AMS – Electricity Distribution Network

Electrical Earths

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1 Executive Summary

This plant strategy is part of the suite of documents forming the Asset Management Strategy for the electricity distribution network. The purpose of this document is to explore issues of permanent electric earths and define AusNet Services' management approach.

AusNet Services' electricity distribution network has approximately 300,000 earths connecting electrical equipment to the general mass of earth at more than 267,000 sites throughout the eastern part of the state of Victoria. Each year more than 3000 new electrical earths are installed.

Earth systems within this strategy are installed in:

- Zone substations and line voltage regulators where individual high, medium and low voltage electrical equipment is directly connected to a single large earth grid located within the security fence.
- Simple distribution substation earths installed to ISO9000 controlled standard designs,
- Multiple Earthed Neutral (ME2N) earthing systems.

Earths are constructed from materials specifically selected for high electrical conductivity and high corrosion resistance. They are designed to match the expected life of the equipment they service and are installed at sufficient depths below ground level to minimise disruption by excavation.

To ensure the reliable operation of electrical protection systems and the management of step, touch and transfer potentials; a rigorous testing regime, based on statistically representative samples, ensures that corrosion or mechanical damage has not jeopardised the resistance to ground of earthing assets.

Earth maintenance and replacement is primarily driven by the testing program and secondarily by the maintenance and replacement of the electrical equipment which the earth serves.

1.1 Strategies

1.1.1 Installation

In accordance with the principles in the AS/NZS 7000 and AS 2067:

- Design and install earthing systems on a case by case basis.
- Progressively implement Common Multiple Earthed Neutral (CMEN) earthing of conductive MV installations in urban areas.
- Amend tools and procedures to ensure compliance to AS 7000 and AS 2067.

1.1.2 Inspection

- Inspect above-ground portions of zone substation earths in conjunction with routine station inspections.
- Inspect above-ground portions of distribution installation earths (including CMEN earthing bonds) in conjunction with equipment inspections as specified in the Asset Inspection Manual (4111).
- Inspect station earths to be undertaken in accordance with section 8.8 of AS 2067. This involves:
    - Visual inspections
    - Continuity testing - critical earthing connection points are tested within stations, including transformers, earth switches, and instrument transformers and REFCL earths.
    - Earth Potential Rise (EPR), and transfer, touch, and step voltage testing.
- Create measurement points in SAP in order to capture tests for station earth grids.

- Consolidate overall report using information in SAP and Enablon to enhance the feedback loop and risk based prioritisation of follow up works.

1.1.3 Testing

- Confirm performance of zone substation earth grids via current injection tests undertaken in conjunction with augmentation projects or specific tests at intervals no longer than 10 years.
- Complete earth testing program of zone substations to quantify any step and touch voltage hazards associated with metallic structures inside and outside the switchyard.
- Each year, conduct resistance to ground tests and analyse results of representative samples of each class of distribution earths in accordance with Section 5.9 of the Standard Installations Manual (4142).
- Amend the annual testing samples for SWER concrete pole earths to quantify the cause and location of non-compliance with Upper Specification Level (USL).

1.1.4 Maintenance

- Review risk levels associated with non-conforming zone substation earth grids and upgrade earth grids with unacceptable risk levels.
- Repair specific earth point defects when discovered.
- Repair or replace-on-condition non-conforming distribution installation earths in accordance with Section 5.9 of the Standard Installations Manual (4142) and Standard Maintenance Guide Line SOP 70-03.
- In accordance with Tolhurst classification of bushfire risk and Standard Maintenance Guide Line SOP 70-03; progressively remediate non-compliant earths on SWER MV concrete poles to less than 3% by 2020.
- On a case by case basis extend CMEN earthing in urban areas to mitigate distribution installation earth inspection, testing and maintenance workloads.

2 Introduction

1.1. Purpose

The purpose of this document is to define the asset management strategies for the AusNet Services electricity distribution network's population of electrical earths. This strategy is intended to assist personnel involved in managing the assets, meeting regulatory obligations and informing other stakeholders by:

- presenting an overview of the electrical earth's population
- prudently managing the emerging performance risks presented by electrical earths
- achieving network reliability targets taking account of risk, costs and customer expectations
- effectively and economicaly manage electrical earths throughout their life-cycle.

1.2. Scope

This asset management strategy applies to all electrical earths associated with the AusNet Services electricity distribution network. This includes electrical earths in zone substations, regulator installations, capacitor bank stations, power stations associated AusNet Services' switchyards, distribution substations, including SWER substations, switches, cable screens, surge arresters and pole earths.

3 Asset Summary

The AusNet Services electricity distribution network, in the eastern part of Victoria, employs various combinations of conductors, connectors and electrodes to connect electrical equipment to the general mass of earth for over 300,000 locations.

