Neutral Earthing Devices

AMS – Electricity Distribution Network

PUBLIC

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Disclaimer

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1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity distribution network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of Neutral Earthing Devices.

Neutral Earthing Devices in this strategy is focused on Neutral Earthing Resisters (NER), Neutral Earthing Compensators (NEC) and Arc Suppression Coils (ASC) used in Rapid Earth Fault Current Limiting (REFCL) systems.

Approximately 80% of NERs installed in zone substations compromise of 8 ohm type and the remaining 20% comprise of 75 ohm and 254 ohm resisters used in open cut mine customer substations. All NECs are expected to be retired or replaced by 2021. All ASC are all relatively new being installed under the REFCL program.

Condition Assessment shows approximately 74% of NERs are in a good/average operating condition (C1 to C3), approximately 13% of the NERs are found to be in "Poor" (C4) and 13% "Very Poor" condition (C5). Failure analysis of NERs show resister element related failures and high resistance connections as the common mode of failure mostly found in [C.I.C] make NERs.

The consequence of failure has been assessed and is relatively high in non REFCL stations due to regulatory compliance, customer power quality, community and public safety risks. Criticality was found to be very high in 16.7% in mine substations.

A risk assessment that's considers both condition and criticality has identified a proactive replacement and enhanced online monitoring program for the 2022-26 period, taking into account current projects and REFCL related replacements.

Proactive management of neutral earthing devices inspection, condition monitoring and replacement practice is required to ensure that stakeholder expectations of cost, safety, reliability and environmental performance are met. The summary of proposed asset strategies is listed below

1.1 Asset Strategies

1.1.1 New Assets

- Continue to purchase NERs to the latest specification with total resistance tolerance 0%/+10% and arc fault contained enclosure, and consider installing online health monitoring
- Continue to purchase NECs and arc suppression coils (ASC) to the latest specification.

1.1.2 Inspection

- Continue maintaining NERs in accordance with plant guidance information, PGI 02-01-04
- Carryout regular oil sampling of NECs and ASCs in accordance with PGI 02-01-04

1.1.3 Condition Monitoring

- Maintain online health monitoring at the six ZSS NERs at BGE, BRA, WGL, WN, WO and BN
- Install online health monitoring of three older NERs at MFA, CLN and TT zone substations

1.1.4 Spares

- Maintain strategic spares holding of complete 8 ohm NER and hold spare resister elements for [C.I.C] types
- Maintain strategic spares holding of NECs and ASCs as per spare holding policies

1.1.5 Replacement

- Proactively replace resister elements of four NERs at MWN and LYS open cut substations

2 Introduction

2.1 Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of Neutral Earthing Devices installed in zone substations in AusNet Services' Victorian electricity distribution network. This document is intended to be used to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of our Asset Management System for compliance with relevant standards and regulatory requirements. It is intended to demonstrate responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

This asset management strategy applies to all neutral earthing resistors, neutral earthing compensators and arc suppression coils associated with the AusNet Services electricity distribution network that operate at voltages between earth potential and 22 kV, 11 kV and 6.6 kV. The power transformer medium voltage winding neutral points within zone substations are directly connected to earth or via neutral earthing resistors (NERs), or in stations with delta-connected phases, through neutral earthing compensators (NECs). Ground Fault Neutralisers (GFN) using arc suppression coils are used to replace NERs for power transformer neutral earthing in bushfire risk areas to further mitigate bushfire ignition risks.

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Comply with legal and contractual obligations;
- Maintain safety;
- Be future ready;
- Maintain network performance at the lowest sustainable cost; and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

- Improve efficiency of network investments;
- Maintain long-term network reliability;
- Implement REFCL's within prescribed timeframes;
- Reduce risks in highest bushfire risk areas;
- Achieve top quartile operational efficiency; and
- Prepare for changing network usage.

3 Asset Description

3.1 Asset Function

NERs are passive devices, with no moving parts, protected from the weather within an enclosure and only operate during medium voltage network phase to earth faults. The NER limits the magnitude of the earth fault current that would flow on the occurrence of a phase to earth fault in a medium voltage circuit. This improves public safety by limiting the energy released at the fault location, reducing risk of bushfire ignition. The reduction in fault current magnitude also improves power quality by reducing the magnitude of operating voltage dips during phase to earth faults on medium voltage circuits. NERs can also be used to bring the single-phase short-circuit level to within the station equipment rating short-circuit level.

NECs are used to connect the neutral point of delta connected medium voltage windings the general mass of earth.

