Network Standard

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Supersedes Network Standard (NETWORK) NW000-S0002 Amendment No.0

NW000-S002 NS222 MAJOR SUBSTATION EARTHING DESIGN

ISSUE

For issue to all Ausgrid and Accredited Service Providers' staff involved with Major Substation Earthing Design and is for reference by field, technical and engineering staff.

Ausgrid maintains a copy of this and other Network Standards together with updates and amendments on www.ausgrid.com.au.

Where this Standard is issued as a controlled document replacing an earlier edition, remove and destroy the superseded document

DISCLAIMER

As Ausgrid's Standards are subject to ongoing review, the information contained in this document may be amended by Ausgrid at any time. It is possible that conflict may exist between Standard documents. In this event, the most recent Standard shall prevail.

This document has been developed using information available from field and other sources and is suitable for most situations encountered in Ausgrid. Particular conditions, projects or localities may require special or different practices. It is the responsibility of the local manager, supervisor, assured quality contractor and the individuals involved to make sure that a safe system of work is employed and that statutory requirements are met.

Ausgrid disclaims any and all liability to any person or persons for any procedure, process or any other thing done or not done, as a result of this Standard.

All design work, and the associated supply of materials and equipment, must be undertaken in accordance with and consideration of relevant legislative and regulatory requirements, latest revision of Ausgrid's Network Standards and specifications and Australian Standards. Designs submitted shall be declared as fit for purpose. Where the designer wishes to include a variation to a network standard or an alternative material or equipment to that currently approved the designer must obtain authorisation from the Network Standard owner before incorporating a variation to a Network Standard in a design.

All designers including external designers authorised as Accredited Service Providers will seek approval through the approved process as outlined in NUS181 Approval of Materials and Equipment and Network Standard Variations. Seeking approval will ensure Network Standards are appropriately updated and that a consistent interpretation of the legislative framework is employed.

Notes: 1. Compliance with this Network Standard does not automatically satisfy the requirements of a Designer Safety Report. The designer must comply with the provisions of the Workplace Health and Safety Regulation 2011 (NSW - Part 6.2 Duties of designer of structure and person who commissions construction work) which requires the designer to provide a written safety report to the person who commissioned the design. This report must be provided to Ausgrid in all instances, including where the design was commissioned by or on behalf of a person who proposes to connect premises to Ausgrid's network, and will form part of the Designer Safety Report which must also be presented to Ausgrid. Further information is provided in Network Standard (NS) 212 Integrated Support Requirements for Ausgrid Network Assets.

2. Where the procedural requirements of this document conflict with contestable project procedures, the contestable project procedures shall take precedent for the whole project or part thereof which is classified as contestable. Any external contact with Ausgrid for contestable works projects is to be made via the Ausgrid officer responsible for facilitating the contestable project. The Contestable Ausgrid officer will liaise with Ausgrid internal departments and specialists as necessary to fulfil the requirements of this Standard. All other technical aspects of this document which are not procedural in nature shall apply to contestable works projects.

INTERPRETATION

In the event that any user of this Standard considers that any of its provisions is uncertain, ambiguous or otherwise in need of interpretation, the user should request Ausgrid to clarify the provision. Ausgrid's interpretation shall then apply as though it was included in the Standard, and is final and binding. No correspondence will be entered into with any person disputing the meaning of the provision published in the Standard or the accuracy of Ausgrid's interpretation.

KEYPOINTS

This Standard has a summary of content labelled "KEYPOINTS FOR THIS STANDARD". The inclusion or omission of items in this summary does not signify any specific importance or criticality to the items described. It is meant to simply provide the reader with a quick assessment of some of the major issues addressed by the standard. To fully appreciate the content and the requirements of the Standard it must be read in its entirety.

AMENDMENTS TO THIS STANDARD

Where there are changes to this Standard from the previously approved version, any previous shading is removed and the newly affected paragraphs are shaded with a grey background. Where the document changes exceed 25% of the document content, any grey background in the document is to be removed and the following words should be shown below the title block on the right hand side of the page in bold and italic, for example, Supersedes – document details (for example, "Supersedes Document Type (Category) Document No. Amendment No.").