These earths:

- Maintain network operating voltages within the limits of the Distribution Code
- Define appropriate electrical circuits for SWER load currents
- Define appropriate electrical circuits for fault currents
- Enable protection systems to disconnect unsafe electrical conditions
- Manage step, touch and transfer potentials within allowable limits.

Earth systems within this strategy are installed in:

- Zone substations and line voltage regulators where individual high, medium and low voltage electrical equipment is directly connected to a single large earth grid located within the security fence.
- Simple distribution substation earths installed to ISO9000 controlled standard designs,
- Multiple Earthed Neutral (ME2N) earthing systems.

Figure 1 illustrates the volume of electrical earths in the AusNet Services electricity distribution network in the eastern part of Victoria.

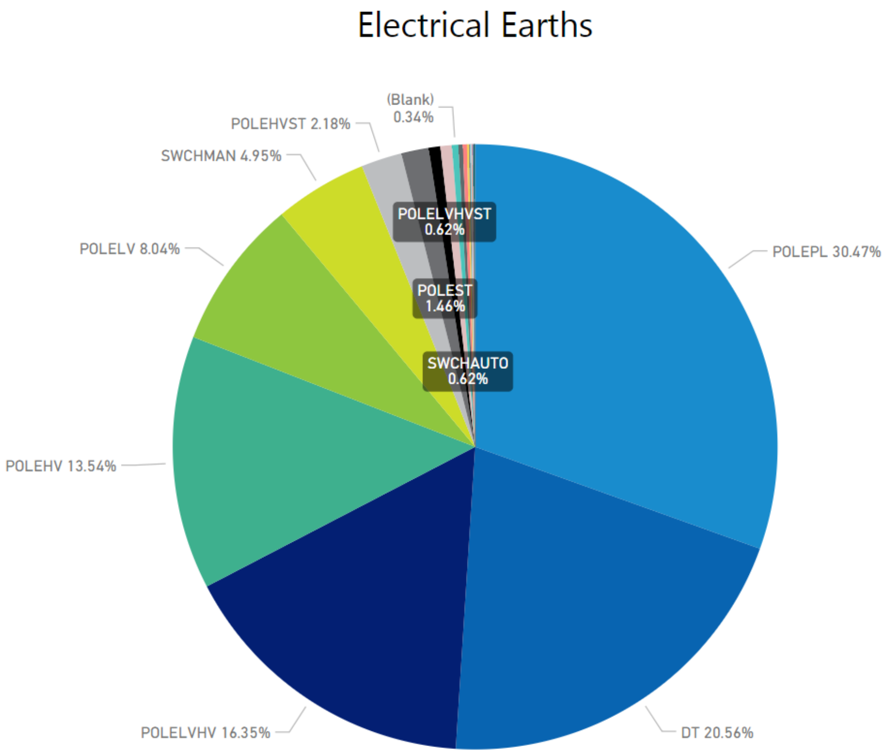

Figure 1 – Electrical Earths by Volume

3.1 Service Age

3.1.1 Zone substations

Station earth grids were installed when the zone substation switchyards were originally established. They may have been progressively augmented as additional plant was installed. Figure 2 below details the zone substation earth grid age profile.

