Engineering

Technical Guideline

TG 0440 - Cathodic Protection Testing

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1 Introduction

SA Water is responsible for the operation and maintenance of an extensive network of buried pipelines. Cathodic Protection (CP) is applied to a large proportion of buried assets (commonly MSCL pipelines) which assists in the management of external corrosion and is therefore an important asset management tool that can greatly increase asset life.

CP uses an electrical current to polarise the buried asset to a potential that results in zero corrosion current flow, thus preventing corrosion of the material. The electrical current can be supplied by sacrificial anodes in which a material that is more anodic than mild steel (e.g. zinc, magnesium, aluminium), this is electrically connected to form a galvanic corrosion cell with the buried structure. The structure becomes cathodic and current flows from the sacrificial anode onto the structure, thereby protecting the structure from corrosion at the expense of the anodes.

Alternatively, an impressed current CP (ICCP) system can be used to protect the buried asset. In these cases, significantly more current is usually required and this is supplied by a transformer rectifier (TR) unit. The TR provides a power supply that drives current to flow from the anodes to the structure. Inert (non-reactive) materials are used as the anodes in ICCP systems to prevent rapid consumption of the anode material.

Regardless of the type of CP system, the aim is to cause a shift in the potential of the buried asset that satisfies the protection criteria in accordance with AS 2832.1 and SA Water TS 0440:

- An instant OFF potential on all parts of the structure equal or more negative than -850 mV vs a calibrated copper/copper sulphate reference electrode (CSE).
- A polarisation of -100 mV vs CSE. That is an instant OFF potential 100 mV more negative than the natural potential of the structure. This criterion may only be accepted if it is not possible to satisfy the -850 mV criterion and if significant galvanic corrosion couples or stray currents are NOT present.
- The instant OFF potential shall not be more negative than -1050 mV vs CSE to avoid coating damage due to cathodic disbondment.

1.1 Purpose

The purpose of this document is to detail the steps required in the testing of a CP system. This includes electrical safety, pipe-to-soil potential measurements, reference cell calibration, and assessment of the performance of sacrificial and impressed current CP systems. This document also offers some troubleshooting advice for commonly encountered problems.

1.2 Glossary

The following glossary items are used in this document:

Term	Description
A	Amperes
AC	Alternating Current
CP	Cathodic Protection
CSE	Copper/copper sulphate reference electrode
DC	Direct Current
HVAC	High Voltage Alternating Current
ICCP	Impressed Current Cathodic Protection
JSA	Job Safety Analysis
MCB	Main Circuit Breaker

MSCL	Mild Steel Cement Lined
mV	millivolts
SA Water	South Australian Water Corporation
SAPN	SA Power Network
SCADA	Supervisory Control and Data Acquisition
SWMS	Safe Work Method Statement
TG	SA Water Technical Guideline
TP	Test Point
TR	Transformer Rectifier
TS	Technical Standard
V	Volts

1.3 References

1.3.1 Australian and International

The following table identifies Australian and International standards and other similar documents referenced in this document:

Number	Title
AS 2832.1	Cathodic protection of metals, Part 1: Pipes and Cables
AS 2239	Galvanic (sacrificial) anodes for cathodic protection
NACE SP0169	Control of External Corrosion on Underground or Submerged Metallic Piping Systems

1.3.2 SA Water Documents

The following table identifies the SA Water standards and other similar documents referenced in this document:

Number	Title
TS 0440	SA Water: Cathodic Protection Part 1 – Pipelines
TS 0300	SA Water: Supply and Installation of Low Voltage Electrical Equipment

1.4 Definitions

The following definitions are applicable to this document:

Term	Description
SA Water's Representative	The SA Water representative with delegated authority under a Contract or engagement, including (as applicable): • Superintendent's Representative (e.g. AS 4300 & AS 2124 etc.) • SA Water Project Manager • SA Water nominated contact person
Responsible Discipline Lead	The engineering discipline expert responsible for defined on page 3 (via SA Water's Representative)
100mV polarisation	Polarisation achieved against the Natural or Depolarised potential as a result of applying cathodic protection. The

	polarisation achieved is determined by measuring the Instant OFF potential and subtracting the depolarised potential.
Anodic interference	Occurs when stray current from a cathodic protection system shifts the potential of a foreign structure to a more positive reading.
Cathodic interference	Occurs when stray current from a cathodic protection system shifts the potential of a foreign structure to a more negative reading.
Depolarised potential	Potential of a structure after cathodic protection has been switched off and the structure potential is allowed to decay fully.
Instant OFF potential	Refers to the potential of a structure measured with respect to a stable reference electrode after the voltage drop (IR drop) is eliminated by interrupting the current before polarisation begins to dissipate, usually within 0.5 seconds of current interruption.
IR free potential	The potential of a structure with errors associated with voltage drops or gradients removed. A close estimate to this can be made by interrupting all current sources simultaneously and taking an instant OFF potential reading.
Natural state potential	Potential of a buried structure prior to application of cathodic protection. Also referred to as 'native state potential'.
Polarisation	The deviation from the natural or depolarised potential that occurs due to the application of cathodic protection. The polarisation achieved is determined by measuring the instant OFF potential and subtracting the natural or depolarised potential.
Project Construction File (PCF)	Document where every element of the cathodic protection system is detailed, including drawings.
Stray current	Current flowing onto a structure that is not part of the intended electrical circuit.

2 Electrical Safety

There are a number of safety hazards associated with CP testing, primarily electrical hazards such as shocks due to working with live currents and voltages. Therefore, appropriate safety measures must be taken in order to mitigate the risks. It is important to note that the safety measures outlined in this section are the minimum required and hazard assessments, SWMS, and JSA should be conducted where necessary.

To avoid accidents associated with the testing of CP systems, the following guidelines should be adhered to:

- Always assume that the potential to be measured may be hazardous so do NOT make physical contact with the circuit until the potential has been measured and deemed safe.
- Measure both AC and DC voltage to be sure there are no hazardous voltages before touching any equipment. Although, the TR will supply DC to the buried structure, any nearby HVAC powerlines can introduce hazardous AC potentials to the structure.