KEY POINTS OF THIS STANDARD

Scope and Risks Addressed

This standard outlines the design requirements for major substation earthing. This standard is limited in scope as indicated below:

- ☐ Applies to major substations connected to the Ausgrid network.
- ☐ Distribution substations are not covered by this standard
- ☐ Sets out the objectives and basic configuration required of an earthing design.
- ☐ It specifies procedures and acceptable practice by which the objectives can be achieved.
- ☐ Relates to detailed design, earthing system compliance, materials and equipment, and commissioning.

Where to for more information?

Section 1, 2

Objectives and Design Compliance

This section identifies the objectives of the earthing system design and requirements for achieving earthing system compliance:

- ☐ Objectives of earthing system design include successful protection operation, safety compliance, interference minimisation, robustness and protection of electrical plant.
- ☐ Details the scope, inputs and requirements for performing Major Substation earthing assessments to achieve design compliance.

Where to for more information?

Section 3, 4

Tools and Forms

Annexure B – Exposure Assessment

Layout Overview and Considerations

An overview of the design considerations are listed for earthing layout followed by requirements for site specific conditions:

- ☐ Flowchart provided for information and documentation requirements to produce Earthing Layout Design
- ☐ Table 2 lists the document references for the various earthing conditions to be considered for earthing designs.
- ☐ Robustness, reliability and redundancy
- ☐ Design inputs/outputs
- ☐ Recommended equipment
- ☐ Testability
- ☐ Connection criticality
- ☐ Cable sizing and rating
- ☐ Connectivity
- ☐ Corrosion
- ☐ Embedded earthing
- ☐ Grid and electrode layout
- ☐ Personnel safety equipment
- ☐ Application of crushed rock
- ☐ Gas insulated switchgear special requirements
- ☐ Lightning protection systems
- ☐ Assessment of interactions with other asset types
- ☐ Use of commonly stocked equipment and materials
- ☐ Commissioning procedures

Where to for more information?

Section 5

Tools and Forms

Annexure A – Corrosion Assessment
Annexure D – Drawing format, etc.

Earthing Construction Site Safety

Consideration is given to earthing construction site safety and includes the following items:

- ☐ Site specific layout
- ☐ Temporary bonding requirements
- ☐ Isolation requirements
- ☐ Use of PPE
- ☐ Earthing requirements for site sheds
- ☐ Connection of LV power sources

Where to for more information?

Section 6

Tools and Forms

Annexure B – Substation Standard Construction Safety Requirements

Network Standard
NS222
Major Substation Earthing Design

Contents

1.0 PURPOSE

This network standard specifies the design requirements and processes for major substation earthing that form part of the Ausgrid network.

2.0 SCOPE

The scope of this standard is limited to the zone and sub-transmission substation earthing design with consideration of the connectivity between the following components:

- The substation grid,
- The embedded earthing system,
- The lightning protection system,
- The substation plant,
- Sub-transmission and distribution earth terminations.

This standard sets out the objectives and basic configurations required of a major substation earthing design. It also specifies procedures and acceptable practice by which these shall be achieved.

For other network earthing requirements refer to:

- NS116 for distribution substation earthing requirements.
- NS260 for earthing system performance issues such as feeder interconnectivity and system wide fault current distribution.
- NS264 for major substation lightning protection requirements.

3.0 OBJECTIVES

An earthing system is required to perform its intended function for the life of the electrical plant for which it is installed, for the range of configurations of the network and nearby infrastructure that are foreseeable. The earthing system may need to be augmented over time to continue to fulfil this function. The substation earthing must achieve the objectives outlined in the sections below.

3.1 Protection operation

The earthing system is required to ensure proper operation of protective devices such as protection relays and surge arresters to maintain system reliability within acceptable limits and minimise equipment damage.

