjusted.
- Five years from the last close-interval corrosion survey.

1.2.2 MINIMUM REQUIREMENTS

1.2.2.1 TEST CP SYSTEM COMPONENTS in accordance with Table 1.1 and accomplish potential measurements of the protected structure (Table 1.2).

CP SYSTEM TYPE	TEST MEASUREMENT
GALVANIC (SACRIFICIAL) SYSTEMS (at each test station)	a) One anode-to-soil potential measurement with the reference electrode placed over the anode, and the anode lead disconnected. b) Anode-to-structure current using (in order of preference) a clamp-on milliammeter, a multimeter measuring millivolts across a calibrated shunt, or a multimeter connected in series measuring milliamperes.
IMPRESSED CURRENT SYSTEMS	a) Perform the rectifier operational checkout. b) Calculate the rectifier efficiency by dividing the calculated output DC power by the factored input AC power. c) Perform the impressed current anode bed survey.

Table 1.1

Close-Interval Survey CP System Component Testing Requirements

STRUCTURE TYPE	POTENTIAL MEASUREMENT LOCATIONS
PIPELINES	Locate the reference cell over the pipeline at intervals not to exceed the depth of the pipeline, normally every (1 to 1.5 meters (3 to 5 feet).
ON GRADE STORAGE TANKS	Locate the reference cell: Next to the tank every 1.8 meters (6 feet) around the tank circumference. At a distance one tank radius away from the tank at eight equally spaced locations around the tank circumference.
UNDERGROUND STORAGE TANKS	Locate the reference cell: Every 1 meter (3 feet) over the tank. At least every 1M over feed and return piping. Over the manhole, fill pipe, and vent pipe. Over all metallic structures in the area if readings indicate an isolated system is shorted to a foreign structure.
ISOLATED STRUCTURES	Take one structure-to-electrolyte (S/E) potential measurement on each side of all dielectric couplings without moving the reference electrode. **Note:** If the potential difference between measurements on each side of a dielectric coupling is < 10 millivolts, verify its integrity using an isolation flange tester
ALL STRUCTURES WITH FOREIGN LINE CROSSINGS	Locate the reference cell: Over the foreign line at all points where it crosses the protected structure. Over the foreign line where it passes near the anode bed.
ALL STRUCTURES WITH CASED CROSSINGS	Locate the reference cell: Over each end of the casing on all casings. **Note:** If the casing is shorted or partially shorted to the pipeline, and the potentials over the pipeline are depressed below criteria described in Chapter 6, take immediate action to clear the short.
ALL STRUCTURES IN SOIL	Annotate the soil condition for comparison of past/future potential and current measurements.

Table 1.2

Close-Interval Survey Potential Measurement Locations

1.2.2.2 REVIEW ALL POTENTIAL READINGS. Annotate the low potential measurements, the high potential measurements, and other significant potential measurements to re-evaluate those locations when performing the corrosion survey.

1.2.2.3 IF THE DATA TAKEN show that the current output is not sufficient to satisfy the criteria in Chapter 6, adjust or supplement the system as necessary. After 30 days, perform a corrosion survey for those locations identified in Paragraph 1.3.

1.3 CORROSION SURVEY. The corrosion survey is conducted to ensure adequate cathodic protection still exists as proven on the last close-interval corrosion survey. The procedures are the same as the close-interval corrosion survey, with different minimum requirements for the potential measurements. The close-interval corrosion survey data should be used to determine where potential measurements must be taken to reasonably ensure that the criteria of cathodic protection are being met for the entire structure being protected and no interference problems exist on any foreign structures.

1.3.1 MAINTENANCE INTERVAL. A corrosion survey must be conducted at the following intervals:

- Thirty days after major modification to the cathodic protection system or the protected structure.
- After any corrosion leak on the protected structure.
- After any inspection or survey which indicates that the current requirement of the last corrosion survey are not valid (low or high potential measurements at the proper current output level).
- One year from last close-interval corrosion survey or corrosion survey which satisfied the Owner’s criteria.

1.3.2 MINIMUM REQUIREMENTS

1.3.2.1 USING DATA from the most recent close-interval corrosion survey, or using sound engineering practices, choose a sufficient number of locations for potential testing to ensure the entire structure has adequate cathodic protection. Test CP system components in accordance with Table 1.3. Table 1.4 presents the requirements for potential testing of the protected structure.

CP SYSTEM TYPE	TEST MEASUREMENT
GALVANIC SYSTEMS (at each test station)	a) One S/E potential measurement with the reference electrode placed directly over/adjacent to the protected structure at the location(s) nearest the anode(s). b) One S/E potential measurement with the reference electrode placed directly over/adjacent to the protected structure midway between anode(s). c) One anode-to-electrolyte potential measurement with the reference electrode placed directly over/adjacent to the anode with the anode lead disconnected. d) Anode-to-structure current using (in order of preference) a clamp-on milliammeter, a multimeter measuring millivolts across a calibrated shunt, or a multimeter connected in series measuring milliamperes.
IMPRESSED CURRENT SYSTEMS	Perform the rectifier operational checkout.

Table 1.3

Corrosion Survey Component Testing

STRUCTURE TYPE	POTENTIAL MEASUREMENT LOCATIONS
PIPELINES	Locate the reference cell: a) Over the pipeline at all test stations and at all points where the structure can be contacted (where it enters/exits the ground, passes through a pit, or is exposed b) Over the pipeline at least every 305 meters (1000 feet) for pipelines off the installation c) Over the pipeline at least every 152 meters (500 feet) for pipelines on the installation
ON GRADE STORAGE TANKS	Locate the reference cell: a) Next to the tank at four equally spaced locations around the tank circumference b) At a distance one tank radius away from the tank at eight equally spaced locations around the tank circumference
UNDERGROUND STORAGE TANKS	Locate the reference cell: a) Over the center and each end of the tank. b) Over each end of the feed/return piping. c) Over the manhole, fill pipe & vent pipe. d) Over all metallic structures in the area if readings indicate an isolated system is shorted to a foreign structure.

Table 1.4

Corrosion Survey Potential Measurements

STRUCTURE TYPE	POTENTIAL MEASUREMENT LOCATIONS
ISOLATED STRUCTURES	Take one structure-to-electrolyte (S/E) potential measurement on each side of all dielectric couplings without moving the reference electrode. **Note:** If the potential difference between measurements on each side of a dielectric coupling is less than 10 millivolts, verify its integrity using an isolation flange tester.
ALL STRUCTURES WITH FOREIGN LINE CROSSINGS	Locate the reference cell: a) Over the foreign line at all points where it crosses the protected structure. b) Over the foreign line where it passes near by the anode bed.
ALL STRUCTURES WITH CASED CROSSINGS	Locate the reference cell: a) Over the protected structure on each side of all casings. b) Over each end of the casing on all casings. **Note:** If the casing is shorted or partially shorted to the pipeline, and the potentials over the pipeline are depressed below criteria described in Chapter 6, take immediate action to clear the short.
WATERFRONT STRUCTURES	At all permanent reference electrodes. Also, locate portable reference cells: a) Adjacent to the structure at all test stations. b) Every 46 meters (150 feet) along a continuous length of sheet pile wall at both the surface and at the bottom. c) At other test points identified in maintenance manuals or past surveys.
OTHER STRUCTURES	Locate the reference cell at test points identified in the maintenance manual or other past surveys.
ALL STRUCTURES	Annotate the soil condition (or tide level for waterfront structures) for comparison to past and future measurements.

Table 1.4 (continued)

Corrosion Survey Potential Measurements

1.3.2.2 REVIEW ALL POTENTIAL READINGS. Annotate the three lowest potential measurements and the highest potential measurement to re-evaluate those specific locations when performing the impressed current system check.

1.3.2.3 FOR ALL STRUCTURES, compare the potential measurements to those previously taken at the same locations to identify changes.

1.3.2.4 IF THE POTENTIAL MEASUREMENTS reveal current output does not satisfy criteria in Chapter 6, adjust or supplement the system as necessary. After 30 days, accomplish the survey again (Paragraph 1.3.1).

1.4 WATER TANK CALIBRATION. The water tank calibration is a comprehensive and thorough survey to ensure that cathodic protection is maintained over the entire surface of the tank to be protected in accordance with Chapter 6 criteria, and there are no excessive voltages on any part of the tank interior that could damage the coating. Water tank calibration comprises an interrupted potential survey on impressed current systems and a non-interrupted potential survey on galvanic systems. The interruption cycle must have an ON cycle that is a minimum of four times longer than the OFF cycle where the OFF cycle is normally one second. On a galvanic system, measurement errors must be accounted for using sound engineering practices, including reference cell placement, anode positions, and coating condition. If the system design permits, this may also include an interrupted potential survey.