  A good work habit is to always measure the AC voltage-to-ground prior to measuring the DC soil-to-pipe potential or touching the structure if HVAC powerlines are in proximity. An AC voltage greater than 15 V is considered hazardous.
- Turning off the circuit breaker in the TR will make the front of the panel safe but will NOT make the back or inside of the unit safe.
- Postpone testing of a CP system during the event of a thunderstorm as lightning strikes can introduce hazardous voltages to buried pipelines.
- If working on the TR, ensure the AC disconnect is switched OFF and the lock out/tag out system is used to prevent it being re-energised while a person is still working on the TR. A voltmeter should be used to confirm the TR is not energised.
- CP TRs have exposed electrical terminals on their panel and physical contact should NOT be made with any electrical terminal while the TR is energised.
- Always use insulated test leads and cables. Use the ‘one-hand method’ when taking measurements and avoid contact with the test lead. Never press a lead and terminal together between your fingers.
- Consider the possible shock hazards from operating CP systems in water.

3 Pipe-to-soil Potential Measurement

This section details the process for measuring the potential difference between a buried asset and a reference electrode in contact with the same electrolyte (i.e. buried in the same soil). Pipe-to-soil, or structure-to-electrolyte, potentials are measured for a variety of purposes such as confirming CP criteria have been met, checking electrical isolations and continuity, coating evaluation, and assessing stray currents. The equipment required for this procedure is a high input impedance AC/DC voltmeter or multimeter, test leads and a calibrated reference electrode.

All potential measurements shall be reported in millivolts (mV).

The most common criterion for the protection of a buried or immersed ferrous structure from the Australian Standard AS2832.1 is as follows:

> *To maintain a potential on all parts of the structure equal to, or more negative than, –850 mV with respect to a copper/copper sulphate reference electrode.*

This potential must be a 'polarised potential' and can be obtained by interrupting all current sources influencing the structure and taking an instant OFF potential. Sections 4.2 and 5.2 explain how to obtain instant OFF potentials.

When the current is applied, a voltage generated by the current passing through the soil is added to the measured potential. This voltage is called voltage or IR drop and must be eliminated in order to obtain the polarised potential.

Now, in some circumstances, the -850mV criterion cannot be met due to age of the coating or the type of soil. For these cases, the -100mV criterion can be used to assess the level of protection of the structure. The -100mV criterion shall be to maintain an instantaneous OFF potential on all parts of the structure, which is at least 100 mV more negative than the depolarised potential (see section 5.3 for instructions).

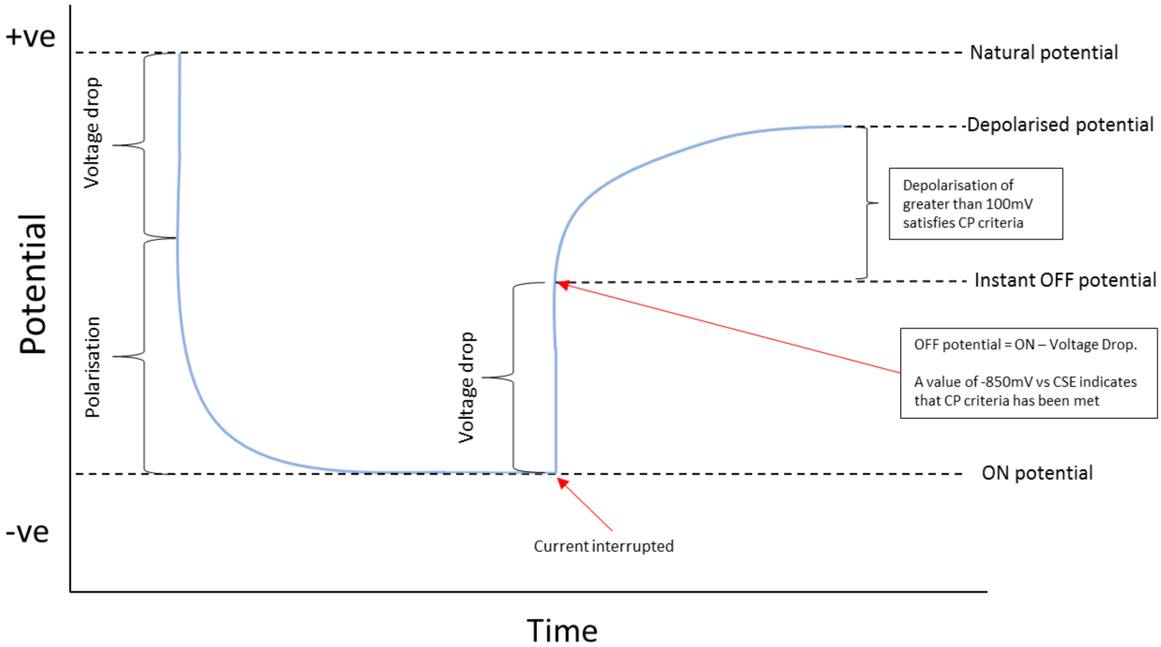


Figure 3-1: Illustration of CP criterion for steel.

Figure 3-1 shows a current being applied (on the left side) developing cathodic polarisation (Note that the potentials become more electronegative when current is applied) on the structure and then interrupted (in the centre). The IR drop is seen immediately on applying the current and immediately after interruption. The remaining change is due to polarisation. The -100 mV can be seen on formation or decay.

3.1 Reference Electrode

Reference electrodes (or cells) are important devices that allow the potential of a metal in contact with an electrolyte to be measured. They provide a stable reference potential against which the potential of the structure can be evaluated. A Copper/copper sulphate (CSE) reference electrode are most commonly used, while a silver-silver chloride (Ag/AgCl) reference electrode is used in areas with high amounts of chloride electrolyte such as by the seawater. If an Ag/AgCl reference is used, then the recorded potential value will need to be converted to CSE in order to determine if protection criteria have been satisfied.