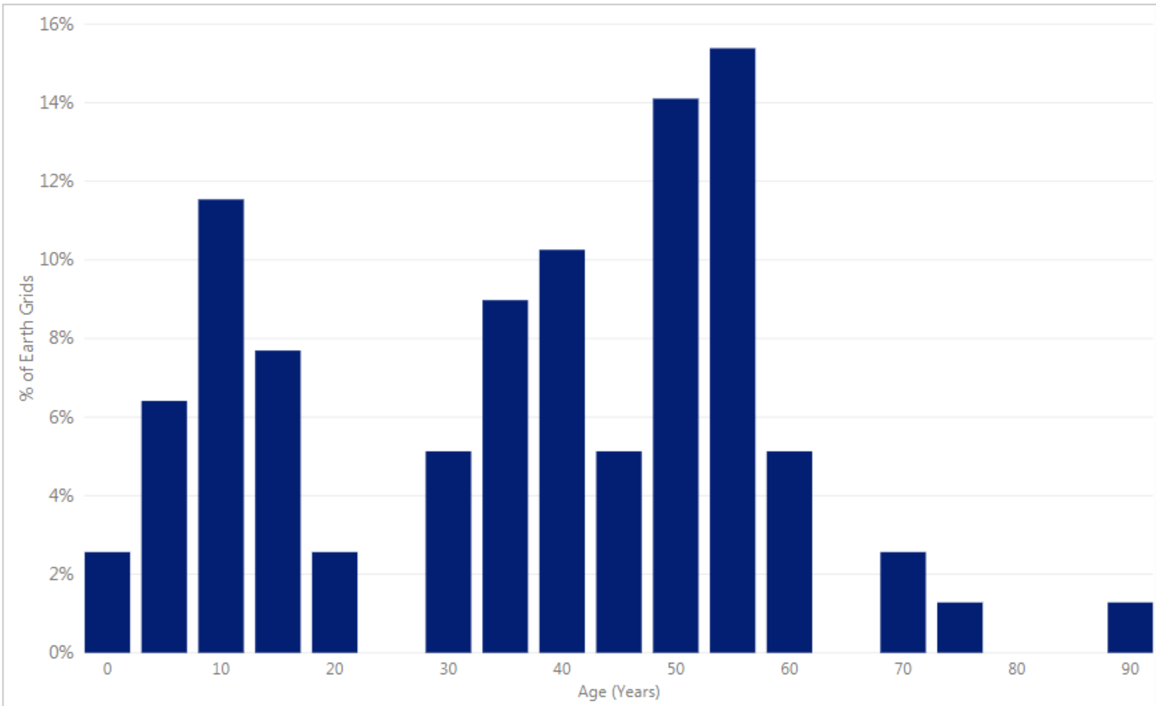

Figure 2 – Zone Substation Earth Age Profile

3.1.2 Distribution Substations

Distribution transformers consist of pole mounted transformers, ground mounted transformers and pad mounted kiosk transformers. Figure 3 illustrates the service age profile of distribution substation electrical earths. From the service age profile it can be seen that most of the pole mounted earth systems are less than 60 years old, while ground mounted substation earth systems are less than 40 years old.

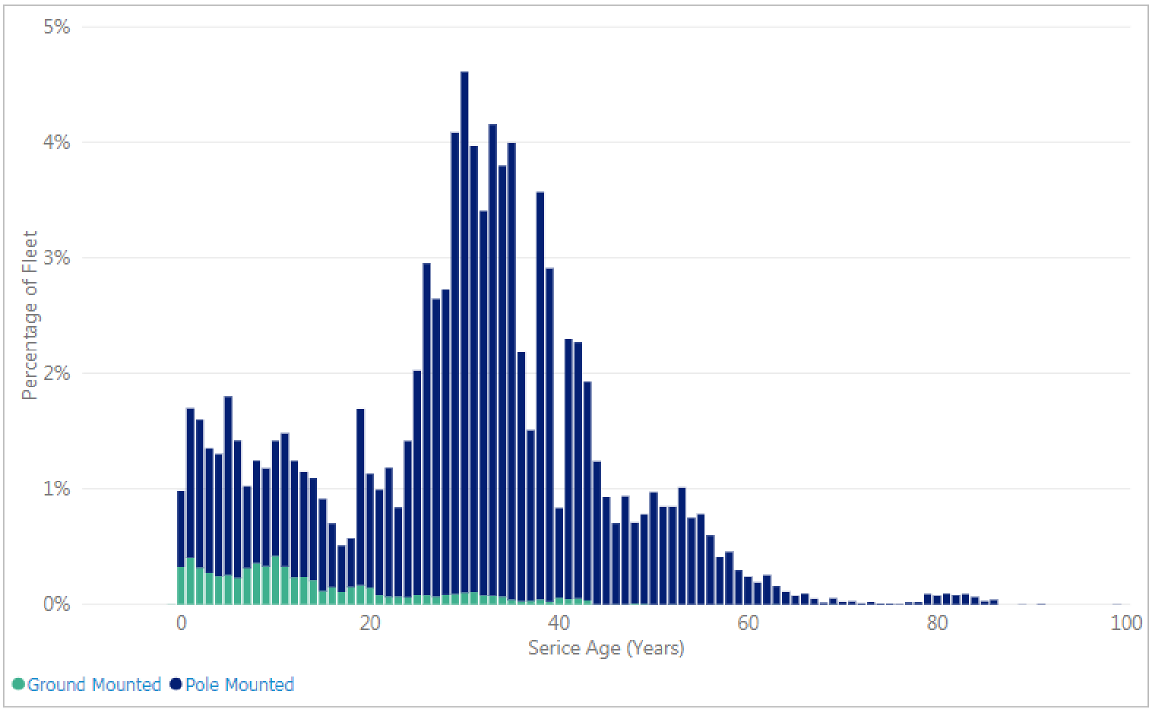

Figure 3 – Distribution Substation Earth Age Profile

3.1.3 Line Poles

Figure 4 illustrates the inferred service age profiles of electrical earths serving concrete poles (POLECONC) and steel poles (POLESTEEL).