1.4.1 MAINTENANCE INTERVALS. Recommended intervals for conducting water tank calibrations are:

- Thirty days after the cathodic protection system is installed, modified, or adjusted.
- One year from the last water tank calibration.

1.4.2 MINIMUM REQUIREMENTS

1.4.2.1. INSPECT WATER TANKS in accordance with Tables 1.5 and 1.6.

CP SYSTEM TYPE	TEST MEASUREMENT
GALVANIC SYSTEMS	Measure anode-to-structure current using (in order of preference) a clamp-on milliammeter, a multimeter measuring millivolts across a calibrated shunt, or a multimeter connected in series measuring milliamperes.
IMPRESSED CURRENT SYSTEMS	a) Perform the rectifier operational checkout. b) Calculate the rectifier efficiency by dividing the calculated output DC power by the factored input AC power.

Table 1.5

Water Tank Calibration CP System Component Tests

STRUCTURE TYPE	POTENTIAL MEASUREMENT LOCATIONS
TANK WALLS	Position the reference cell near the water surface, at mid-depth and at the bottom in the following locations: a) Next to the tank wall directly adjacent to each anode string. b) Next to the tank wall midway between two adjacent anode strings.
TANK BOTTOM	Locate the reference cell: a) Two inches above the tank bottom directly beneath each anode string. b) Two inches above the tank bottom and as far away from the anode strings as possible.
METALLIC RISER (Elevated Water Tanks)	Locate the reference electrode adjacent to the riser wall at intervals of 1.5 meters (5 feet) from the top to the bottom of the riser.
PERMANENT REFERENCE CELLS	Measure and compare the potential of each permanent cell to a portable reference cell to determine its accuracy.
ALL TANKS	Annotate the water level for comparison to past and future measurements.

Table 1.6

Water Tank Calibration Potential Measurements

1.4.2.2 FOR ALL TANKS, compare potential measurements to measurements previously taken at the same locations to determine if changes have occurred.

1.4.2.3 IF POTENTIAL MEASUREMENTS do not satisfy criteria and the current output meets the current requirement from the last survey, adjust or supplement the system as necessary. After 30 days, perform a water tank calibration (refer to Paragraph 1.4).

1.5 RECTIFIER OPERATIONAL INSPECTION. The purpose of the rectifier operational inspection is to determine the serviceability of all components required to impress the current to the anodes of the impressed current system. The inspection should be thorough to ensure dependable current until the next inspection.

1.5.1 MAINTENANCE INTERVALS. This checkout should be accomplished together with the close-interval corrosion survey, the corrosion survey, the water tank calibration, or when any inspection or survey indicates that problems with the rectifier may exist.

1.5.2 MINIMUM REQUIREMENTS

1.5.2.1 VISUALLY CHECK all rectifier components, shunt box components, safety switches, circuit breakers, and other system power components.

1.5.2.2 TIGHTEN ALL ACCESSIBLE CONNECTIONS and check temperature of all the components listed in 1.5.2.1.

1.5.2.3 USING A DEPENDABLE HAND-HELD METER, measure the output voltage and current, and calibrate the rectifier meters, if present.

1.5.2.4 FOR RECTIFIERS with more than one circuit, measure the output voltage and current for each circuit using a dependable hand-held meter, and calibrate the rectifier meters, if present.

1.5.2.5 FOR RECTIFIERS WITH POTENTIAL VOLTMETERS, using a dependable hand-held meter, measure the potentials for each voltmeter, and calibrate that rectifier meter. Using a known good reference electrode, measure the potential difference to the installed permanent reference electrode by placing both electrodes together in the electrolyte with CP current off. If the difference is more than 10 mV, replace the permanent reference electrode.

1.5.2.6 CALCULATE THE CATHODIC PROTECTION SYSTEM CIRCUIT RESISTANCE of each circuit by dividing the rectifier DC voltage output of each circuit by the rectifier DC ampere output for that circuit.

1.5.2.7 FOR ALL CLOSE-INTERVAL CORROSION SURVEYS, or if otherwise required, calculate the rectifier efficiency. This also includes timing the revolutions of the kWh meter and annotating the meter factor from the face of the kWh meter.

1.6 IMPRESSED CURRENT ANODE BED. The impressed current anode bed survey is a non-interrupted survey of the ground bed to determine the condition of the anodes. It should be comprehensive and thorough to identify any possible problem with the impressed current anodes. It may also be used to predict failure and to program replacement. This survey would normally be done together with the close-interval corrosion survey. As a minimum, an impressed current anode bed survey should include ON potential over-the-anodes at intervals described in Table 1.7, unless the system has incorporated other means for monitoring the anodes (e.g., individual anode leads in an anode junction box).

CP SYSTEM TYPE	TEST MEASUREMENT
REMOTE SHALLOW ANODE GROUND BEDS	a) Measure anode-to-soil potentials at 0.6-meter (2-foot) intervals along the length of the anode bed, beginning 3 meters (10 feet) before the first anode, and ending 3 meters past the last anode in the ground bed. b) Plot test results on graph paper to give a visual indication of the anode bed condition.
DISTRIBUTED SHALLOW ANODE GROUND BEDS	Measure one anode-to-soil potential with the reference cell located directly over each anode.
DEEP ANODE GROUNDBEDS	a) In lieu of anode potential measurements, measure anode circuit current using (in order of preference) a clamp-on milliammeter, a multimeter measuring millivolts across a calibrated shunt, or a multimeter connected in series measuring milliamperes. b) Measure the anode current for each anode if separate leads are available.

Table 1.7

Recommended Over-the-Anode Intervals for the Impressed Current Anode Bed Survey

1.7 IMPRESSED CURRENT SYSTEM CHECK. The impressed current system check is an operational check of the impressed current system to ensure the system is operating at the same level as the last close-interval corrosion survey or corrosion survey. This is a non-interrupted check and the potential measurements should be compared to previous ON cycle potential measurements. The locations for the potential measurements must be taken from the last close-interval corrosion survey, or corrosion survey, whichever is most recent, to reasonably ensure that the current output of the system is still being applied and is still sufficient.

1.7.1 MAINTENANCE INTERVALS. The recommended period for conducting the impressed current system check is within 60 days of the last close-interval survey, corrosion survey, or impressed current system check. More frequent checks may be required by public law or local regulations. Note: Underground storage tank CP rectifiers must be inspected at a frequency not exceeding 60 days to ensure compliance with regulations. Check with your state EPA authorities as state regulations may be more stringent or may impose additional requirements.

1.7.2 MINIMUM REQUIREMENTS

1.7.2.1 MEASURE RECTIFIER DC VOLTAGE AND DC AMPERE OUTPUTS.

1.7.2.2 ENSURE THE DC AMPERE OUTPUT OF THE RECTIFIER meets the current (ampere) requirement found on the last close-interval or corrosion survey. If necessary, adjust the rectifier output, and measure outputs again. Repeat procedure as necessary.

1.7.2.3 CALCULATE THE RECTIFIER SYSTEM CIRCUIT RESISTANCE by dividing the rectifier DC output voltage by the rectifier DC output current. If the rectifier has more than one circuit, calculate the resistance of each circuit.

1.7.2.4 TAKE S/E POTENTIAL MEASUREMENTS at the locations of the three lowest and three highest potential measurements identified in the most recent close-interval or corrosion survey.

1.7.2.5 COMPARE THE POTENTIAL MEASUREMENTS to previous measurements at the same locations and determine if changes have occurred. If potential measurements do not satisfy criteria in Chapter 6, and the rectifier current output meets the current requirement from the last survey, adjust or supplement the CP system as necessary. Conduct a corrosion survey 30 days after adjustment or modification to the cathodic protection system.

1.8 GALVANIC ANODE CHECK. The galvanic anode system check is conducted to determine its operational condition. It is normally conducted as part of the close-interval survey, corrosion survey, or water tank calibration surveys described in Paragraphs 1.2, 1.3, and 1.4.

1.8.1 PROCEDURE

1.8.1.1 MEASURE THE POTENTIAL of the structure with the reference electrode located directly over the structure, adjacent to an anode (structure-to-earth, DC volts).

1.8.1.2 MEASURE THE POTENTIAL of the structure with the reference electrode located directly over the structure, midway between anodes (remote structure-to-earth, DC volts). In this case, remote is as far as possible from the anodes, directly over the protected structure.