3.2 Safety compliance

The earthing system is required to manage any hazardous potential differences to which personnel or members of the public may be exposed. These potential differences include:

- Touch Voltages (including transferred touch voltages)
- Step Voltages
- Hand-Hand Voltages

These voltages can be present on metallic equipment within substations, external to substations (eg. Feeder earthing), or non-power system plant metallic items nearby not associated with the electrical system. For a hazardous situation to arise, a power system earth fault must be coincident with a person being at a location where a hazardous voltage arises (refer Section 4.0).

The earthing system achieves an acceptable risk of shock for people by equipotential bonding or isolation of metallic equipment and infrastructure. The earthing system may also involve the use of insulating barriers to reduce the risk of hazardous potential differences.

3.3 Interference minimisation

Earthing systems shall be constructed such that the interference (eg. electrical noise, harmonic pathways, voltage offsets, DC superposition) to nearby utility assets (such as telecommunications plant and pipelines) meets the requirements of the relevant standards, (refer to Clauses 5.12 and 9.2).

3.4 Robustness

Earthing systems shall be constructed such that they:

- are adequate for the life of the substation,
- enable condition to be monitored throughout its operational lifetime,
- enable the system to be tested at the time of commissioning,
- effective maintenance can be undertaken as required.

The earthing system must be capable of conducting the expected fault current or portion of the fault current which may be applicable, without exceeding material or equipment limitations for thermal and mechanical stresses. This shall be achieved by meeting the level of redundancy specified by the performance design (refer Clause 5.2).

Consideration shall also be given to the effect of corrosion over the lifetime of connections and conductors (refer to Clause 5.5).

3.5 Protection of electrical network equipment

The earthing system is a necessary component for controlling transient voltage and power frequency voltages impressed on electrical equipment. This is achieved by minimising conductor lengths between plant and the bulk of the earthing system.

The earthing system is also required to provide appropriate current paths for fault energy in such a manner that those fault energies do not impair equipment or equipment operation (refer Clause 5.3 and 5.4).

4.0 EARTHING SYSTEM COMPLIANCE ASSESSMENT

This section details the scope, inputs and compliance requirements for performing major substation earthing assessments to achieve design compliance and an acceptable risk profile to Ausgrid.

4.1 Scope of Assessment

A major substation earthing design or assessment must consider the following:

i) Earth faults on all HV systems associated with the substation

ii) Voltage hazards inside and transferred outside the substation where workers or the public could be located. Transferred hazards include earth potential rise impact on secondary assets downstream, the surrounding MEN and third-party assets

iii) Contact scenarios applicable to identified hazard locations, inside and outside the substation

4.2 Information Gathering

This section details the main inputs required when performing a major substation earthing compliance assessment.

4.2.1 Fault data

The highest and future maximum fault levels, source impedances, contributions (feeder and transformer neutral) and associated X/R ratios are provided by Ausgrid's Asset Investment.

Primary and backup clearing times are provided by Ausgrid's Secondary Systems.

Where the fault is cleared in a stepped manner, fault current data and times for each discrete step are required.

For the 11kV distribution network, the fault levels and source impedances shall be provided for each independent section of 11kV busbar and the applicable worst case (or slowest) 11kV feeder primary earth fault protection characteristic/curve.

4.2.2 Fault frequency

Fault frequency data can be provided by assigned Earthing Engineer.

The fault frequency used shall consider the most applicable of either historical network asset data or standard system fault rates from EG-0.

Where the historical fault frequency exceeds EG-0 standard curve system fault rates then a site specific EG-0 risk assessment is required.

For historical primary fault frequency, the design shall consider faults at upstream substations as well as the substation under analysis. For each upstream substation, a proportion of faults shall be based on the number of feeders supplying the substation under assessment divided by the total number of feeders at the upstream substation (at the relevant voltage under consideration). Each calculated proportion of upstream substation fault frequency shall be summed and added to the fault frequency at the substation under assessment to give a single fault frequency for primary faults. Initially, conservatively assume all faults are bus faults and do not occur part way along feeder. If necessary, a more detailed fault distribution may be used in the analysis for specific cases where compliance is difficult to achieve i.e. it may be required to calculate and combine the risk from various fault scenarios. Ausgrid's Network Earthing function can provide data on request to facilitate this.