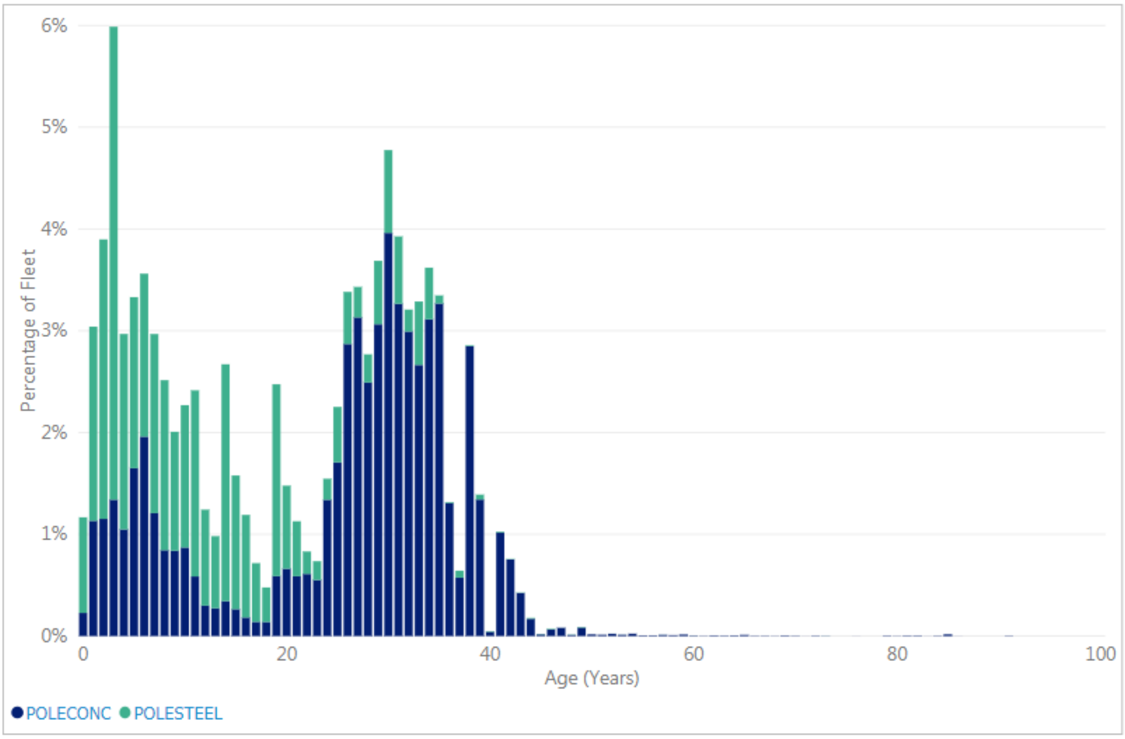

Figure 4 – Line Pole Earth Age Profile

The mean age of line pole earths is 25 years while there are very few as old as 91 years. Steel pole earths demonstrate a younger age profile compared to the concrete pole age profile, with a mean age of 12 years.

3.2 Condition

3.2.1 Zone Substations

The visible portions of electrical earths are inspected for corrosion or mechanical damage in conjunction with routine inspection cycles of electrical equipment in zone substations. The visual inspection includes the condition of connections to equipment, the mechanical support and mechanical protection of earthing conductors.

Current-injection testing of a zone substation earth grid consists of injecting current (2 – 10A) into the earth grid from a remote location to create an earth grid voltage rise as shown below in Figure 5.

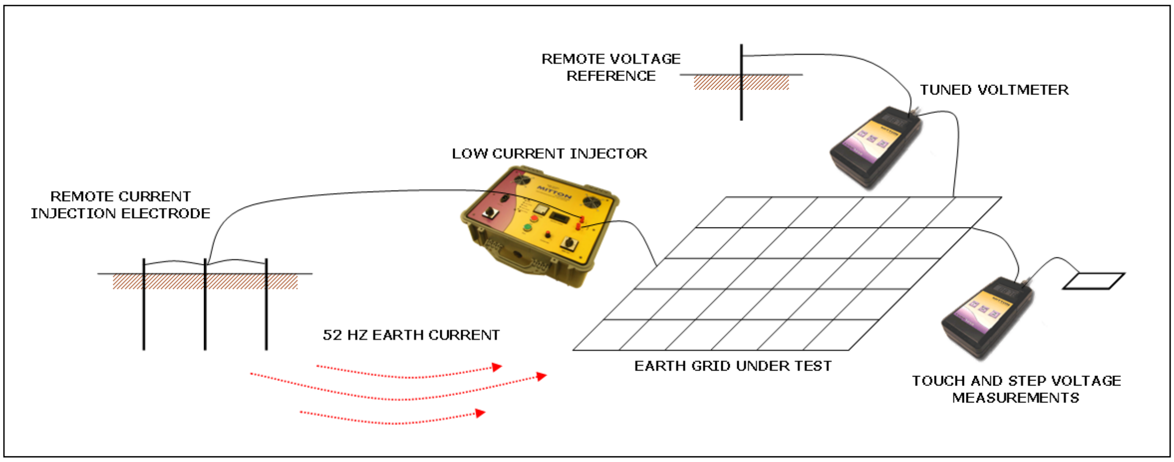

Figure 5 – Off-Frequency Current Injection Circuit

Injection testing is made off-frequency to avoid errors caused by stray power system currents in the earth grid or test leads. An off-frequency generator is used to inject current and tuned voltmeters are used to measure the earth potential rise and step and touch voltages.