1.8.1.3 DISCONNECT THE ANODE LEAD from the structure and measure potential of the anode with the reference electrode located directly over the anode (anode-to-earth, DC volts).

1.8.1.4 MEASURE STRUCTURE-TO-ANODE CURRENT (anode output current, mA).

1.8.1.5 COMPARE MEASUREMENTS to those previously taken at the same location. Loss of anode-to-earth potential indicates a failed anode or failed anode lead. Loss of anode output current with stable anode-to-earth potential indicates consumption of the anode and pending failure. Loss of structure-to-earth potential with stable anode-to earth potential and anode output current indicates loss of isolation.

1.9 RESISTANCE BOND CHECK. The resistance bond check is an operational check of two metallic structures connected with some type of semi-conductor or resistor, to ensure that the structures affected by the bond are maintained at proper levels and interference is mitigated. This bond may include reverse current switches, diodes, resistors, or other protective devices whose failures would jeopardize structure protection. These bonds may be between different sections of a protected structure, or may be between a protected structure and any other metallic structure (unprotected or protected with a different cathodic protection system). This is a non-interrupted check and the potential measurements should be compared to previous ON cycle potential measurements taken at the same locations. The locations for the potential measurements and meter connections must be the same and the operational status of any cathodic protection system must be known.

1.9.1 MAINTENANCE INTERVAL. The recommended period for conducting the resistance bond check is within 60 days of the last check or immediately following failure of the CP system protecting either (or both) sides of the bond (unless immediate repair of the failure is possible). More frequent checks may be required by public law or local regulations.

1.9.2 MINIMUM REQUIREMENTS

1.9.2.1 MEASURE RECTIFIER DC voltage ampere output of the cathodic protection system on either (or both) sides of the resistance bond.

1.9.2.2 MEASURE THE DC AMPERE CURRENT flow through the bond and annotate the direction of the current flow.

1.9.2.3 MEASURE POTENTIAL OF THE METALLIC STRUCTURES on both sides of the bond.

1.9.2.4 EVIDENCE OF PROPER FUNCTIONING may be current output, normal power consumption, a signal indicating normal operation, or satisfactory cathodic protection levels on the structures, according to the function or design of the bond.

1.9.2.5 COMPARE MEASUREMENTS to measurements previously taken at the same locations to determine if changes have occurred.

1.9.2.6 IF THE POTENTIAL MEASUREMENTS, current flow, current direction, or other measurement has changed from the last check, adjust or repair the component as necessary, and repeat the test of the bond.

1.10 LEAK SURVEY. The leak survey is a comprehensive, thorough survey to identify the cause of all leaks and the action required to prevent future leaks from occurring, or to reduce the leak rate.

1.10.1 MAINTENANCE INTERVAL. Leak surveys should be conducted after excavation, before backfilling of any leak on any pipeline or tank.

1.10.2 MINIMUM REQUIREMENTS

1.10.2.1 MEASURE THE PH of the soil where it contacts the pipeline or tank.

1.10.2.2 MEASURE THE "AS FOUND" S/E POTENTIAL of the pipe or tank where it contacts the soil. "As found" means before any adjustments of existing cathodic protection systems, addition of any form of cathodic protection, or installation of isolation or bonding components.

1.10.2.3 DETERMINE the cause of the leak.

1.10.2.4 EVALUATE the condition and determine appropriate repairs to the pipe or tank coating system.

1.10.2.5 MEASURE the "as left" S/E potential of the pipe or tank where it contacts the soil. "As left" means after all actions are taken to prevent future leaks. If these actions are taken after backfill operations, surface potentials are usually acceptable.

1.10.2.6 IF THE LEAK SURVEY DETERMINES the cause to be corrosion, determine the type of corrosion. Table 1.8 lists recommended corrective actions to prevent future leaks:

CP SYSTEM TYPE	RECOMMENDED ACTION
STRUCTURE NOT CATHODICALLY PROTECTED	a) Take appropriate action to reduce the possibility of future leaks according to the type of corrosion found. b) Determine the presence of interference, and if found, take action to mitigate interference corrosion. c) Install isolation couplings, electrical continuity bonds, or cathodic protection as appropriate.
STRUCTURE CATHODICALLY PROTECTED	a) Troubleshoot, repair, or adjust existing CP system. b) Supplement the existing CP system until protection is achieved, if necessary. c) Conduct a corrosion survey of the system 30 days after any repairs, adjustments, or installations.

Table 1.8

Recommended Corrective Actions for Preventing Leaks

1.10.3 GALVANIC ANODE SYSTEMS. Galvanic anode systems are typically used in low resistivity soil, or on small or well-coated structures, or as “hot spot” protection on unprotected structures. Galvanic anodes may be easily installed before the backfill operation. Impressed current systems are typically used in high resistivity soil or on large or poorly coated structures. Also, consider bonding to an existing impressed current system.

1.11 RECORD KEEPING REQUIREMENTS. Historical records should be maintained of all surveys and inspections for the life of the protected structure. This is important for maintaining proof of cathodic protection and for a reference for troubleshooting or repair of the system.

Each CP system should have a folder with the following information on permanent file:

- Drawings of CP system from as-builts or other sources showing the location of all components.
- Drawings of the structure protected by the system showing all casings, foreign line crossings, test points, dielectrics, test stations or other pertinent information.
- Close-interval corrosion surveys and corrosion surveys (water tank calibration records for water tanks) conducted on the system.
- Rectifier operational checkout records (if impressed current system).
- Impressed current anode bed surveys (if impressed current system).
- Impressed current system checks (if impressed current system).
- Leak survey data records for the structure protected.
- Any other pertinent data of historical significance, such as anode drawings, anode data, manufacturer data, source of supply, anode types, rectifier data sheets, wiring diagrams, manufacturer’s data or manufacturer’s manual, contract information, in-house drawings, or life cycle estimates or information.

2. UNSCHEDULED MAINTENANCE REQUIREMENTS

2.1 INTRODUCTION. Impressed current cathodic protection systems require a higher level of maintenance than sacrificial (galvanic) CP systems. More things can, and do, go wrong. There are five major components to the operational impressed current system: the rectifier, the anode bed, the structure lead, the anode lead (header cable), and the structure. There are two major components to the operational sacrificial system: the anode and the structure lead. If adequate cathodic protection does not exist on the protected structure, then troubleshooting must be accomplished to determine the cause of this lack of protective current.

2.1.1 TROUBLESHOOTING. The starting point for all troubleshooting for impressed current systems is at the rectifier. Indications of all problems are present at this location. The greatest aids to troubleshooting are historical data and drawings of the system. Usually, the fault may be isolated, then verified by testing.

2.1.2 PROCEDURES. For impressed current systems, there are sufficient test points on the face plate of the rectifier to isolate the faulty component. Follow the troubleshooting procedures in Paragraph 2.2; the typical rectifier wiring diagram, Figure 2.2; the troubleshooting block diagram, Figure 2.1; the shunt multiplication factor, Figure 2.3; and the anode gradient samples, Figure 2.6. The starting point for all troubleshooting for galvanic systems is at the anode (or anode connection). For galvanic systems, there must be an anode test lead for conclusive testing of the anodes. For isolation of a fault to the major component, follow the troubleshooting procedures in Paragraph 2.4.

2.2 TROUBLESHOOTING IMPRESSED CURRENT SYSTEMS WARNING: All connections should be made with alligator clip leads with the rectifier circuit breaker or power switch OFF. If needlepoint leads are used with power ON, employ electrical safety practices for working with live circuits.

2.2.1 DC VOLTAGE. Measure the DC voltage output of the rectifier with a handheld multimeter. With power ON, scale on DC volts, measure voltage from N4 to P4 (Figure 2.2). One of three conditions may exist: voltage may be near zero (proceed to Paragraph 2.2.1.1), near half of normal (proceed to Paragraph 2.2.1.2), or near normal (proceed to Paragraph 2.2.1.3).

2.2.1.1 NO DC VOLTAGE INDICATES that one of the components in the rectifier is faulty or there has been a loss of AC power (proceed to Paragraph 2.2.5).

2.2.1.2 HALF THE NORMAL VOLTAGE OUTPUT indicates defective diodes/selenium plates or improper AC input. Proceed to Paragraph 2.2.5 to check the AC input to the stacks and Paragraph 2.2.7 to troubleshoot the diodes/selenium plates.