The copper/copper sulphate electrode comprises a pure copper electrode immersed in a super-saturated solution of copper sulphate. The electrolyte is contained within a container which is either fitted with a porous plug or is itself a porous container. This enables ionic contact between the electrode and the buried pipeline via the soil, sufficient to allow measurement of the voltage (or potential) between them.

3.1.1 Portable copper/copper sulphate reference electrodes

Portable reference cells need to be inspected prior to measuring potential to ensure there is no damage and that there are undissolved crystals present, which indicates that the $Cu/CuSO_4$ solution is saturated with copper ions.

Figure 3-2: Copper/copper sulphate reference cell

It is important to check that the reference cell is calibrated prior to recording any measurements. To do this, place the field reference electrode in a bucket of water with a brand-new electrode (or freshly recharged) kept in the office. With a multimeter measure the potential difference between both electrodes. If the measurement differs by more than 5mV then the reference cell solution shall be discarded and the reference electrodes cleaned and recharged with a fresh solution (distilled water and excess high-purity crystals of copper sulphate). During the replacement of the solution, it is necessary to clean the copper rod with a non-metallic abrasive material (Scotchbrite pad).

The reference electrode must be shielded from direct sunlight during measurements by placing, for example, a dark tape over clear strip on side of electrode). The potential of a reference electrode in the sun can decrease from 10 to 50mV versus an electrode kept in the dark.

Potentials can also vary to temperature differences. A temperature correction of 0.9mV/˚C must be either added or subtracted when reference temperature is above or below 25˚C, respectively.

3.1.2 Non-rechargeable reference electrodes

Some reference electrodes utilise gelling agents to limit the diffusion of electrolyte through the porous plug (See Figure 3-2) which does not need recharging.

It is important to check that the reference cell is calibrated prior to recording any measurements. To do this, place the field reference electrode in a bucket of water with a brand-new electrode (or freshly recharged) kept in the office. With a multimeter measure the potential difference between both electrodes. If the measurement differs by more than 5mV then the reference cell should be discarded.

Figure 3-3: Non-rechargeable copper/copper sulphate reference cells

3.1.3 Permanent reference electrodes

Reference electrodes are regularly buried for permanent monitoring close to buried pipelines. The installation can be either by direct burial of the reference electrode close to the pipe or, in some applications, the reference electrode can be installed within or directly below a chamber or box with access at ground level, typically above the pipeline. This is to facilitate calibration and replacement of the reference electrode with the avoidance of excavation, resulting in reduced costs.

Permanent reference electrodes are frequently used in conjunction with permanent monitoring systems which enable pipe/soil potential data to be recorded and transmitted to the asset owner. However, it should be taken into account that reference electrode errors may be significant and vary in magnitude with time. Permanent reference electrode accuracy should be assessed using calibrated portable reference electrodes.

Copper/copper sulphate permanent reference electrodes are the most common electrodes, but other reference electrodes like silver/silver chloride (saturated) and zinc can be used. However, readings shall be converted to copper/copper sulphate (See Table 3-1 for conversion details).

Table 3-1 – Conversion of Voltage Measurements to Copper/Copper Sulphate Electrode (CSE)

Electrode	Equivalent to -850mV CSE	Correction
Silver/Silver Chloride Saturated	-759mV	Add -91mV
Silver/Silver Chloride Seawater	-784mV	Add -66mV
Zinc	+250mV	Add -1,100mV

Note: From Table K1 of AS 2832.1:2015

3.2 Operating Procedure

1. Ensure the multimeter/voltmeter is set to DC ‘V’ (in the 2V range).
2. Remove the protective cap from the reference electrode and gently drive this end into soil over or near as possible to the buried pipe. If the soil is dry, make sure to pour some water out first to moisten it so that a more reliable reading is obtained.
3. Connect the positive terminal of the voltmeter to the buried structure (e.g. via a Test Point) and the negative terminal to the reference cell.
4. A steady, negative reading should be displayed on the voltmeter (“On Potential”). If the reading is fluctuating, then either the soil is too dry or the connection is poor (e.g. broken pipe connection or multimeter lead). If the reading is steady, record the potential in mV and note the date, time, location/CP number, weather, and type of reference cell.
5. Interrupt the current and immediately record the “instant Off Potential”. The reading shall be taken within 0.5 seconds of interruption and recorded in mV. Generally, the second result on the changing digital screen.
6. Remove the test leads from the structure and reference cell. Clean the reference cell with water and put the protective cap back on.

4 Measurement of Sacrificial Anode Systems

The performance of sacrificial or galvanic anode systems is commonly assessed by measuring the current output by the anodes and the potential of the buried structure that is to be protected by the anodes.

4.1 Current Measurement

Current can be measured using a DC multimeter. The multimeter should be set to DC milliamps and connected in series with the CP system i.e. negative terminal connected to the anode cable and the positive to the pipe. This will produce a positive current reading that represents the amount of current flowing through the cable and therefore on to the structure. This value should be recorded along with the date, time, anode type and test point number, and location. The current measurement should be repeated for each sacrificial anode (when removed one at a time) associated with the CP system. If several anodes are connected the total current should also be measured.

4.2 Potential Survey

To determine if the sacrificial anode system is satisfying protection criteria as outlined in AS 2832.1 and SA Water TS 0440, the ON and instant OFF potential of the structure must be measured. Depending on the system, a number of measurements can be taken at many different TPs. To carry out the potential survey, a multimeter, portable CSE reference electrode, test leads, and access to designated TPs is required. The following procedure can then be carried out if the system has anodes connected to a single test point:

1. Set the multimeter/voltmeter to DC 'V'.
2. At a TP, set up the reference cell, connect the multimeter/voltmeter, and record the ON potential reading in mV as outlined in Steps 2 through 4 of Section 3.2.
3. Now, the current from the sacrificial anode must be interrupted so that an instant OFF reading can be obtained. To do this, disconnect the anode cable and pay close attention to the reading on the multimeter/voltmeter. The reading should make a sudden drop which can be relatively large (e.g., few hundred mV) followed by another, smaller change. To minimise the effects of the IR (voltage) drop, the second reading displayed approximately 0.5 seconds after the current is interrupted should be recorded as the instant OFF potential in mV of the structure.
4. Reconnect the anode cable immediately after taking the instant OFF reading to prevent depolarisation of the structure.