The step and touch voltages suggested by earth grid modelling software are verified by measurement with a high impedance voltmeter. These voltages are independent of the resistivity of the switchyard surface. With 1,000 Ω resistor across the voltmeter to approximate human body resistance, a similar measurement duplicates the step or touch voltage that may appear across a person. This measurement is dependent on the resistivity of the switchyard surface.

Current injection testing of zone substation earth grids operates on a continuous program based on an 10 year cycle.

In addition to determining the adequacy of the overall earth grid, continuity tests are undertaken at critical earth points such as transformers, earth swithes and instrument transformers. Points with inadequate earthing are identified for repair.

3.2.2 Distribution Installations

The above ground portions of electrical earths, associated with distribution equipment, are visually inspected for corrosion or mechanical damage in conjunction with the inspection of poles and other electrical equipment on a 5-yearly or 10-yearly cycle. The visual inspection includes the condition of connections to equipment, the mechanical support and mechanical protection of earthing conductors.

The procedures and the management plan for electrical earth testing of distribution installations are explained in Section 15 of the Asset Inspection Manual (document number 4111). The SWER substations are tested on a cyclic program of 5 years for Isolating substations and 10 year plan for distribution substations.

Electrical earths are tested using digital earth resistance testers “stakeless methodology” at a frequency of 55 Hz. This method improves safety and customer convenience compared to historical methods as installations can be tested without de-energising equipment, disconnect earths or touch earthing conductors. The test results are recorded using a mobility device and recorded in SAP as measurent documents.

In accordance with the Asset Inspection Manual (30-4111) SWER isolating transformers, SWER distribution subs and “key” switches are tested on a 5 or 10 year schedule. All other distribution earthing systems are sample tested, with sample sizes adjusted based on statisitical analsysis of the results.

Figure 6 shows the results of earth resistance tests undertaken on pole mounted assets (ie. switches, substations, regulators, VTs, cap banks) and concrete poles without pole mounted assets.