2.2.1.3 NORMAL DC VOLTAGE indicates a break in the anode lead, failed anodes, or a break in the structure lead (proceed to Paragraph 2.2.). If the voltage is normal and the rectifier voltmeter reads significantly different, the connections or the voltmeter are faulty (proceed to Paragraph 2.2.1.3a). WARNING: AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. All connections inside the rectifier cabinet should be made with alligator clip leads connected with the power to the rectifier OFF. If needlepoint leads are used with power ON, use prudent electrical safety practices for working with live circuits.

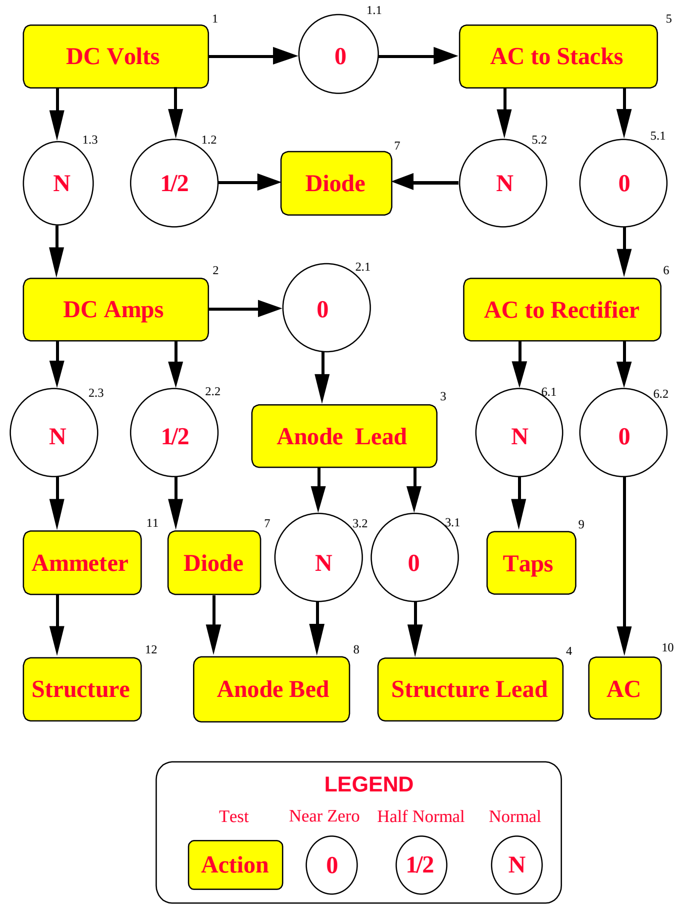

Figure 2.1

Troubleshooting Block Diagram

- With power OFF, check for loose connections from P2 to P3, N2 and N5 through N7, including any press-to-test switch or button, and continuity of all wires between those points. This will require disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation. Repair or replace loose connections and replace damaged or broken wires. If problems are not found, proceed with Paragraph 2.2.1.3b.

- With power OFF, remove voltmeter from rectifier. This will require disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Disconnect one end of the resistors on reverse side of meter. Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter). Replace resistor or meter as required.

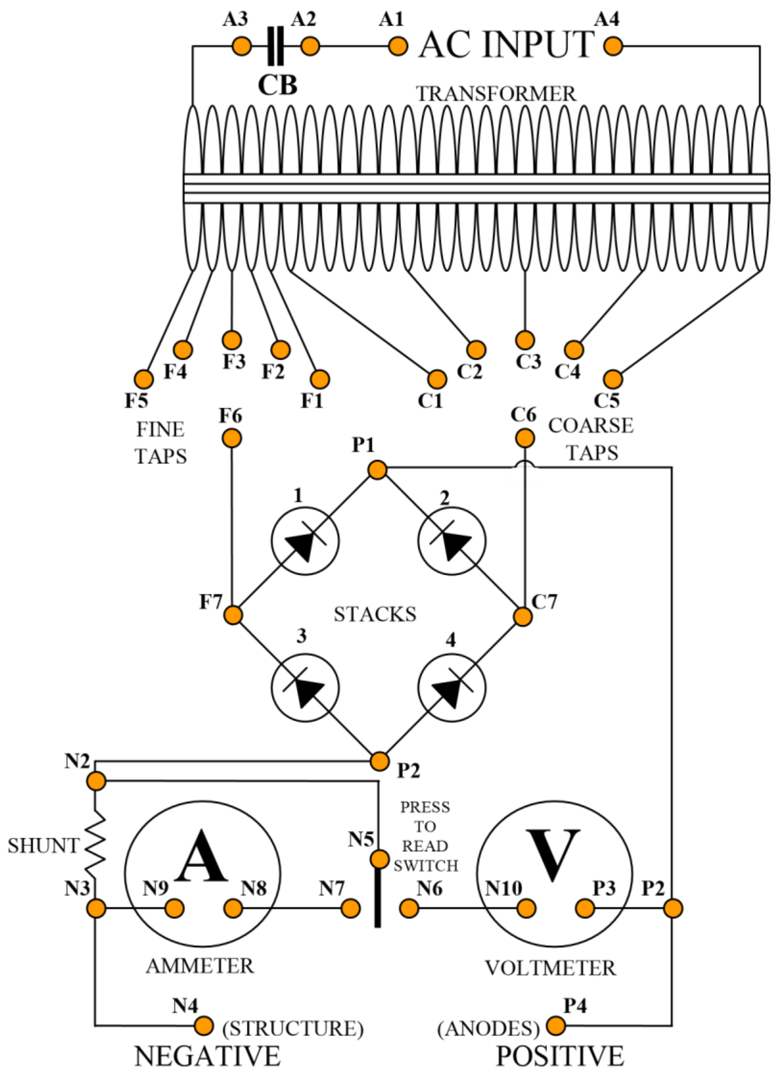

Figure 2.2

Typical Rectifier Wiring Diagram

2.2.2 DC CURRENT. Measure the DC current output of the rectifier with a handheld multimeter on the mV scale. Measure mV from N2 to N3. Multiply the indicated reading by the appropriate multiplication factor (Figure 2.3). One of three conditions may exist: the current may be near zero (proceed to Paragraph 2.2.2.1), near half of normal (proceed to Paragraph 2.2.2.2), or be near normal (proceed to Paragraph 2.2.2.3).

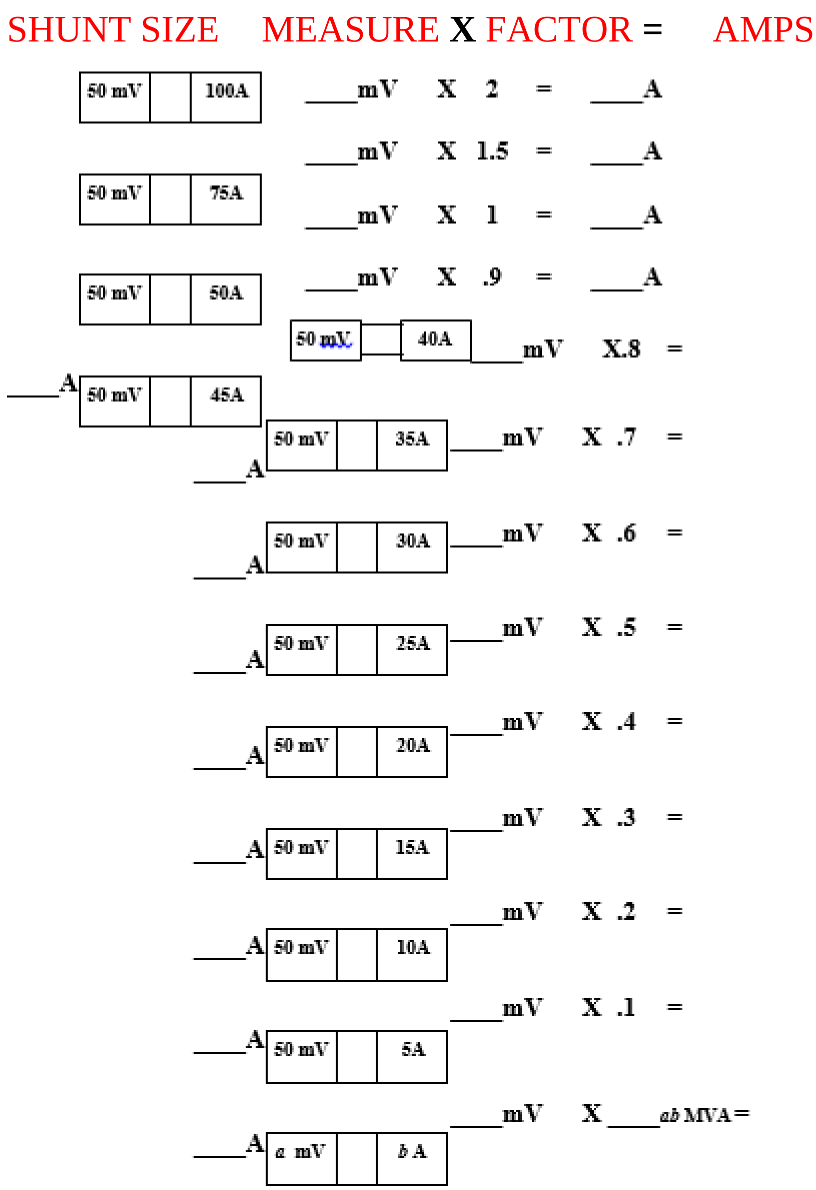

Figure 2.3

Shunt Multiplication Factors

2.2.2.1 NORMAL DC VOLTAGE with near zero current indicates a break in the anode lead, failed anodes, or a break in the structure lead (proceed to Paragraph 2.2.3).