If there are anodes connected to several test points, the true polarised potentials cannot be obtained unless all anodes are disconnected at the same time. Sometimes this is not practical so only ON potentials will be measured.

Along with recording ON and OFF potentials, the sacrificial anode open circuit potential itself shall be checked to ensure expected potential of the anode (Refer to typical open circuit potentials of different anodic materials in Table 4-1. Both the current output by the anode and the potential of the anode needs to be read as part of this.

For the current check, connect the positive to the structure and negative to the anode cables into the terminals of your multimeter in series. The multimeter must be set to DC milliamps.

For the potential check, connect the anode cable and reference cell to the multimeter (set to DC volts) and record the reading. As a rule of thumb, when the ON potential of the buried structure is -1000mV vs CSE or more positive, the anode should be flagged and checked for their installation date. If it was installed approximately 10 years ago then the anode should be replaced. However, if it is only a few years old then the cathodic protection shall investigate the issue and provide further direction.

Table 4-1: Typical Anode Open Circuit Potentials

Anode Material	Open Circuit Potential (mV) vs CSE
Zinc	-1,100
Magnesium – High Potential	-1,700
Magnesium – Low Potential	-1,500
Aluminium	-1,050 to -1,100

Source: Table B1 from AS 2239-2003 Galvanic (Sacrificial) Anodes for Cathodic Protection Standard

The following schematic diagram of the various readings that can be conducted for a sacrificial anode system is included for reference. Typical measurements recorded during a sacrificial anode cathodic protection system survey are presented in

Table 4-2.

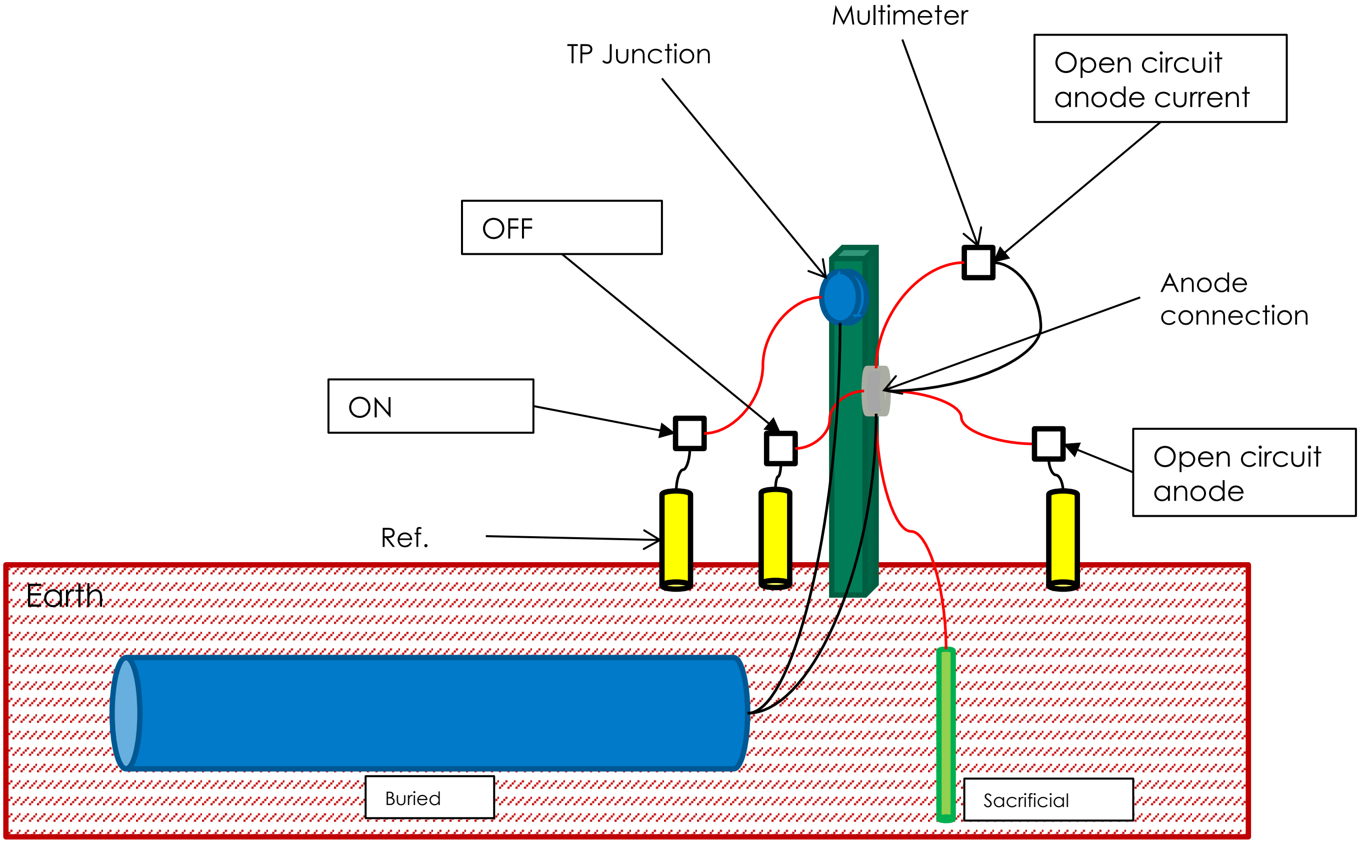


Figure 4-1: Sacrificial Anode Cathodic Protection System Survey Schematic

Table 4-2 - Typical measurements recorded

Location	Voltage on (-mV CSE)	Voltage off (-mV CSE)[1]	Current (mA)
TP1 Structure/Junction	ON	OFF	
Anode 1		Open	A1 current
Anode 2		Open	A2 current
Total anode current		Open	Total current
TP2	ON	OFF	
TP3	ON	OFF	

Note: 1. For cathodic protection systems with sacrificial anodes located in more than one location, only Voltage On is required

5 Measurement of ICCP Systems

The performance of an ICCP system is assessed similarly to that of a sacrificial anode system, however, can be more complicated and varied due to factors such as the number of TRs and the potential for stray currents from the system that may interfere with foreign structures. Additionally, there may be a large number of test points and these may be spread over a significant distance. In order to make the process of testing ICCP systems more efficient, features such as remote interruption of TRs using SCADA have begun to be implemented by SA Water and this is discussed in detail in the following section. However, it should be noted that as of yet not all TRs currently in service are compatible with this feature.