Arc suppression coils (ARC) under the GFN system is a relatively new technology introduced in Victorian electricity distribution networks under Rapid Earth Fault Clearance (REFCL) project. This new technology uses ARCs in place of NERs in identified areas under three tranches in zone substations. It helps to minimise the risk of fire ignition caused by phase to earth faults on medium voltage feeders in highest fire risk rural areas on recommendations of Royal Commission into 2009 bushfires.

3.2 Asset Population

3.2.1 Neutral Earthing Resistors (NER)

AusNet Services has a total of 54 Neutral Earthing Resisters installed in AusNet Services zone substations as at end 2017. There are three resistance type designs in service in zone substations namely 8 ohm, 75 ohm and 254 ohm. 75 ohm and 254 ohm designs are installed in open cut substations. The population of NERs by service voltage and value of resistance is given in Figure 1.

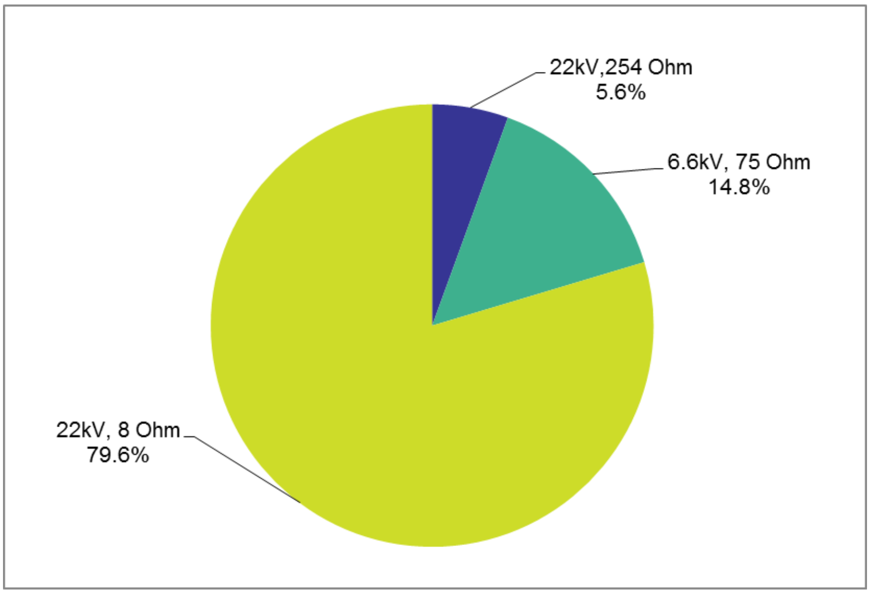

Figure 1 – Population of Neutral Earthing Resisters by Voltage and value of Resistance

Figure 2 below provides the population of NERs by manufacturer. [C.I.C] NERs contribute to about 57.4% of the NER population.

C.I.C

3.2.2 Neutral Earthing Compensators (NEC)

In the AusNet Services electricity distribution network, NECs are installed to connect the neutral point for delta-connected medium voltage windings to the general mass of earth. Hence there are currently five NECs installed in Morwell Power Station (MPS), Yallourn Power Station (YPS) and new Yallourn Power Station (YPSS). NECs are basically zigzag wound, oil-filled transformers. Technical details of NECs are shown in Table 1.

Table 1 – NECs Installed in Zone Substations

Zone Substation	Description	Manufacturer	Rating	Neutral Connection
MPS	No 2 NEC	C.I.C	11 kV, 3000A/30 seconds	Solidly earthed
MPS	No 3 NEC		11 kV, 3000A/30 seconds	Solidly earthed
YPS	No 5 Group NEC		11 kV, 5 Ohm/phase, 3000A/30 seconds	Direct earthed
YPSS	No 1 NEC		11 kV, 5 Ohm/phase, 3000A/30 seconds	Direct earthed
YPSS	No 2 NEC		11 kV, 5 Ohm/phase, 3000A/30 seconds	Direct earthed

NECs installed at MPS are expected to be retired by end 2019 with the closure of MPS substation. A project is in progress to retire No 5 Group NEC and YPSS NECs with the installation of new 11kV YPS switchboard during the current period.