4.2.3 Contact Profile

The contact profile defines the contact scenario being assessed as part of the risk assessment eg. current path, footwear type, soil resistivity, surface layer, number of contacts and duration.

Where the contact profiles identified for the substation assessment exceeds EG-0 standard curve profiles then a site specific EG-0 risk assessment is required.

Where safety criteria are derived utilising EG-0 principles then guidance on typical contact scenario profiles for use in a risk assessment are provided in Annexure B.

Standard contact scenarios do not account for contact during construction. The project Construction Safety Plan and/or Safety In Design documentation will be required to address construction safety aspects with a focus on eliminating or avoiding shock voltages. No construction safety profiles are to be considered as part of the earthing assessment.

4.3 Achieving Design Compliance

The following sub sections detail the requirements for achieving earthing system design compliance.

4.3.1 Earth Potential Rise (EPR) determination

For a major substation, it is necessary to consider EPR for all system voltages present (except LV).

4.3.1.1 Primary EPR determination

The primary EPR at a major substation may be determined via the following methods:

- By direct measurement using off-frequency current injection commissioning testing (as per AS2067) and scaling test results utilising fault data.
- By developing a sub-transmission model and determining the EPR at the substation when it is faulted
- By developing a substation earth grid model with appropriate auxiliary network connections represented by input impedances and applying the fault current

4.3.1.2 Secondary EPR determination

Secondary EPR at a major substation is typically determined by modelling unless stated otherwise in the Ausgrid Earthing Brief.

Where the standard EG-0 withstand curves are used, the worst-case fault scenario shall be assessed (worst case combination of fault level and clearing time).

Where a site specific EG-0 risk assessment is undertaken, the preferred method for determining the substation EPR for secondary faults is to utilise a model which faults all downstream assets with earthing (eg. kiosk, PT, UGOH) along each of the secondary feeders. Then the risks are added for all fault scenarios for a total risk to an individual (at a particular location). Assumptions regarding fault levels, clearing times and distribution of fault frequencies across fault scenarios are to be documented.

4.3.1.3 Stepped Fault EPR determination

For the cases where there is a stepped fault, the analysis is to be undertaken as follows:

1. Use the highest fault current to determine the EPR at the full duration clearing time
2. If step 1 results in a non-compliance:
   a. Scale the EPR in accordance with the initial step current and perform all analysis using the initial step clearing time, and
   b. Calculate the rms value of the fault current for the full duration of the fault and scale the EPR accordingly. Recalculate the analysis using this EPR and the full duration clearing time.

   Note: Both methods a and b are required to achieve compliance.

4.3.2 Safety Criteria

The following applicable safety criteria listed in Table 1 shall be used for hazard assessment:

Table 1: Applicable Safety Criteria used for Hazard Assessment

Item	Relevant Standard or Guide
Major Substations	AS2067, EG-0, EG-1
Pipeline and Ancillaries	AS4853
Telecommunications Assets	AS3835
Mines	AS3007

Standard withstand curves/limits such as those presented in EG-0 Appendix E and AS4853 may be used provided the case under investigation meets the assumptions used in the generation of the standard curves/limits. Where boundary conditions for the standard withstand curves/limits are not applicable then a site specific EG-0 risk assessment is required.

4.3.3 Design Verification and Validation

Verification of the installed earthing shall be completed on the primary and secondary side fault scenarios to validate the design.

Where non-compliances are identified, further control specification shall be achieved while minimising cost and time by aligning any remedial works within project scope or associated projects with the substation.

The sub-transmission earthing should be considered first as small changes (eg. rectifying a high impedance connection between an OHEW and substation earth grid) may result in large performance improvements to the distribution network. Refer to NS260 for details on sub transmission feeder earthing requirements.