5.1 Transformer Rectifier Checks

Transformer-rectifier units (TR) shall be inspected during every potential survey. As a minimum the parameters shown in Table 5-1 shall be checked and recorded.

Table 5-1: TR Checks Records Table

Parameter	Unit	Date 1	Date 2
Display output VOLTS	VDC		
Display output AMPS	ADC		
Display Structure VOLTS	VDC		
Instrument check			
Output VOLTS	VDC		
Output AMPS	ADC		
Reference cell VOLTS	VDC		
Bond Current AMPS	ADC		
Earth Current			
Initial mA	mA		
Reset mA	mA		
Battery Volts	VDC		
Battery O/C Volts	VDC		
GPO/Charger Input Volts	VAC		
Charger Output Volts	VDC		
Transducer Output - Voltage	mA		
Transducer Output - current	mA		
Transducer Output - Potential	mA		
Operational Status - RTU			
Operational Status - Modem			
RCD test			
TR Unit cleaned out (Remove dirt, dust, insects, birds' nest, or other debris from inside of rectifier housing)			

5.2 Assessment of loop resistance

The loop resistance of the CP system can provide information of the anode performance and remaining life. To do so, simply adjust the TR current output to the values in Table 5-2 and record the corresponding voltage reading, continue at 5 A intervals until the maximum output current for the TR is reached.

Table 5-2: Loop resistance data.

Current (A)	Voltage (V)
1	
2	
3	
4	
5	
10	
15	
20	
25	

5.3 SCADA Interruption

In order to record ON/OFF potentials of ICCP systems, ALL TR(s) that supply power to the system must be synchronously switched from continuous mode to interrupt mode in order to intermittently halt the impressed current, thereby producing an ON/OFF cycle. Recently, SA Water began works that will allow SCADA to remotely switch TRs to interrupt mode in order to improve the efficiency of testing ICCP systems. This change was implemented due to repeated difficulties in manually synchronising multiple TRs associated with the same ICCP system. For all new TRs this will be a feature, while for older, existing TRs these changes will be rolled out over time.

To remotely interrupt TRs using SCADA, the procedure below should be followed:

1. Navigate to the "Cathodic Protection" page on SCADA and select the appropriate CP system. An overview of the system with all associated TRs should now be displayed on screen similar to Figure 5-1.

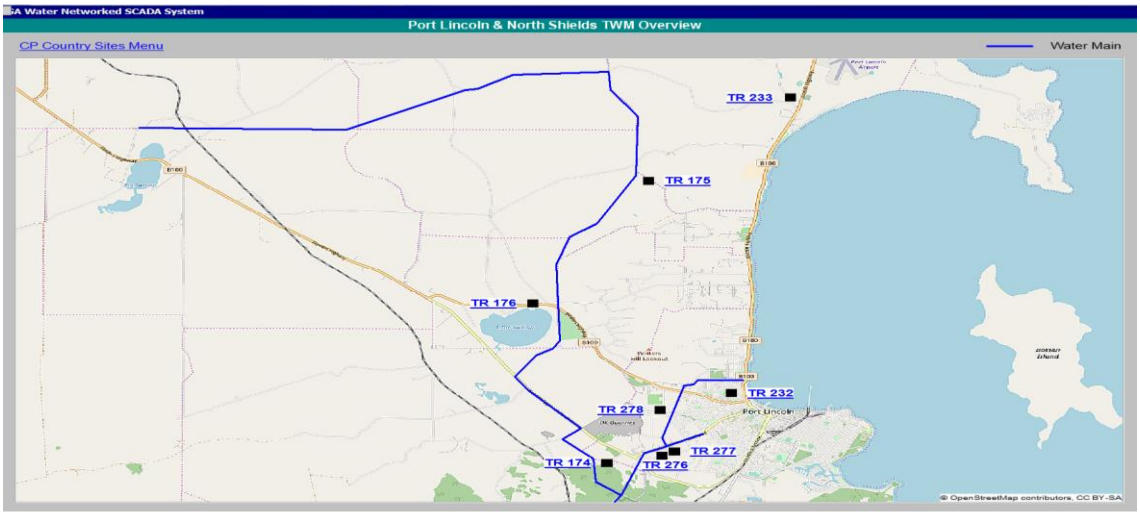


Figure 5-1: Example of SCADA overview page.

2. Select one of the TRs displayed on the overview. The screen should now display the full list of TRs for the CP system and associated data. In the top right of this page, click the "interrupt test control" button (see Figure 5-2).