2.2.2.2 HALF THE NORMAL CURRENT OUTPUT indicates either a defective diode/selenium plate; a break in the header cable between anodes; or, if there are multiple anode leads, loss of one anode lead or anode bed. Measure the DC voltage output of the rectifier with a handheld multimeter on the DC volts scale. Measure voltage from N4 to P4. If voltage is also half of normal, proceed to Paragraph 2.2.7 to troubleshoot the diodes/selenium plates. If voltage is normal, proceed to Paragraph 2.2.8 to troubleshoot the anode bed.

2.2.2.3 IF THE CURRENT IS NORMAL and the rectifier ammeter reads significantly different, either the shunt, the connections, or the ammeter is faulty (proceed to paragraph 2.2.2.3a). If the current is normal, the rectifier ammeter reads normal, and structure potentials are still significantly changed from normal, proceed to Paragraph 52.2.3d.

a) Measure the DC current with a handheld multimeter connected in series and with the meter on the DC amps scale. Disconnect anode header cable at P4 and measure current from P4 to anode lead. Compare the measured current value to the current value taken in Paragraph 2.2.2. If values are significantly different, replace the shunt. If values are the same, proceed with Paragraph 2.2.2.3b. WARNING: AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. All connections inside the rectifier cabinet should be made with alligator clip leads connected with the power to the rectifier OFF. If needlepoint leads are used with power ON, observe prudent electrical safety practices for working with live circuits.

b) With power OFF, check for loose connections from N2 through N9, including any press-to-test switch or button, and continuity of all wires between those points. This will require disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation. Repair or replace loose connections and replace damaged or broken wires. If problems are not found, proceed with Paragraph 2.2.2.3c.

c) With power OFF, remove ammeter from rectifier. This will require disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Disconnect one end of the resistors on reverse side of meter. Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter). Replace resistor or meter as required.

d) Normal current values accompanied by loss of potential shifts indicate a change in the protected structure. If the protected structure is isolated, check all dielectrics and repair or replace faulty ones. If the protected structure is not isolated, check for additions to the protected structure, or new structures in the area which are continuous with the protected structure, increase current to protect larger structure(s), isolate other structure(s), or install additional impressed current system(s) as required.

2.2.3 ANODE LEAD WIRES. With power OFF, disconnect anode lead(s) at P4. Use an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods, and connect to P4 (positive terminal). For a short period of time, turn power ON and note AC current (Paragraph 2.2.2). One of two conditions exists: either current is now present (changed); or it is not present (not changed). Note: If the structure being tested is the inside of a water tank or tower, and the lack of water will not allow current flow (no electrolyte), fill the tank, and then retest.

2.2.3.1 CURRENT IS PRESENT. If current exists, the anode lead is broken or the anodes have failed (proceed to Paragraph 2.2.8).

2.2.3.2 CURRENT IS NOT PRESENT. If no current exists, the structure lead may be broken (proceed to Paragraph 2.2.4).

2.2.4 STRUCTURE LEAD. For this test, the temporary or alternative anode should remain connected to terminal P4 as described previously in Paragraph 2.2.3. With power OFF, disconnect structure lead at N4. Use an alternative isolated metallic structure (isolated from structure being tested, if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods, and connect to N4 (negative terminal). For a short period of time, turn power ON and note AC current (Paragraph 2.2.1). One of two conditions exist, either current is now present (changed) (proceed to Paragraph 2.2.4.1); or it is not present (not changed) (proceed to Paragraph 2.2.4.2).

2.2.4.1 SINCE CURRENT IS NOW PRESENT, the structure connection is broken. Use the fault detector and cable locator, connected directly to the structure lead at N4, to trace the structure lead from the rectifier towards the structure. This can be extremely difficult in some cases. An alternative method is to locate the first structure connection (from drawings, markers, or induction methods). Excavate to the structure and measure continuity back to the rectifier using a cathodic protection multi-combination meter continuity check circuit. Use the fault detector and cable locator, connected directly to the structure lead, to trace the lead from the structure towards the rectifier. If this is still unsuccessful, replace the structure lead from the rectifier to the structure. Note: When using the direct connection method, it is essential to have a low-resistance isolated ground for the fault detector or cable locator to put a strong locator signal on the cable under test.

2.2.4.2 IF CURRENT STILL DOES NOT EXIST (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, then repeat Paragraph 2.2.3.

2.2.5 AC VOLTAGE TO STACKS. Measure the AC voltage input to the stacks of the rectifier with a handheld multimeter on the AC volts scale. Measure voltage from F6 to C6 (tap bars). One of two conditions may exist: voltage may be near zero (proceed to Paragraph 2.2.5.1), or near normal (proceed to Paragraph 2.2.5.2).

2.2.5.1 VOLTAGE NEAR ZERO. This indicates loss of AC power to the rectifier, bad fuses or circuit breakers, or a bad transformer (or connections) in the rectifier (proceed to Paragraph 2.2.6).

2.2.5.2 VOLTAGE NEAR NORMAL. This indicates faulty diodes/selenium plates or bad connections inside the rectifier (proceed to Paragraph 2.2.7). If the rectifier does not have taps, proceed to Paragraph 2.2.6; if that test is normal, the rectifier must be removed from the cabinet for checkout. Refer to specific rectifier manual to troubleshoot the diodes/selenium plates and the transformer. For general reference, see Paragraph 2.2.7 for the stacks and Paragraph 2.2.9 for the transformer.

2.2.6 FUSES. Check all fuses and measure AC voltage input to the rectifier. With power OFF, remove all fuses at the rectifier and any fusible disconnect. Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse. Corrosion on fuse end caps or fuse holders will also cause loss of voltage. Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found. If a disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale. Measure the voltage on the rectifier side of the disconnect. If a disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale. For 110/120 volt, single-phase rectifiers turn power to the rectifier OFF, open cabinet and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker. For 220/240 volt, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead (not shown on drawing). If voltage is present, proceed to Paragraph 2.2.6.1. If voltage is not present, proceed to Paragraph 2.2.6.2.

2.2.6.1 VOLTAGE IS PRESENT. This indicates either the transformer or the connections inside the rectifier are faulty (proceed to Paragraph 2.2.9).

2.2.6.2 VOLTAGE IS NOT PRESENT. This indicates loss of AC Power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volt scale. For 110/120 volt, single-phase rectifiers turn power to the rectifier OFF, open cabinet and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier. For 220/240 volt, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead (not shown on drawing). If voltage is not present, proceed to Paragraph 2.2.10; or if voltage is present, replace circuit breaker or fuse.

2.2.7 DIODES. Check the diodes/selenium plates of the rectifier with a handheld multimeter on the diode check scale. With power OFF, remove the tap bars or shorting wires and the anode lead (P4) and/or the structure lead (N4). Check the diode/selenium plate sets by connecting one test lead to N4 and the other to F6 (diode 3), then to C6 (diode 4). Both should beep or not beep. Reverse test leads and repeat connections. The beep should be opposite (both should "not beep" or "beep"). Repeat the test using P4 instead of N4 to test diodes/selenium plate sets (diodes 1 and 2). Note: An ohms scale may be used. A good diode has very high resistance in one direction and low resistance in the other direction. With power OFF, check for loose connections from F6 to F7, C6 to C7, P1 to P2, P2 to P4, and N1 through N4, and continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If no problems are found, replace the stacks.