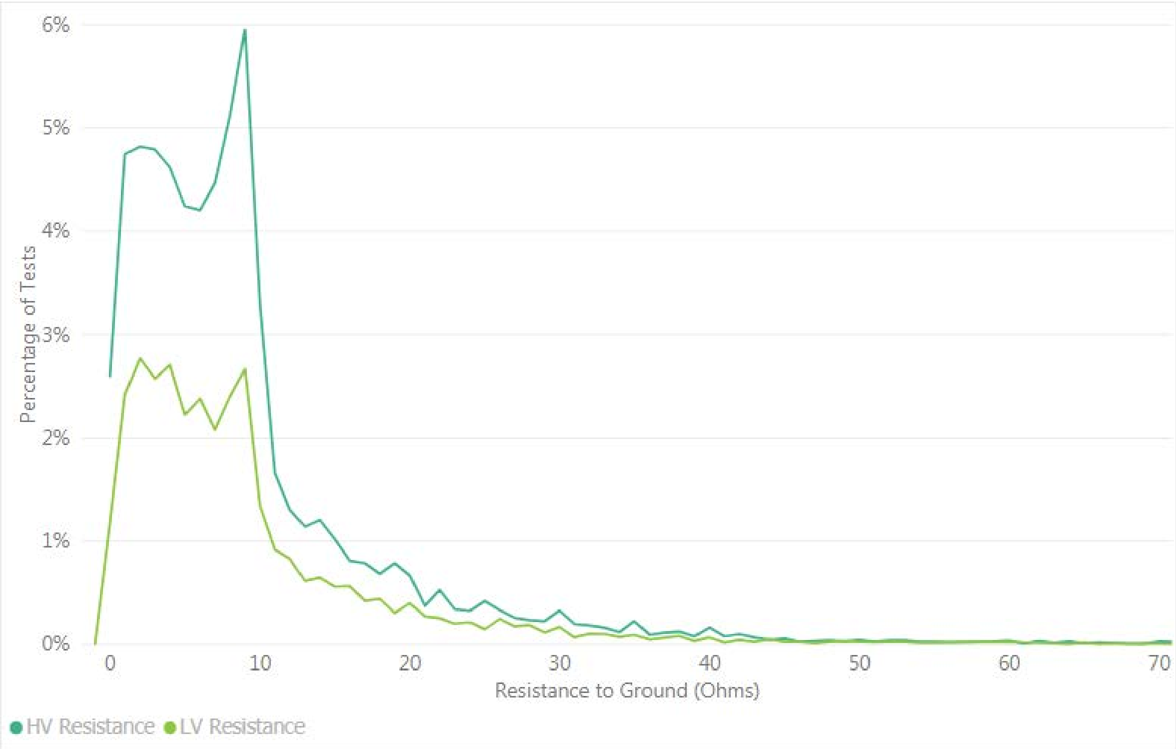

Figure 6 – Earth Resistance 2014 - 2019

Figure 7 shows the same test results undertaken on ground mounted substations which have a relatively low population.

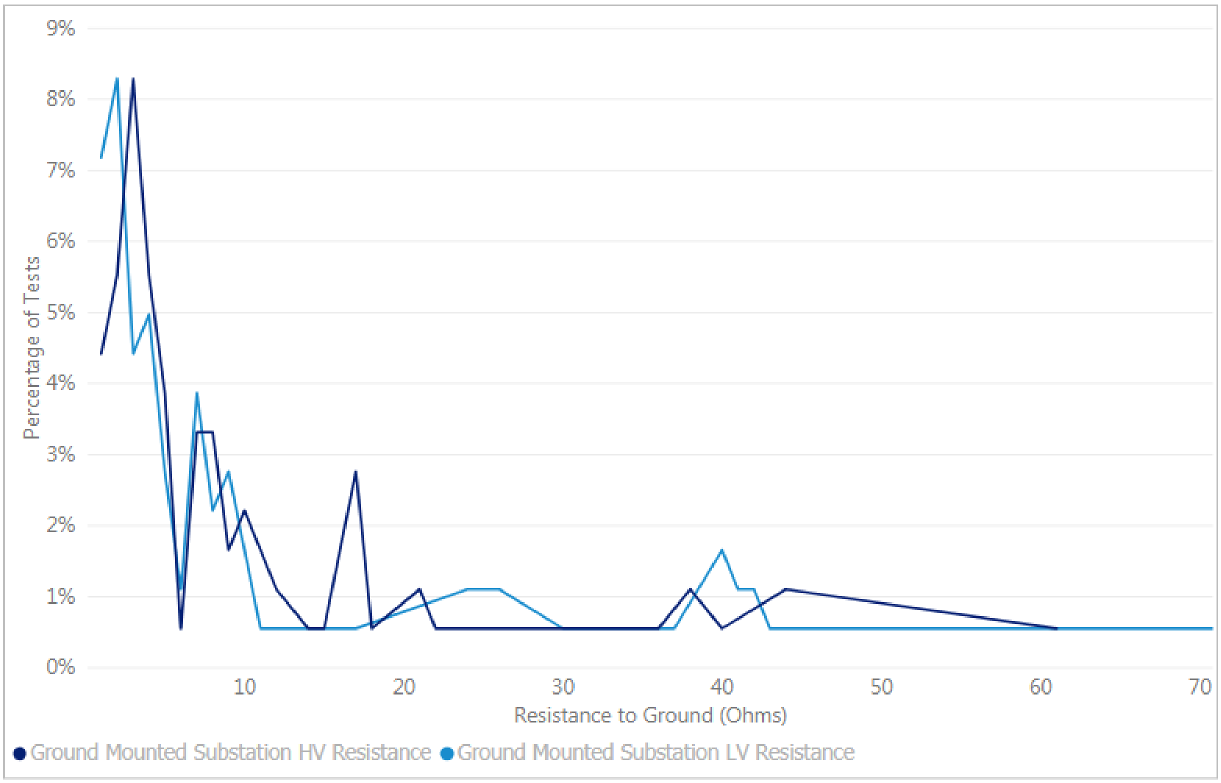

Figure 7 – Ground Mounted Substation Earth Resistance

4 Failure Mode Effect Criticality Analysis (FMECA)

FMECA is a technique for analysing and evaluating a life cycle strategy to ensure that the function has the desired reliability characteristics by obviating critical failure modes through redundancy, maintenance, re-furbishment or replacement. It is an extension of the Failure Mode Effect Analysis (FMEA) process which was originally developed by the US military in 1949 to classify failures "according to their impact on mission success and personnel/equipment safety". FMECA includes a criticality analysis, which charts the probability of failure modes against the severity of their consequences. The result highlights failure modes with relatively high probability and severity of consequences, allowing remedial effort to be directed where it will produce the greatest value.