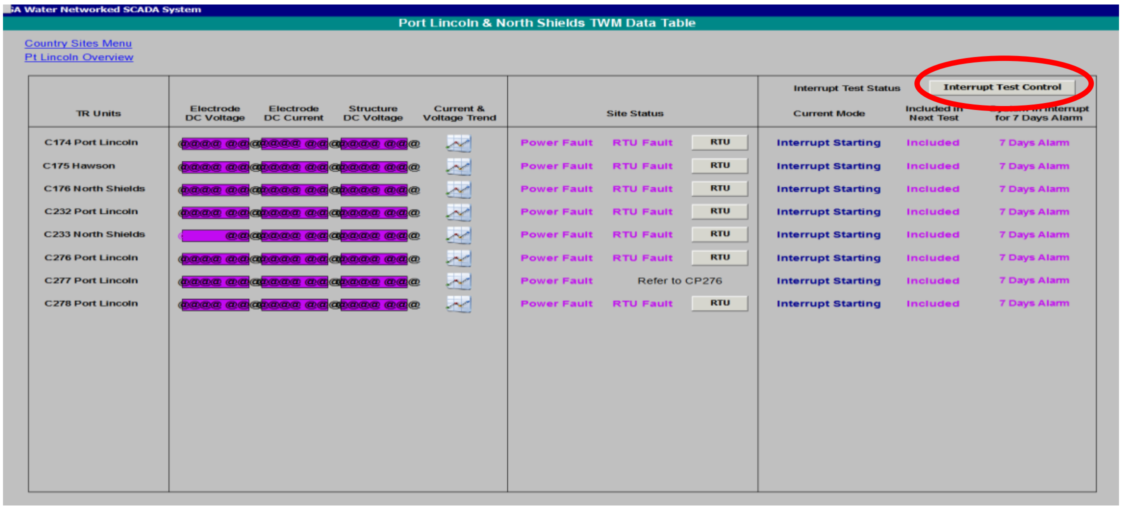


Figure 5-2: TR summary page on SCADA.

3. After clicking "interrupt test control", a popup window should prompt you to select which TRs you would like to include in the test (see Figure 5-3). Include all the appropriate TRs and then click start. The TRs in the field should then synchronously switch to interrupt mode, thus allowing for ON/OFF potentials to be easily assessed as discussed in *Section 5.2*.

4. Following the potential survey, return the TRs to continuous mode by clicking 'stop.'

For all other CP systems where this facility has not been installed, the synchronisation shall be done with Portable Current interrupters. Follow manufacturer's instructions.

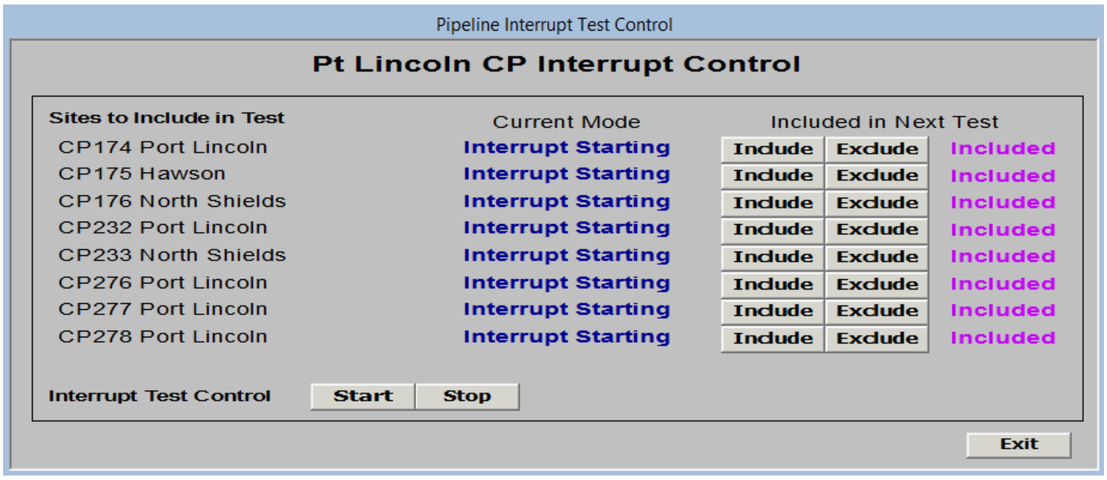


Figure 5-3: Interrupt test control window.

5.4 Potential Survey

In order to conduct an ON/OFF potential survey to determine if an ICCP system satisfies protection criteria as outlined in AS 2832.1 and SA Water TS 0440, the procedure outlined below should be followed:

1. Synchronously interrupt ALL TRs associated with the CP system remotely using SCADA. If there is only one TR for the CP system then initiate interrupt mode manually in the field, and for all other systems without SCADA interruption, use the portable current interrupter as explained in the previous section.

2. At a TP, set up the reference cell and connect the multimeter/voltmeter set to DC 'V' as detailed in Steps 2 and 3 of Section 3.2.

3. Now, watch the reading on the meter. The value should fluctuate in a distinct pattern. This represents the ON/OFF cycle. At SA Water it is standard to set the cycle to 15s ON and 5s OFF during CP commissioning. Hence by observing how the reading fluctuates, the ON and OFF potentials can be identified.

4. Record the ON potential in mV as well as the time, date, location/CP number, weather, and type of reference cell.

5. Wait for the potential to drop to the OFF reading and then record this in millivolts along with the time, date, location/CP number, weather, and type of reference cell.

6. Repeat Steps 2 to 5 for all TPs associated with the CP system.

7. Return the TR(s) to continuous mode either manually or via SCADA.

Table 5-3 - Typical measurements recorded

Location	Voltage on (-mV CSE)	Voltage off (-mV CSE)
TP1	ON	OFF
TP2	ON	OFF
TP3	ON	OFF

5.5 Anode bed checks

The anode bed associated with the CP system is required to undergo a variety of checks in order to ensure that they are in good working condition and will remain so for the foreseeable future. These checks are made as follows:

1. Identify the location of the anode bed (this may be several hundred meters from the TR location) based on the Project Construction File. For some systems, at this site there will be an anode box marshalling panel which when opened reveals the cables connected to each individual anode box for the system as shown in Figure 5-4. Using a clamp meter, measure and record the current of each cable. The values should total to the reading displayed on the TR resident meter but may vary slightly. It should also be confirmed that each anode box is outputting a current and therefore all are functional. For those anode beds without marshalling box, the current output shall be measured from the anode boxes. Table 5-4shows parameters to be recorded.

Figure 5-4: Cables within anode marshalling panel, each corresponding to a different anode.