2.2.8 ANODE BED. Before a great deal of time is expended troubleshooting an anode bed, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault. Generally, if the current and time is calculated to amp years, comparing that number to the weight of the installed anodes and the weight loss of the anode material will indicate if the anodes are expended or have significant life remaining. Another indicator is if a gradual failure occurred over a period of time, the anodes have failed. If the failure was sudden, a cable break can be expected. If failed anodes are found, replace the anode bed. If a broken anode lead is found, repair the cable. The first step to locating the break is to find the location of any excavations that have occurred in the area of the anode cable. There are two methods of troubleshooting anode beds, depending upon whether all anodes have failed (no current), or some (or most) of the anodes have failed. If one or more anodes are functioning, see Paragraph 2.2.8.1. If no anodes are functioning, see Paragraph 52.8.2.

2.2.8.1 IF ONE OR MORE ANODES ARE FUNCTIONING, the best method is first to locate the functioning anodes, then an anode bed gradient graph to isolate and locate the problem. Note: If separate anode lead wires in a junction box were installed, use these to measure the anode current and determine the functioning anodes.

Perform a close interval survey over the anode bed. For the purpose of troubleshooting, you may adjust the rectifier to the highest voltage setting that would not result in coating damage to the structure, to allow easier location of the anodes. Measure the potentials over the anodes with a handheld multimeter on the DC volts scale. With power ON, connect the positive lead of the multimeter to the structure lead (N4) of the rectifier. Using a copper/copper sulfate reference cell connected to the negative lead of the multimeter, locate the point of highest voltage on the surface of the ground (this will be directly over an anode). Repeat by locating all operational anodes. Mark each anode found and compare to system drawings. Starting in a straight line 3 meters (10 feet) from the first anode, perform a potential test every 0.6 meters (two feet) over the entire length of the anode bed, to a point 3 meters (10 feet) past where the last anode is (or is supposed to be) located. Using graph paper, and using vertical lines to represent the measured potentials, and horizontal lines to represent the 0.6-meter (twofoot) intervals, graph all readings. This will show the condition of all anodes, and will indicate if a broken header cable (anode lead) or failed anodes exist. It will show a broken cable between functional and non-functional anodes. If anodes are failing, the gradients will peak differently, or the gradients will fall, then rise intermittently.

2.2.8.2 IF NO ANODES ARE OPERATIONAL, use the fault detector and cable locator, connected directly to the anode cable P4, to trace the anode lead from the rectifier towards the anode bed. This can be extremely difficult in some cases. An alternative method is to locate the first anode (from drawings, markers, or induction methods). Excavate to the first anode and measure continuity back to the rectifier using a cathodic protection Multi-Combination meter continuity check circuit. Use the fault detector and cable locator, connected directly to the anode to trace the anode lead from the anode towards the rectifier. If this is still unsuccessful, replace the anode lead from the rectifier to the anode. Note: When using the direct connection method, it is essential to have a low-resistance isolated ground for the fault detector or cable locator to put a strong locator signal on the cable under test.

2.2.9 RECTIFIER TAPS. Measure the AC voltage on the taps of the rectifier with a handheld multimeter on the AC volt scale. Remove the tap bars or shorting wires. Measure the voltage from F5 to F4, F4 to F3, F3 to F2, F2 to F1, and F1 to C1. All readings should be approximately the same. Measure the voltage from C5 to C4, C4 to C3, C3 to C2, and C2 to C1. All readings should be approximately the same. Any lead that tests different must be checked for connection (proceed to Paragraph 2.2.9.1). Note: On some rectifiers, F1 to C1 may be a unique voltage.

2.2.9.1 WITH POWER OFF, check for loose connections from F1 through F5 and C1 through C5, including any tap bar or shorting wire, and continuity of all wires between those points. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation. Repair or replace loose connections and replace damaged or broken wires, if possible. If only one tap is inoperative, a different tap setting may be operational, and testing will reveal functioning taps. If replacement of wire is not possible, replace the transformer. If no problems are found, proceed with Paragraph 52.9.2.

2.2.9.2 WITH POWER OFF, check for loose connections from A2 through A4 and continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If replacement of wire is not possible, replace the transformer. Note: Checkout of transformers or pole fuses require personnel certified for work on high voltage lines and proper equipment beyond the scope of these procedures.

2.2.10 RECTIFIER INPUT VOLTAGE. First verify that the circuit breaker has not tripped or the fuse has not blown. If properly operating, measure the AC voltage from the circuit breaker or fuse where power is supplied to the rectifier with a handheld multimeter on the AC volts scale. For 110/120 volt, single-phase systems, open the circuit breaker panel or fuse panel and connect meter to the output of circuit breaker or the output side of the fuse (not shown on drawing) and ground or neutral bar. For 220/240 volt, single-phase systems, use the same procedures, but connect the meter to the output lugs of the circuit breakers or the output side of the fuses. If voltage is not present, proceed to Paragraph 2.2.10.1. If voltage is present, locate the break in the power feed from that point to the rectifier circuit breaker (or rectifier fusible disconnect, whichever was last tested).

2.2.10.1. MEASURE THE AC VOLTAGE to the circuit breaker or fuse supplying power to the rectifier with a handheld multimeter on the AC volt scale. For 110/120 volt, single-phase systems open the circuit breaker panel or fuse panel and connect the meter to the main lugs of the circuit breaker panel or the input side of the fuses (not shown on drawing) and ground. For 220/240 volt, single-phase systems, use the same procedures, but check individual legs separately. If voltage is not present, locate the circuit breaker panel or transformer supplying power to the panel and repeat Paragraph 2.2.10; if voltage is present, replace the circuit breaker or fuses.

2.3 IMPRESSED CURRENT SYSTEM COMMON PROBLEMS. Table 2.1 lists common problems associated with impressed current cathodic protection systems and the symptoms of these problems.

SYMPTOM	POSSIBLE CAUSE
Zero output current and slight increase in output voltage. Historical data indicates that output has remained relatively constant for a long period of time.	Broken anode lead (header cable)
	Broken structure lead
Zero output current and maximum output voltage. Historical data shows that system voltage increased several times and output current decreased slowly at first, then faster as time progressed	Failed anode bed
Zero output current and/or zero or minimal output voltage. No historical data immediately available	Loss of AC power
	Defective meters
	Broken anode or structure leads
	Blown fuses or tripped circuit breakers
	Defective lightning arrester
	Defective stacks or transformer
	Loose or bad wire connections
Blown fuses or tripped circuit breakers.	Lightning or other power surges
	Electrical short circuits
	Sudden decrease in soil resistivity (long period of heavy rain)
Rectifier voltage suddenly about half of normal. Rectifier output required to be turned up to regain proper amount of current.	Rectifier is half waving. One of the diodes or selenium plates burned out.
Rectifier output current decreased, but voltage near normal.	Failure of some anodes or anode leads. Soil dried out (increase resistivity)

Table 2.1

Common Impressed Current Rectifier Problems

2.4 TROUBLESHOOTING GALVANIC (SACRIFICIAL) CATHODIC PROTECTION SYSTEMS. Galvanic cathodic protection is inherently maintenance-free. The current is merely a result of the potential difference of the two metals. Recurring maintenance checks are performed to ensure continued satisfactory performance. Galvanic anodes sacrifice themselves to protect the structure. They normally consume themselves at a constant rate and failure can be predicted by current measurement versus time.

2.4.1 COMMON PROBLEMS. The most common problem in sacrificial anode systems are shorts around or failure of dielectrics on isolated protected structures. Due to the very limited voltage, sacrificial anodes usually cannot supply sufficient current to protect the structures if isolation is lost. On well-coated structures, the contact resistance to earth is high. Other metals in the earth that are not coated have a very low contact resistance, providing a low resistance path for anode current. Maintaining the dielectrics in an isolated system is essential to continued satisfactory performance of sacrificial anode systems. One failed dielectric can result in loss of protection for the entire system.

2.4.2 LEAD WIRES. Failure of the anode lead wires is uncommon, since copper exposed by nicks or insulation defects is cathodically protected by the anodes. However, these wires can be cut by extraneous excavations. Exercising control over digging permits in the areas of the anode ground beds may ensure that if the wires are cut, they can be repaired on site, before backfilling occurs. Troubleshooting to locate the break at a later date is usually not successful, and replacement of a prematurely failed anode is more economical in almost all cases. A sudden zero anode current output reading indicates probably failed lead wires.

2.4.3 ANODE CONSUMPTION. When sacrificial anode systems reach the end of their useful life, potential, current, and voltage measurements begin to change. When performing recurring maintenance, a significant drop in anode current indicates imminent failure of the anode. Potential measurements over the protected structure will begin to show dips or drops in the areas of failed anodes. A significant drop in anode potential indicates a failed anode. Anode current may actually reverse after failure, due to the copper center tap of the anode being cathodic to the protected structure. When drops in the potential of the protected structure begin to occur, a closer inspection should be made to determine the extent of the damage to the anodes.