3.2.3 Arc Suppression Coil used in REFCL/GFN systems

The Rapid Earth Fault Current Limiter (REFCL) technology is being installed at number of AusNet Services zone substations is called a Ground Fault Neutralizer (GFN). The GFN helps to reduce the disruption of phase to earth faults on a network. It does this by using resonant earthing with an additional 'residual current compensation feature' which involves injecting current into an arc suppression coil at 180° out of phase with the residual fault current. This reduces the large fault current to less than five Amps and then close to zero Amps within 3 cycles or 60 milliseconds.

Currently there are 12 off 200A rated oil filled Arc Suppression Coils (ASC) being installed under tranche 1 of REFCL project at nine zone substations. They are all supplied by the manufacturer, Swedish Neutral.

The purpose of the ASC is to compensate for the leakage current during an earth fault and along with a Residual Current Compensator (RCC) further reduce fault current by compensating for the active current during an earth fault. The ASC comes as one unit and is connected to the power transformer 22 kV neutral and comprise of arc suppression coil, tuning capacitor module, current transformers and manual control cabinet provide connections RCC located in the station control room.

3.3 Asset Age Profile

3.3.1 Neutral Earthing Resistors (NER)

The service age profile of zone substation NERs by value of resistance and by manufacturer is shown in Figures 3 and 4 respectively. Average age of NERs is 19 years, oldest being 51 years.

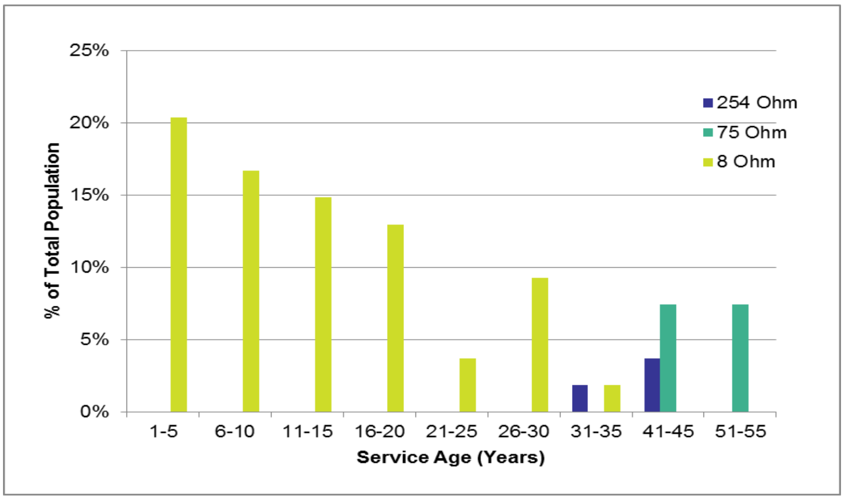

Figure 3 – Age Profile of NERs by value of resistance

C.I.C

3.3.2 Neutral Earthing Compensators (NEC)

NECs that are in service at MPS and YPS stations are all 54 years old.

3.3.3 Arc Suppression Coils

All Arc Suppression Coils in service are less than 3 years old, majority were installed during the year 2018.

3.4 Asset Condition

Table 2 provides the condition assessment criteria of NERs in zone substations.

Table 2 – Condition Assessment Criteria

Condition Score	Condition Description	Summary of details of condition score	Remaining Service Potential
C1	Very Good	These NERs are generally less than 10 years old and in good operating condition with no past history of defects or failures. Manufacturer support and spares are readily available for routine maintenance. Routine maintenance and continued condition monitoring is recommended.	**95%**
C2	Good	This category includes NERs which are in better than average condition for its service age and technology type. They may not have developed actual faults but showing signs of developing high resistance. They do not require intervention between scheduled maintenance nor do they show any trends of serious deterioration in condition or performance. Manufacturer support and spares are available.	**70%**
C3	Average	This category includes NERs which are with an average condition for its respective service age and technology type. (Some NERs may had majortiy of resistors replaced and by doing so condition had improved average level.) They may have developed corrosion of some resistors and overheating due to frequent network earth fault currents. These units particularly require increased maintenance. Spare resistors are being used to replace cracked resistors and manufacturer support is becoming limited.	**45%**
C4	Poor	This category includes NERs which are in worse than average condition. They may have developed an increasing number of defects such as more than one resistor failures, cracked /flashed over support insulators or earth bushings ,flashovers to earths. Manufacturer support and spares are typically not available salvaged resistors from retired equipment or in situ repair are becoming the most practical solution.	**25%**
C5	Very Poor	This category includes NERs which are typically maintenance intensive and have history of recurrent resistor failures,flashovers, cracked or flashed support insulators or earth bushings and resistor corrosion is widespread. These NERs are approaching the end of economic life. The defects develop within the maintenance inspections and lack of availability of spare parts is a major concern . Salvaged resistors from retired equipment are used. Manufacturer support is very limited and spares will not be available in 3-5 years. The maintenance of NERs is typically no longer economical compared to asset replacement.	**15%**

Condition profile of NERs by Value of resistance and manufacturer are shown in Figures 5 and 6 respectively.