Earthing design documentation shall state how earthing compliance is achieved by including the pertinent design details such as: physical installation description, assumptions and design decisions, commissioning results, non-conformances and any specified controls.

5.0 EARTHING DESIGN LAYOUT

5.1 Overview

This section lists the specific tasks that the earthing designer shall undertake, the inputs required to undertake the design task and the outputs produced. There are six types of documentation that make up the earthing design:

- Earthing layout electrical drawing set – specifications, layout and construction detail.
- Earthing layout civil drawing set – specifications, layout and construction detail.
- Earthing design report – calculations and justifications
- Commissioning requirements inspection and test plan (ITP), timetable and signoff.
- Final commissioning documentation.
- Earthing construction safety requirements for live brownfield construction.

The information and documentation required to produce an earthing design is summarised in Figure 3 below.

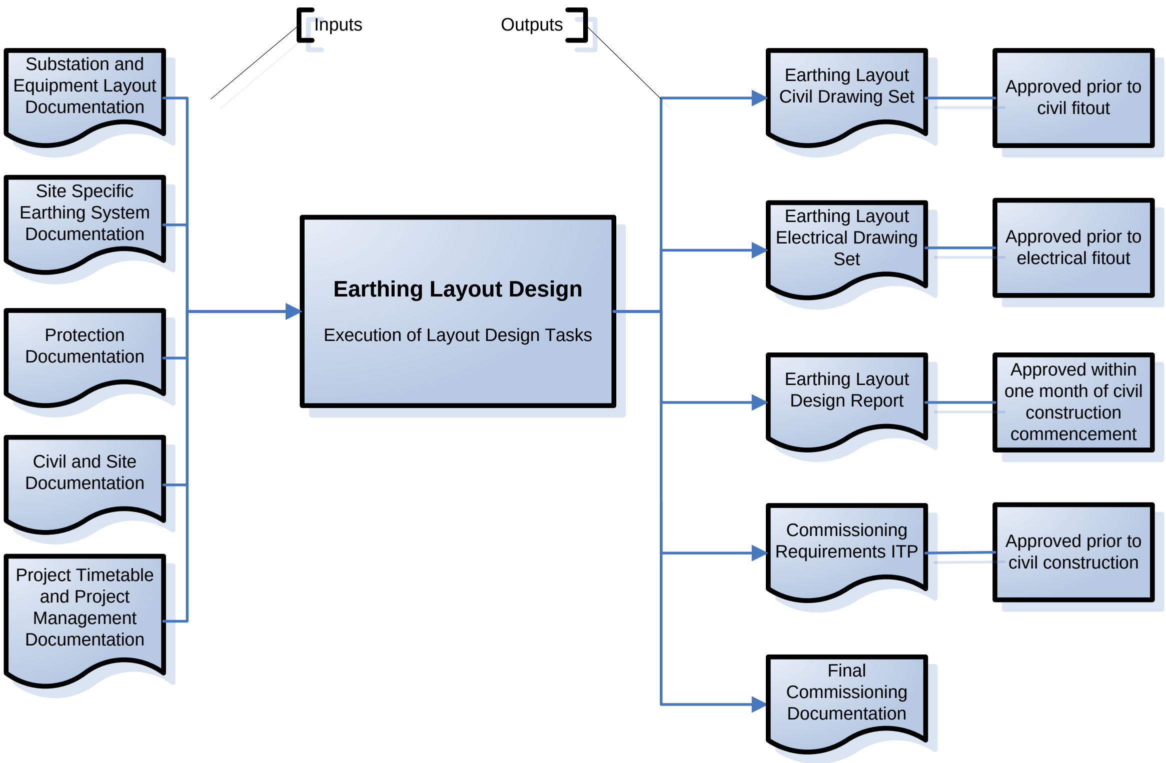

Figure 3: Earthing Design Process

The earthing design is completed by addressing the design objectives outlined in Section 4 and documenting the outcome as required. Commissioning requirements are part of the design and require administrative and testing actions to be coordinated, assessed, and signed off.