2.4.4 IMPROPER USE. Except on small or extremely well coated structures, such as underground storage tanks or short pipelines with butyl rubber/extruded polyethylene coatings, it is normally not economical to replace a distributed galvanic anode system. When galvanic anodes begin to fail on a distributed system, impressed current cathodic protection should be considered.

2.5 INTERFERENCE TESTING. Although impressed current cathodic protection systems overcome all of the shortcomings of galvanic cathodic protection systems, there are problems. The two main problems are that impressed current CP systems require a higher level of maintenance and there is a possibility of interference corrosion on other metallic (foreign) structures. Interference corrosion is the most serious form of corrosion. When a metallic structure experiences interference corrosion, 9.4 kilograms (20.7 pounds) of steel is transformed to iron-oxide for every ampere of current which flows for one year. For a coated pipeline, this current is leaving from the holidays and the time to failure is extremely short. Whenever signs of interference corrosion are noted on any scheduled maintenance or leak survey, emergency steps must be taken to preclude further damage to the structure.

2.6 INTERFERENCE CORROSION CONTROL. Cathodic protection interference, whether caused by the influence of cathodic protection systems or by other current sources, can be effectively controlled. Examples of typical corrective actions are presented in this manual to illustrate some of the methods employed and to show how to perform field measurements to determine the continuing effectiveness of the corrective measures. Correction of actual interference problems is beyond the scope of this manual. When interference is suspected, assistance in correcting the problem can be obtained through the local Engineering Field Division.

2.6.1 CORRECTING INTERFERENCE. One method of correcting interference is to bond the foreign structure to the protected structure. Thus, both are protected. Figure 2.4 shows correction of an interference problem by bonding. A test station is usually installed at such a location to either verify the continuity of the bond, or to measure the current flowing through the bond. Extra wires to each structure allow potential testing of individual structures using a non-current carrying conductor results in a four-wire test station. Current measurements are normally taken using a calibrated shunt. Other methods include using a clamp-on ammeter (or milliammeter), or disconnecting and measuring in series using a low input resistance ammeter.

2.6.2 DIRECT BONDING. Direct bonding is often not desirable, either because the existing cathodic protection system cannot supply enough current to protect both structures, or the foreign structure is not owned by the same organization as the one supplying the current, and minimization of extra current is desired. In this case, a resistive bond is installed between the structures and adjusted so that only that amount of current is supplied to the foreign structure which is required to bring its potential to the same level as it would have been without the interference present. Figure 2.4 shows such an installation. Test stations are normally installed where resistive bonds are used in order to facilitate testing of the corrective action and adjustment or replacement of the resistor. Direct bonding usually is not possible if the protected structure is well coated and the foreign structure is bare or poorly coated. Resistors may fail due to substantial interference currents and the possibility of surges or fault currents. If failure of the resistor would result in loss of adequate protection to a structure that requires cathodic protection, the resistance bond would be considered a “critical bond.” Critical bonds must be tested on a recurring schedule of not less than 60 days.

2.6.3 CONTINUITY. Bonding, as shown in Figure 2.5, is also used to ensure continuity of buried structures, both for the prevention of interference and for the proper operation of cathodic protection systems.

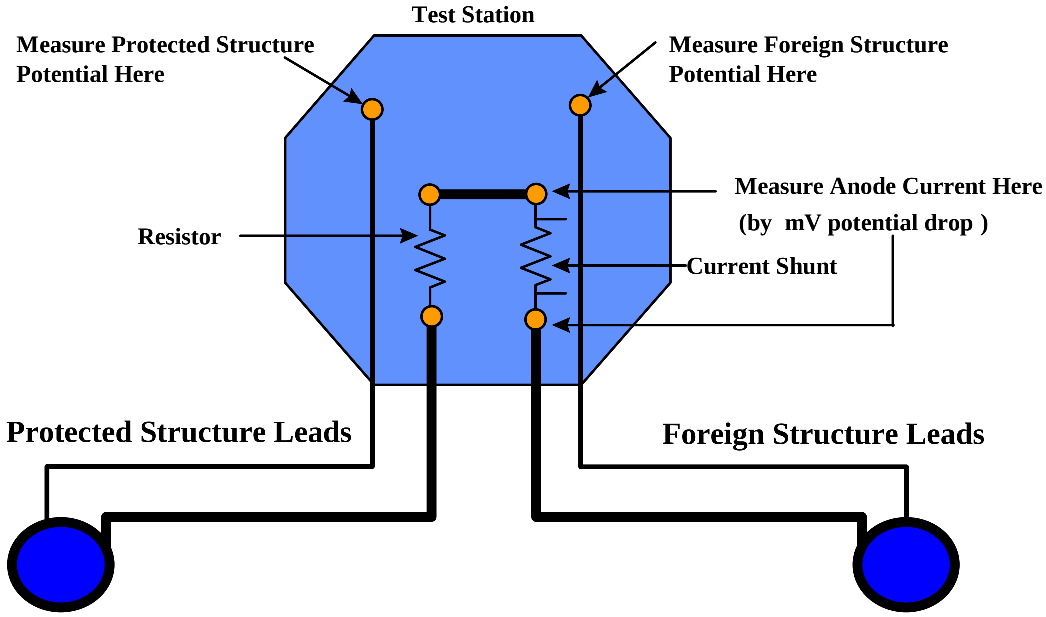

Figure 2.4

Correction of Interference by Resistive Bonding

2.6.4 INSTALLING A SACRIFICIAL ANODE. In some cases, interference is controlled by installing a sacrificial anode or anode bed on the foreign structure to raise the potential of the foreign structure and provide a lower resistance path for discharge current to flow from the installed anodes instead of the foreign structure. The use of a sacrificial anode to control interference is shown in Figure 2.6. This method normally works well when the interference current is fairly low and the foreign structure has a relatively good coating. This method may be combined with coating the cathode (protected structure) near the discharge area to lower the interference current.