4.1 Failure Modes

4.1.1 CMEN

The redundant nature of Common Multiple Earthed Neutral (CMEN) earthing systems which have multiple connections to multiple earths means that failure of a single earth in a CMEN system has negligible impact on the functioning and safety of connected installations. The testing of individual earths within a CMEN system is not necessary as the multiple connections of CMEN earthing systems are readily visible to asset inspectors.

4.1.2 Concrete Poles

When conductive concrete poles form part of an earth their large below-ground surface area makes a significant contribution to the resistance-to-ground value. In low resistivity soils, concrete poles often achieve the target value for resistance-to-ground without the benefit of additional electrodes. Where the USL is relatively low, as for SWER MV earths, then the combination of a concrete pole without additional electrodes located in high resistivity soils can exceed the USL. In the case of most other earths, the presence of the concrete pole is sufficient to maintain the resistance-to-ground value below the USL for typical values of soil resistivity.

To a large degree this means that concrete poles are inherently earthed. Installations constructed on concrete poles are less susceptible to failure following mechanical damage or corrosion of the earth.

4.1.3 Soil Resistivity

The electrical resistivity of earth mass determines the effectiveness of the earth grid. If the soil is sandy the soil resistivity is likely to be high causing difficulty to pass the fault current. Thus soil resistivity is an important factor for designing the earth grid.

If the design of an electrical earth is fit for purpose and it has been correctly installed then seasonal changes in soil resistivity will not cause the resistance-to-ground value of an earth to exceed the USL.

However, the gradual deterioration of an earth, as characterised by small changes in the resistance values over a long period, is often disguised by the year-to-year variations in soil moisture. In particular, droughts lower water tables which limits the mobility of the ions necessary for conductivity in soils. Older earths installed in the surface layers of soils are most susceptible to wide movements in resistance during droughts when some soils dry and crack to depths below two metres. The extensible nature of the copper clad electrodes introduced in the 1980s has enabled earths to be established at greater depths with more exposure to moist ground near the water table. Hence, earths installed since the 1980s are more resistant to seasonal variations in surface soil resistivity.

Thus if the design of an electrical earth is fit for purpose and it has been correctly installed then mechanical damage and corrosion are the predominant causes of the resistance-to-ground rising toward the USL.

4.1.4 Mechanical damage

Mechanical damage to the above-ground portion of an electrical earth is not common. It is essentially a random event which arises from a wide variety of causes including:

- Vehicles, such as road graders or grass slashers, mowers, striking the supporting pole
- Theft of copper conductors
- Improper connections
- Vandalism.

Careful placement of poles near roads, erection of warning signage, use of protective cover strips or cable guards and laying conductors inside hollow poles with connections above reach or below the ground line are the principal methods of protecting the above-ground portions of earths from mechanical damage.

Mechanical damage to the below-ground portion occurs in agricultural areas and on road reserves during works by utilities contractors. Depth of burial is the principal defence mechanism but land easements; improved signage and the introduction of dial-before-you-dig have reduced the incidence of mechanical damage to the below-ground portion of earths.

In the absence of damage reports by customers or the public, the 5-year asset inspections are effective at detecting mechanical damage to the above-ground portions of earths but electrical testing is the only technique able to detect damage to the below ground portion of an earth prior to complete failure.

The standard method of earth conductor joints is brazing that requires experience and skill. It has been found that some joints in zone substations were not properly installed especially those that were done in wet weather conditions.

In the period around 2007, world copper prices were rising rapidly. Because of the attractive market values, copper theft occurred all over Australia and in Victoria. In several occasions, thieves broke into several AusNet Services' premises and removed conductors used as part of the earth system.

4.1.5 Corrosion

Earth grids are made up of stranded copper conductor and earth rods driven into ground. These conductors are subjected to various environmental conditions like ground water, heat and salinity. As a result, the earth grid can be subject to galvanic corrosion, particularly in the oxygen rich surface layers of soil when in the presence of dissimilar metals such as brass and galvanized steel.

Pre-1980 materials included mild steel electrodes which were particularly prone to corrosion in areas with acidic soils; often found near dairy and orchard activity. Brass split-bolt connectors were also used in earths prior to 1980 and these were found to corrode rapidly if used to earth concrete poles.

Corrosion generally results in a slow reduction of the cross sectional area of the conductor, connector or electrode. This initial reduction can be difficult to measure. However, a rapid rise in the resistance–to-ground value then follows as a portion of the earth, with insufficient mechanical strength, is electrically disconnected by the passage of fault currents or movement in adjacent soils. This change can be readily measured and remedial action is prioritised in accordance with the proximity to the USL.

The copper-clad mild steel electrodes, stainless steel connectors and dezincification resistant brass connectors (to connect earths to concrete poles), since the early 1980s have significantly improved the corrosion resistance of earths.