The considerations made to complete the earthing design are summarised in Table 2 below.

Table 2: Design Considerations

Phases	Design Considerations	Clauses
Detailed Design, Materials and Earthing Equipment	Robustness, Reliability and Redundancy	5.2
	Cable sizing / rating	5.3
	Connectivity	5.4
	Corrosion	5.5
	Embedded earthing	5.6
	Grid and electrode layout	5.7
	Personnel Safety Equipment	5.8
	Crushed Rock	5.9
	Gas Insulated Switchgear (GIS)	5.10
	Lightning Protection Systems (LPS)	5.11
	Acceptable Interaction with Other Assets	5.12
	Future developments	5.13
	Standardisation and equipment normalisation	5.14
Commissioning	Commissioning	5.15
Earthing Construction Site Safety	Earthing Construction Site safety	6.0

Some details of the following material are open to alteration provided the alterations are consistent with Ausgrid's design outcomes. A dispensation can be requested using the NS181 variation process.

5.2 Robustness, reliability and redundancy

The components specified in the substation earthing design shall be of sufficient dimensions and construction to withstand the expected deterioration over their required design life. The earthing of critical items of plant shall have N-1 redundancy (see Clause 5.3.4). This requires that the item of plant shall remain adequately earthed after any one failure, of any one earthing connection or protection system, involving the item of plant.

5.2.1 Design inputs

- Required redundancy level
- Recommended equipment
- Site specific earthing system design

5.2.2 Design outputs

- Locations on drawings showing each required connection.
- Connection criticality to be assessed and documented in the earthing design report.

5.2.3 Recommended equipment

The following list outlines the recommended equipment and practices. Any deviations from the following list must be accompanied by justification in the earthing design report and be approved prior to issuing the design.

Bolted Connections: No bolted connections shall be direct buried in ground or concrete. Stainless Steel 304 or 316 grade bolts/nuts/washers shall be used. A spring washer or Belleville washer is typically required. A maximum of one lug per bolt shall be used (i.e. connections shall not be ganged on a single bolt). The bolts/nuts/washers shall not be installed in the current path i.e. the lug or copper bar shall make direct contact with the face to be earthed/bonded.

Crimped Connections: Compression or crimp connections shall be used below ground level for all practical purposes ('C' crimps, 'P' crimps etc. to be used for all stranded copper and electrode connections). The number of crimps required for each connection shall form part of the earthing design to achieve the required redundancy. This should generally result in two crimps per connection (a minimum 100mm apart) being specified.

Crimp Lugs: Tinned copper lugs utilising hexagonal crimping dies shall be used to terminate stranded conductor. These lugs shall be used above ground only. No open palm lugs are permitted. Lugs shall be individually terminated and not ganged. Indent crimp lugs are not permitted. The lug face shall be in direct contact with the face to be earthed/bonded. Longer barrel (to facilitate 2 or 3 hexagonal crimp terminations to the conductor) and longer face (to facilitate double bolted lug terminations) shall be used for critical terminations such as Earth Continuity Conductors and single conductor Neutrals.

Earth Bar: Tinned hard drawn copper bar should be used as earth bar in all locations. Earth bars shall be installed above ground or in 'dry' pits or link boxes to avoid corrosion. Terminations to bars shall be made as bolted connections.

Fasteners: All fasteners including bolts, dyna bolts, saddles, 'knock-ins', and clamps to be stainless steel grade 304 or 316. Saddles and clamps may be non-metallic where approved in the design. Fasteners to be secured at least every 1000mm and more frequently where required. Theft prevention shall be considered as part of the design. Typically, mushroom head spikes will be used to secure earth bar to floor, walls or ceiling. Dyna bolts shall be used for fixing to masonry.