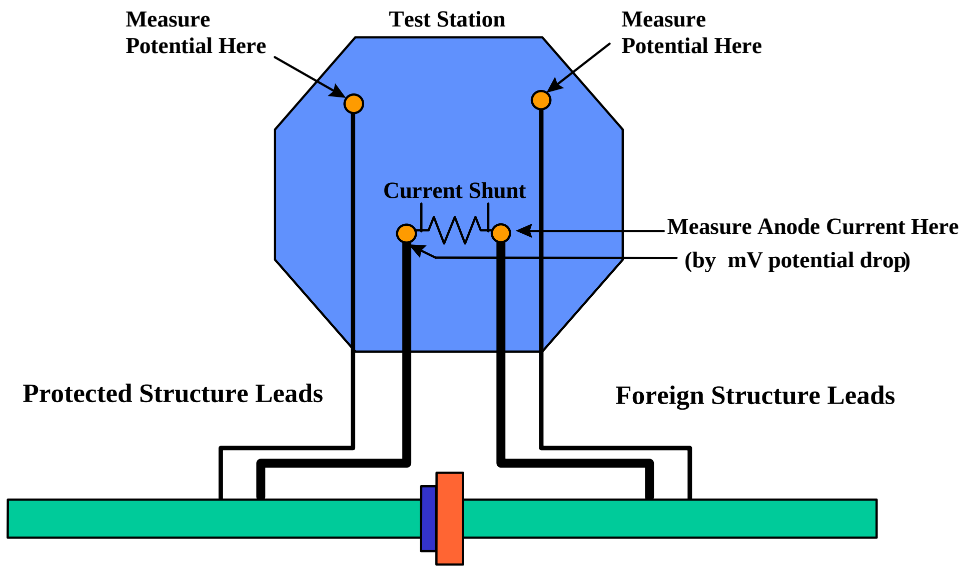

Figure 2.5

Bonding For Continuity

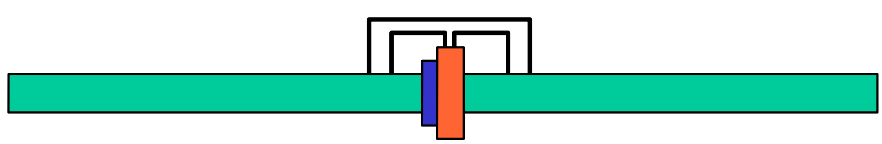

Figure 2.6

Use of Galvanic Anodes to Control Interference

2.6.5 ADDITIONAL COATING. Applying additional coating to the protected structure in the area of the current discharge on the foreign structure raises the resistance of the stray current path, thereby reducing the magnitude of the interference current. This method will usually just lower the interference current, and is used with other methods to stop interference. When interference current levels are very low, this method may be adequate to stop the interference. Although normally used at pipeline crossings, this method could apply to any interference problem. During the installation of a protected structure, additional coatings can be easily installed in areas where stray currents may be expected; for example, at all foreign pipeline crossings or foreign structure crossings (metal fences, metal culverts, electrical grounds). During installation a butyl rubber or similar mastic in combination with extruded polyethylene may be used on the protected structure in these areas. As a retrofit to an existing structure, a primer and tape wrap system may be used, with the additional requirement to excavate and clean the protected structure. This method of interference control is most economically used during the design and installation of the protected structure. As an alternative to applying additional coating, non-conductive barriers are sometimes used between crossing pipelines for similar reason. Barriers do not require uncovering, cleaning, and coating the protected pipeline if it is sufficiently deeper than the foreign structure, and may be more economical in some cases. Barriers must be much larger. Coating the protected structure for 12 meters (40 feet) on each side of a foreign pipeline crossing would be as effective as a 24-meter (80-foot) diameter barrier. This method of interference control is most economically used during the design and installation of the foreign structure. See Figure 2.7 below.

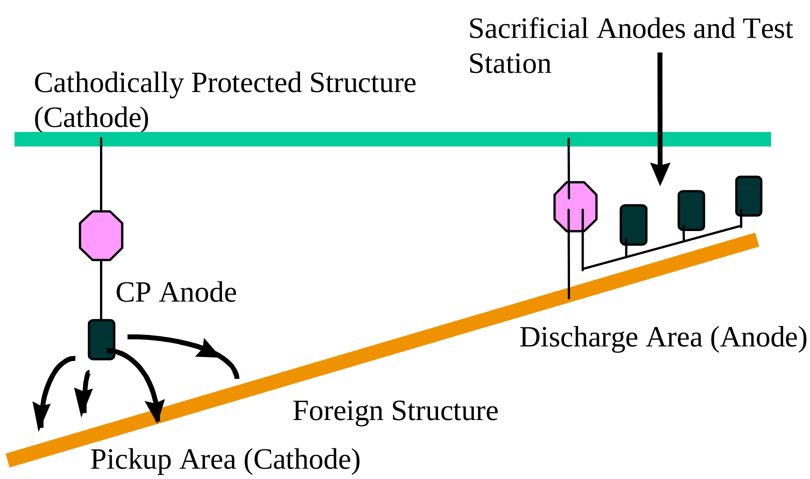

Figure 2.7

Use of Coating Cathode to Control Interference

2.6.6 INSTALLATION OF NONMETALLIC SECTIONS OR ISOLATIONS. Installation of nonmetallic sections or isolations on the foreign structure in the stray current pickup area and between the pickup area and the discharge area may significantly reduce the amount of interference current by substantially raising the resistance of the stray current path. This type of action is usually adequate for metal fences. By isolating sections of fences, use two non-contacting fence posts, wooden fence posts or dielectric materials between the fence hardware and the fence posts. Isolations can be made in the current pickup area and between the pickup area and the discharge area, sometimes supplemented with a sacrificial anode in the discharge area(s). This may be considered as part of a design for an impressed current installation, if there is a continuous metallic fence in the area where an impressed current anode bed is to be installed, or if a metallic fence is to be installed in an area with an existing anode bed. See Figure 2.8 below.

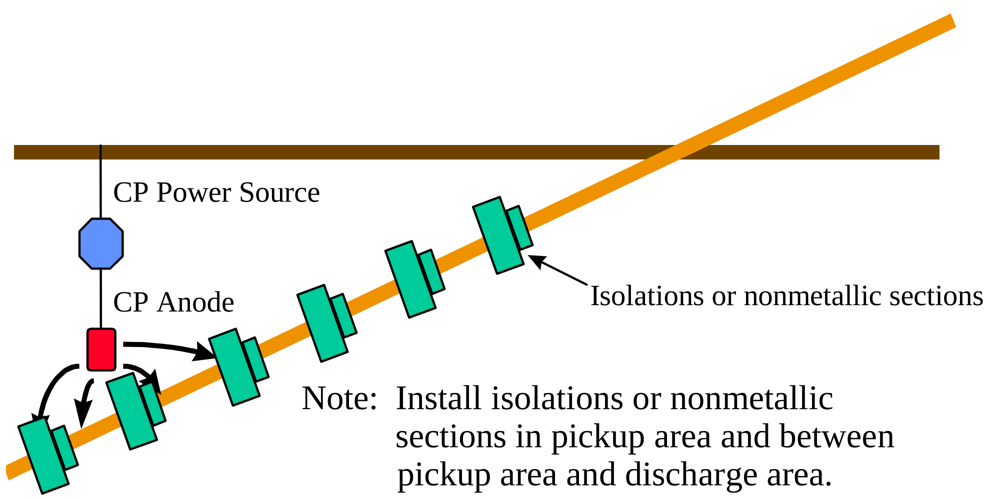

Figure 2.8

Use of Isolation on Foreign Structure to Control Interference

2.6.7 APPLICATION OF A SMALL IMPRESSED CURRENT SYSTEM. For interference problems which are more serious, and where bonding or resistance bonding is not possible or practical, consider the application of a small impressed current system on the foreign structure in the discharge area to protect the foreign structure from stray current corrosion. As shown in Figure 2.6, substituting a rectifier and impressed current anodes for the sacrificial anodes, the corrosion is stopped by the application of sufficient cathodic protection to the discharge area. Caution should be used to balance the two systems, since this installation may interfere with the original protected structure that was causing the stray current corrosion.

2.6.8 COMBINATION OF TECHNIQUES. In many cases, a combination of the preceding mitigation techniques may be prudent. The magnitude of stray current, the soil resistivity, the protected structure coating efficiency, the foreign structure coating efficiency, and the type of foreign structure should be considered to ascertain the most cost effective choice for mitigation techniques. See Figure 2.9 below.

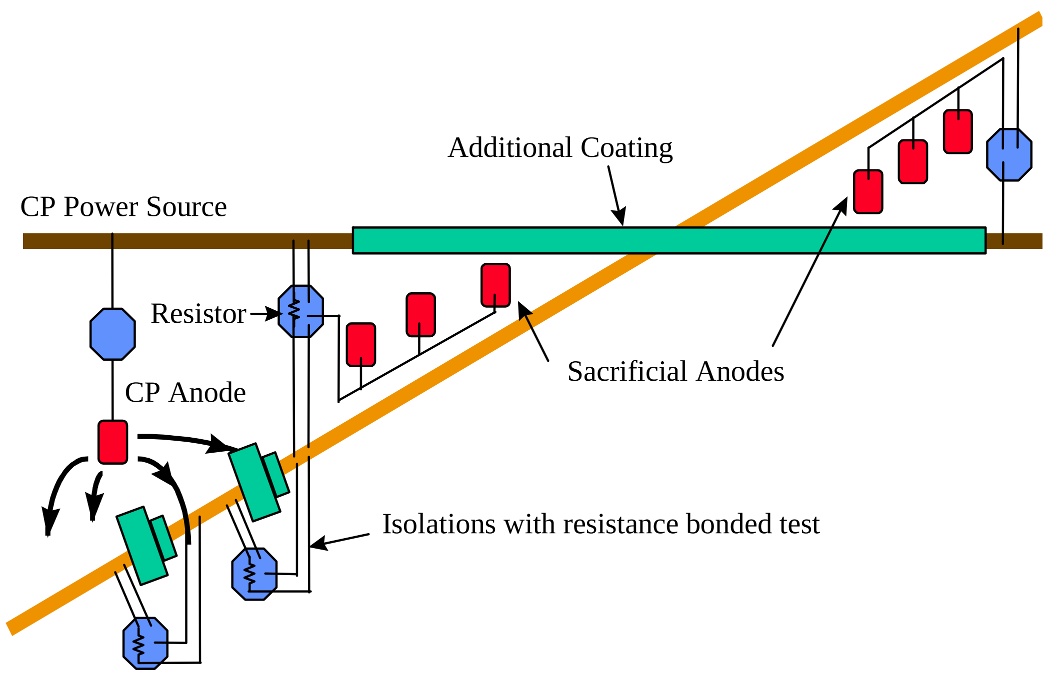

Figure 2.9

Use of a Combination of Mitigation Techniques to Control Interference