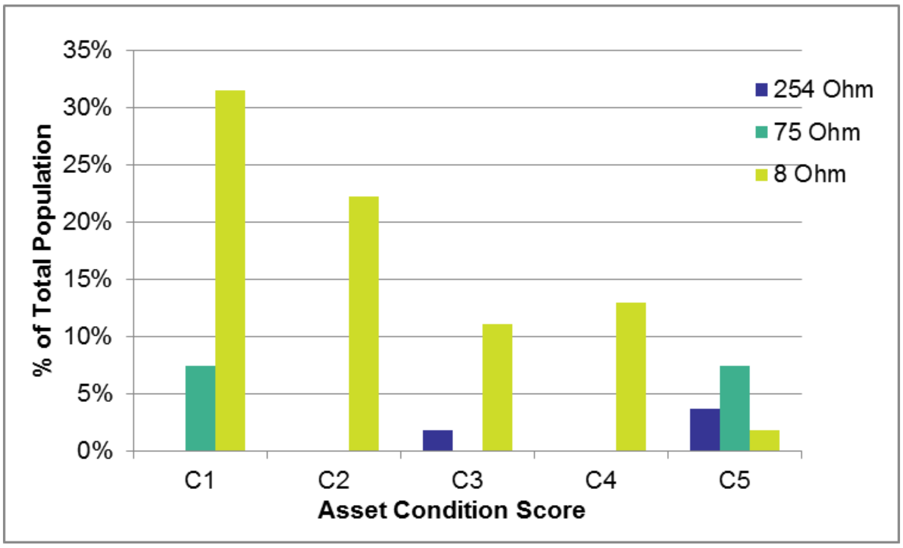

Figure 5 – Condition Profile of NERs by Resistance type

C.I.C

It is observed 75 ohm and 254 ohm type NERs located in open cut substations are in asset condition C5. There is one 8 ohm NER at BGE zone substation in C5 condition. Retrofit of resister element replacement of six 75 ohm [C.I.C] at MWW, YN and MWE open cut substations will be retrofitted during the current period as a cost effective solution.

3.5 Asset Criticality

Asset Criticality was determined by considering the following consequences of NER failure with the failure effects mentioned below.

I. Bushfire safety & Public safety
II. Customer power quality
III. Collateral damage to NER

Asset criticality is the severity of consequence in a major failure of a NER at a certain location due to above failure effects irrespective of the likelihood of the actual failure.

Bushfire safety impact is assessed on fire loss consequence model' for NERs. Public safety is estimated based on risk of fatality due to failure of NER. Customer power quality is due to not meeting voltage quality as per distribution code resulting in customer complaints and damage claims. Often NER resister elements get damaged when it open circuit or short circuit due to internal flashovers and burnouts when one element fails resulting in collateral damage.

Figure 7 shows the relative base criticality profile of NERs. Very high criticality is due to NERs located in mine substations due to high mine safety and compliance requirements. Very low criticality refers to NERs installed in GFN systems where NER becomes the secondary earthing device in comparison to Arc suppression coil being the primary neutral earthing device.

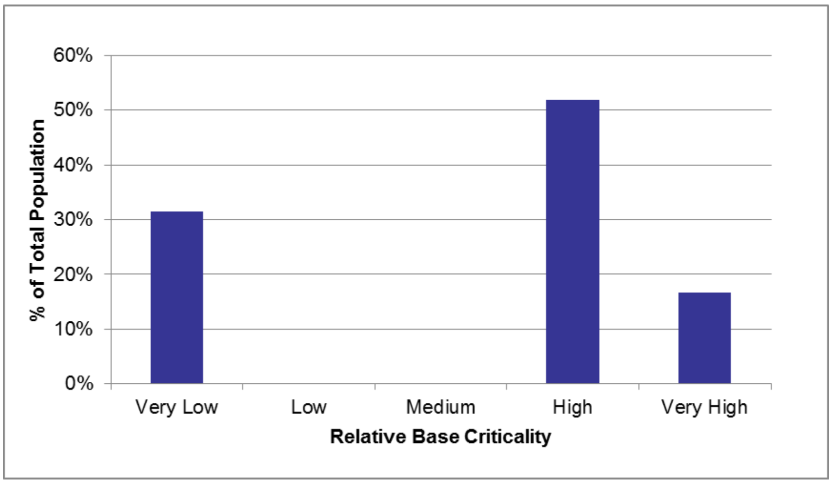

Figure 7 – Relative Base Criticality Profile of NERs

The applied interpretation of relative base criticality is shown in Table 3.