Table 5-4: Typical measurements recorded for the anode bed

Location	Current (A)
Total Current	
Anode 1	
Anode 2	
Anode 3	
Anode 4	

2. Each anode box must then be inspected for physical defects. It is particularly important that the anode box has breather holes (see Figure 5-5) on its lid. Breather holes are required to release chlorine gas that is produced by the anode beds during operation. If chlorine gas were to build up inside the anode box, then this would significantly impair

functionality of the anode and potentially the CP system. Furthermore, personnel conducting maintenance on the system may open the box and be exposed to a plume of chlorine gas, hence the absence of breather holes poses a serious safety hazard.

Note that the coke breeze within the anode column can become acidic and caution must be taken if handling if excavating the material.

Figure 5-5: A standard anode box. Six breather holes can be seen on the lid.

3. Depending on the location of the anode bed, some systems (e.g. those in dry soil) will be fitted with a water supply to prevent anode beds drying out and losing functionality. If this is the case, the water supply should be turned on and each anode box should be opened and checked to ensure that water is flowing in. The water supply should then be turned off, unless specified otherwise, as it is normally a long-term contingency and not immediately active after commissioning.

5.6 Depolarisation Testing

In some cases, where the type of soil or coating does not allow the pipe to achieve the -850mV criterion, it is of interest to depolarise the buried asset in order to assess the -100mV criterion. Contact SA Water Engineering for more details.

The depolarisation testing consists in measuring the polarisation decay of the structure after the TRs are switched off. Figure 5-6 shows that the potential after the TR is switched off continues to decay (becomes more positive). If at the end of the depolarisation testing 100mV is measured, then the system is considered to be compliant.

To do this, follow the steps below:

1. Measure ON/OFF potentials at every test point of the system in mV
2. Switch off the TR by turning the rectifier main circuit breaker (MCB) off.
3. Allow the system to depolarise overnight.

4. Record the potential of the pipe following the same method outlined in Section 3.2.
5. If not all test points achieved a decay of 100mV, retest at the following day (48 hours).
6. Re-energise the TR, being sure that the output DC current reading returns to the designated value.

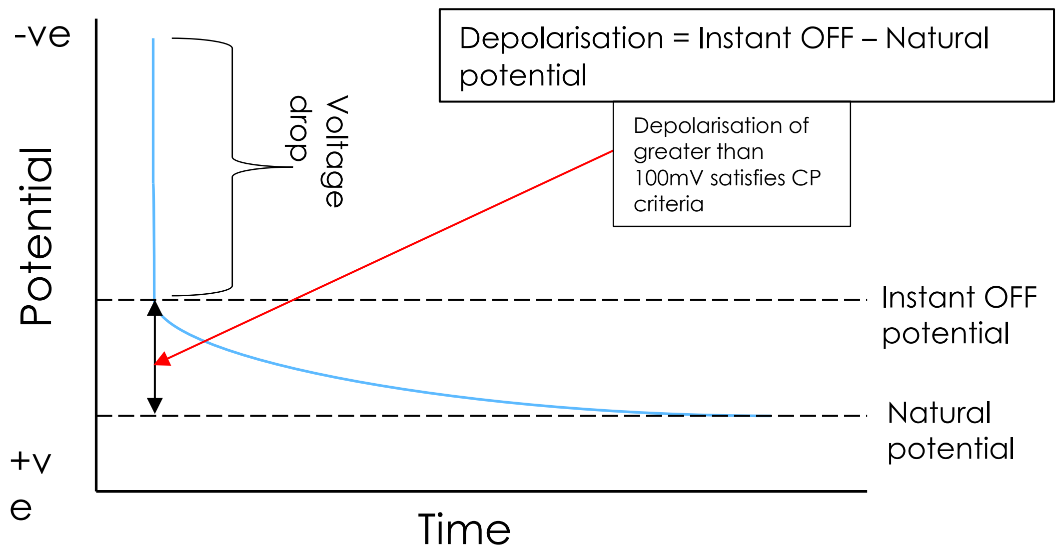


Figure 5-6: Illustration of the -100mV criterion

Table 5-5: Typical measurements recorded on test points

Location	Voltage on (-mV CSE)	Voltage off (-mV CSE)	Voltage Off for 24 hours	Voff -Voff 24Voff -Voff 24>100mV?	Voltage Off for 48 hours
TP1	ON	OFF		Yes	
TP2	ON	OFF		Yes	
TP3	ON	OFF		No	

5.7 Insulation Joints Testing

5.7.1 Structure to Electrolyte Potential Testing for Insulating Joints

The effectiveness of an insulating joint can be tested using structure-to-electrolyte potentials. Placing the reference electrode **in one location and not moving the electrode**, a structure potential can be measured from each side of the joint. Change the voltmeter to the DC millivolt range and measure the potential difference across the insulated joint making sure the probes contact clean bare metal surfaces.

If the testing is done with the transformer-rectifier **on**, the following procedure will be followed:

If the structure potentials are identical or nearly identical, the possibility exists that the insulating joint is shorted. If there is appreciable difference in structure potentials from one side of the joint to the other, the two sides of the joint are electrically isolated. The following shall be followed:

- When the difference is above 50 millivolts, the joint is considered isolated,
- if the difference is less than 10 millivolts, the joint is considered short.
- When the difference is between 10 and 50 millivolts, further investigation is required. (for example, by using a radio frequency insulation checker or other method).

Table 5-6 presents an example of insulating joint testing.

Table 5-6: Typical measurements recorded across insulating joints

Insulating Joint	Flange A (mV CSE)	Flange B (mV CSE)	Difference	Status
IJ 1	-850	- 700	150	OK
IJ2	-800	- 820	20	Investigate
IJ3	-750	-755	5	Shorted

If the testing is conducted with a **current interrupter** connected to the transformer-rectifier, the following procedure will be followed:

Using a current interrupter installed in the nearest CP current source (or a temporary current source), the protective current can be cycled ON and OFF and the ON and OFF structure to electrolyte potential measured on each side of the insulating joint with the reference in one position. With a functioning insulated joint, the side with the current source that is interrupted will have a more negative ON potential than the OFF potential and the two values will be cycling on the same timing as the current interrupter. On the opposite side of the insulating joint, the ON and OFF potentials will be nearly the same and sometimes, the OFF potential will be more negative than the ON potential.