4.2 Failure Effects

4.2.1 Low Voltage Earths

A LV earth electrically connects the neutral of the LV winding in a distribution transformer to the general mass of earth. This connection maintains the transformer's output voltages within the Distribution Code specification and provides a low impedance path for any fault currents from the general mass of earth to the transformer.

The failure of a low voltage earth is often detected by abnormal supply voltages in a customer's installation. The abnormal supply voltage may:

- limit a customer's ability to use appliances such as motors
- damage electronic appliances such as televisions
- lead to unsafe touch voltages on appliances or plumbing within the customer's installation.

The consequences of a LV earth failure thus include costs associated with an urgent response to unsafe touch voltages within customers' installations, investigation of quality of supply complaints and compensation for damage to installations or appliances. In some cases the failure results in an electrical shock to a customer or member of the public as LV fuses are unable to detect an unsafe electrical condition due to the restriction of fault currents.

4.2.2 MV Earths

A MV earth provides a low impedance path for any fault currents to the general mass of earth enabling protective devices such as fuses and circuit breakers to disconnect unsafe electrical conditions. Under fault conditions, the failure of a MV earth will slow the disconnection of a damaged circuit causing an increase in:

- the extent of supply outages as back-up protection systems operate
- collateral damage to MV equipment
- unsafe step, touch and transfer voltages near the failing earth
- inadequate operation of overvoltage protection such as surge arresters.

4.2.3 SWER MV Earths

SWER MV earths carry load current as well as providing a low impedance path for any fault currents which enables protective devices to disconnect unsafe electrical conditions. Thus the failure of a SWER MV earth is promptly detected by a range of consequences including:

- abnormal supply voltages, particularly at times of peak loading
- unsafe step, touch and transfer voltages near the failing earth
- in rare occasions steam or smoke around the ground near the pole.

4.2.4 Zone Substation Earths

As the zone substation electrical earth is provided by a wire grid, compared to limited points in the distribution network, in the event of failure only the performance of the grid is compromised. Any electrical fault involving earth in the network will allow a fault current into the surrounding ground and return to the source transformer in the zone substation. The return current will result in voltage rise in all metallic structure inside the zone substation. Reduced performance of the earth grid due to failures could cause:

- Hazardous step and touch voltages
- High supply voltages to the distribution network
- Protection systems not operating as expected; operation of back up protection causing wide spread supply outages
- Equipment damage to equipment including ancillary items such as communication cables (insulation breakdown, thermal or mechanical damage).

5 Strategies

This section includes asset management strategies for both zone substation and distribution network electrical earths.

5.1.1 Installation

In accordance with the principles in the AS/NZS 7000 and AS 2067:

- Design and install earthing systems on a case by case basis.
- Progressively implement Common Multiple Earthed Neutral (CMEN) earthing of conductive MV installations in urban areas.
- Amend tools and procedures to ensure compliance to AS 7000 and AS 2067.

5.1.2 Inspection

- Inspect above-ground portions of zone substation earths in conjunction with routine station inspections.
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- Inspect station earths to be undertaken in accordance with section 8.8 of AS 2067. This involves:
    - Visual inspections
    - Continuity testing - critical earthing connection points are tested within stations, including transformers, earth switches, and instrument trasnformers and REFCL earths.
    - Earth Potential Rise (EPR), and transfer, touch, and step voltage testing.
- Create measurement points in SAP in order to capture tests for station earth grids.
- Considate overall report using information in SAP and Enablon to enhance the feedback loop and risk based prioritisation of follow up works.

5.1.3 Testing

- Confirm performance of zone substation earth grids via current injection tests undertaken in conjunction with augmentation projects or specific tests at intervals no longer than 10 years.
- Complete earth testing program of zone substations to quantify any step and touch voltage hazards associated with metallic structures inside and outside the switchyard.
- Each year, conduct resistance to ground tests and analyse results of representative samples of each class of distribution earths in accordance with Section 5.9 of the Standard Installations Manual (4142).
- Amend the annual testing samples for SWER concrete pole earths to quantify the cause and location of non-compliance with Upper Specification Level (USL).

5.1.4 Maintenance

- Review risk levels associated with non-conforming zone substation earth grids and upgrade earth grids with unacceptable risk levels.
- Repair specific earth point defects when discovered.

- Repair or replace-on-condition non-conforming distribution installation earths in accordance with Section 5.9 of the Standard Installations Manual (4142) and Standard Maintenance Guide Line SOP 70-03.
- In accordance with Tolhurst classification of bushfire risk and Standard Maintenance Guide Line SOP 70-03; progressively remediate non-compliant earths on SWER MV concrete poles to less than 3% by 2020.
- On a case by case basis extend CMEN earthing in urban areas to mitigate distribution installation earth inspection, testing and maintenance workloads.