Relative Base Criticality	Banding	Economic Impact
Very low	1	Total failure effect cost < 0.30 times Replacement Cost
Low	2	Total Effect Cost is between 0.30 – 1.0 times of replacement cost
Medium	3	Total Effect Cost is between 1.0 - 3 times of replacement cost
High	4	Total Effect Cost is between 3 -10 times of replacement cost
Very high	5	Total Effect Cost exceeds 10 times replacement cost

Table 3- Interpretation of Relative Base Criticality

3.6 Asset Performance

AusNet Services routinely analyses the root cause of unplanned work undertaken on NERs and investigates all major failures and tracks their effects on reliability and power quality to the customers.

3.6.1 Corrective Maintenance

All NERs, NECs and ASCs are subjected to routine maintenance in accordance with PGI 02-01-04 and relevant standard maintenance instructions (SMI). Poorer condition [C.I.C] are inspected 6 monthly and all other NERs are inspected annually except NERs with online condition monitoring are inspected by biannually.

Typical defects found during planned & unplanned maintenance inspections carried out in NERs during the period 2015 -2018 are:

- Resistor element connection cracks at MWW, MWE, YN & BGE (8), ([C.I.C])
- High total earth path resistance found at several stations (8),
- Broken earth bushings at BGE (1),
- Poor condition of resisters and enclosure at MWE (8) and
- Moisture ingress in Ampcontrol type (4).
- Loose bolts (1)

High earth resistance path is a defect found external to the NERs, defects associated with resister elements is the key issue found in older NERs.

No reportable defects were found in NECs and ASCs during the period 2015-2018.

4 Other Issues

4.1 NER Condition Monitoring

NER is a single system neutral point earthing device in zone substations essentially required to be in circuit 100% of time to safely operate the electricity distribution network at all times. Defective NERs are occasionally found after about 10 -15 years in operation. Resister defects are normally come to know during planned inspection or after an inspection following protection mal operation found sometimes during phase to ground faults.

Based on historical failures, older NERs of certain types are inspected more frequently than others, yet resister defects are found during maintenance inspections. In order to overcome this issue, an online health monitoring scheme was introduced recently on few older NERs may need setting changes to make it more effective and expand the application to other NERs passed midlife.

5 Risk and Option Analysis

The key drivers of this program are bushfire risk, public safety, customer power quality and collateral damage risk to NERs.

Table 3 provides an assessment of the risk based on the condition of the assets and the monetised consequence of failure.

Table 3 – Zone Substation NER Risk Assessment

Criticality Banding	C1	C2	C3	C4	C5
5	4	0	1	0	4
4	12	7	3	4	2
3	0	0	0	0	0
2	0	0	0	0	0
1	5	5	3	3	1

Within the higher risk zones, four NERs in C5 asset condition will be replaced during the current period.

To address the higher risk zone, the following work is proposed to be undertaken under EDPR 2022-26 program:

- Proactive replacement of resister elements of four NERs at LYS and MWN open cut substations
- Install online NER Health Monitoring at MFA, CLN and TT

6 Asset Strategies

6.1 New Assets

- Continue to purchase NERs to the latest specification with total resistance tolerance 0%/+10% and arc fault contained enclosure, and consider installing online health monitoring
- Continue to purchase NECs and arc suppression coils (ASC) to the latest specification.

6.2 Inspection

- Continue maintaining NERs in accordance with plant guidance information, PGI 02-01-04
- Carryout regular oil sampling of NECs and ASCs in accordance with PGI 02-01-04

6.3 Condition Monitoring

- Maintain online health monitoring of six ZSS NERs at BGE, BRA, WGL, WN, WO and BN
- Install online health monitoring of three older NERs at MFA, CLN and TT zone substations

6.4 Spares

- Maintain strategic spares holding of complete 8 ohm NER and hold spare resister elements for [C.I.C]types
- Maintain strategic spares holding of NECs and ASCs as per spare holding policies

6.5 Replacement

- Proactively replace resister elements of four NERs at MWN and LYS open cut substations