If the insulating joint is not functioning properly, the ON and OFF potentials will be the same on each side of the insulating joint and the potentials on both sides will be swinging with the same timing cycle as the current interrupter. If there is a small difference between each side, the current should be increased and the test repeated.

Table 5-7: Example of using a current interrupter on insulated flange (Flange A is on the CP protected side)

Insulating joint	Flange A (-mV CSE)		Flange B (-mV CSE)		Status
	On	Off	On	Off	
IJ 1	-1000	-850	- 700	-705	OK
IJ2	-1000	-850	- 850	-850	OK
IJ3	-1000	-850	-995	-850	Shorted

5.7.2 Testing Insulating Joints with an Insulation Checker

An insulation checker is a radio frequency instrument specifically built to check both below ground and aboveground insulating joints.

For above ground insulating joints, the RF-IT insulation checker probes are placed in contact with each side of the insulating joint and as close together as possible. A functioning electrical insulation joint will show a full-scale deflection while an electrically shorted device will show a deflection toward zero on the scale associated with a change in the sound. It can be used to test for a shorted bolt or stud if it has double insulating washers and sleeve.

For below ground insulation joints which is buried, and test wires exist on both sides of the insulating gasket, an CE-IT underground insulation checker may be used. This instrument is similar to the above ground insulation checker but is designed to be used only with an underground insulated joint.

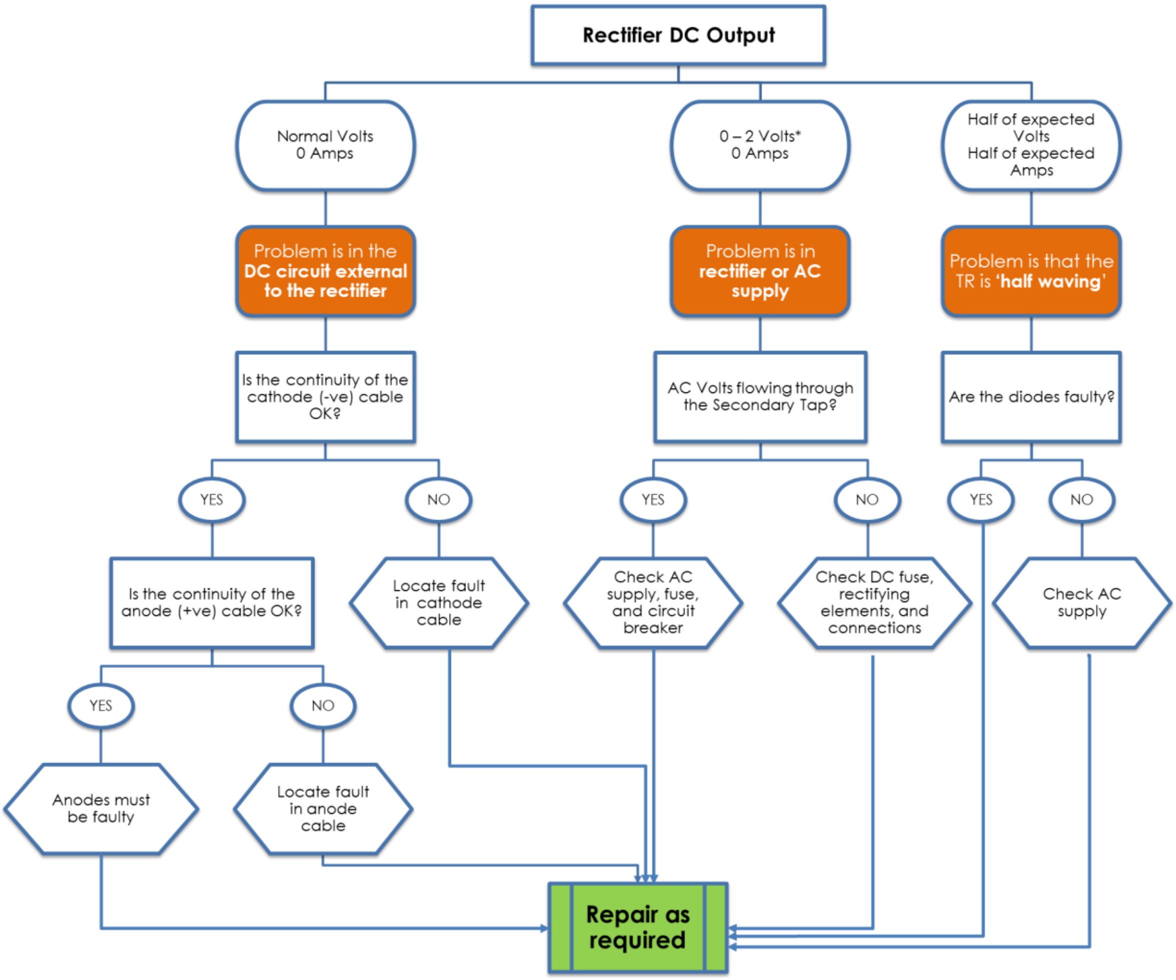
5.7.3 High Voltage Insulation Tester (Megger Test)

Another test to measure the integrity of the insulated joint is the High Voltage Insulation Test or Megger Test. The resistance between bolts and flanges are measured with the insulation tester before Denso wrapping the joint. The pass criterion shall be 1 Megaohm @ 1000V DC. This method is applicable when one or both sides of the joints are electrically isolated from the ground.

6 Rectifier Troubleshooting

During the testing of a CP system, it is not uncommon to encounter technical difficulties. Particularly when working with ICCP systems and TRs, as hardware malfunctions can often result in the system failing to meet protection criteria. The majority of issues that will be encountered can be solved by simple troubleshooting in the field.

The following flowchart has been adapted from the National Association of Corrosion Engineers (NACE) to provide some guidance in troubleshooting an ICCP system.



*confirm that it is a back electromagnetic force (EMF) by disconnecting a DC cable.

Figure 6-1: Troubleshooting flowchart for an ICCP system.