Labelling: All earthing terminations that cannot be visually traced shall be labelled with a permanent tag identifying the connection. The tag shall be constructed to meet the design life of the substation (e.g. corrosion resistant, UV stable). The text and location of the label shall form part of the earthing layout design. Some examples are included in Table 3 where label size requires the description to be abbreviated.

Table 3: Sample Connection Labelling

Termination	Sample label
Transformer	TRF3
Earth Grid	GRD
Reinforcing Steel	REO
Electrode	ELTD
11kV Switchboard	11 S/B
Counterpoise	CTRP

Stranded Copper: Stranded copper conductors shall be PVC sheathed above ground so as to protect the conductor. Black PVC sheaths are to be utilised. Above ground connections shall be made with tinned copper hexagonal crimp closed palm lugs, individually terminated. Bare stranded copper shall be used for buried earth grid only, or bare copper strap where it is required to match or join an existing earth grid where it shall be jointed by brazing or by silver soldering.

Tinned Copper Braid: Tinned copper braid shall be used on all equipment subjected to movement with infrequent use, such as operating arms and handles. Adequate length of braid shall be allowed to ensure no undue stressing of the conductor. The braid shall be installed so it does not foul the mechanism or suffer damage from the mechanism.

Welded Connections: All mild steel surfaces requiring an electrical connection shall be welded with suitable welding practice (length and quality etc.). Typically, a 75mm weld on one side or a 50mm weld on both sides of the join represents the minimum weld length when joining two sections of reinforcement steel. Where welded mesh reinforcement is interconnected, four welds of 50mm length are required on the overlapped sections of the mesh. Multiple welds will need to be made to achieve the required level of redundancy.

Weldflex: Flexible welding cable with stiffened terminations shall be used on equipment subject to frequent movement, primarily gates. Above ground connections shall be made with tinned copper hexagonal crimp closed palm lugs, individually terminated. Heavy duty heat shrink shall be used to reduce bending stress of the conductor at the lug barrel. Weld flex shall be installed with a downwards sag to avoid the conductor bending over and individual strands failing due to mechanical stress.

5.2.4 Testability

All earthing terminations shall be located with provisions for reasonable test access. This includes locating the terminations such that test personnel can reach the termination without special equipment, and cables shall be spaced from each other and from fixed walls in selected locations such that instruments of 100mm diameter can be temporarily installed around the conductor. This clearance may be achieved if the cables are flexible enough without requiring that the earth-bar terminations to be spaced at 100mm intervals.

5.2.5 Connection criticality

Connection criticality is determined by assessing the likelihood of a connection forming part of the primary current path during an earth fault event as shown in Table 4.

Multiple connections made to the same structure to satisfy redundancy requirements shall be made at physically displaced locations to maximise the benefit of multiple connections, and so ensure the required redundancy is not compromised.

Table 4: Connection Criticality Rating

Connection Description	Criticality Rating	Minimum Required Redundancy
Connection may be a primary current path during foreseeable earth fault events and there are no significant parallel current paths	A	N-1
Connection is not a primary current path during an earth fault event or connection has significant parallel current paths	B	N

Examples:

- A transformer would receive a criticality rating of A (could be part of the primary fault current path).
- A gate would receive a criticality rating of B (not likely to be part of the primary current path).
- A section of metallic fence would receive a criticality rating of B (not likely to be part of the current path). Note that a long fence would normally receive multiple bonds along its length as fences are not normally constructed with connectivity as a primary consideration.
- A HV cable sheath would receive a criticality rating of A.

5.2.6 Physical robustness

When rating all buried earthing conductors, additional factors such as the long-term service life of the conductors, future equipment requirements, fault level creep and the corrosive nature of the soil and environment in which they are installed should also be considered. This may justify the selection of a larger sized conductor considering the cost involved in future reinforcement or replacement of the earth conductors (in a live installation).

Earthing conductors also need to be sufficiently physically robust to match the intended duty, taking into consideration factors such as exposure to traffic, corrosion, physical protection and support.

Earthing conductors should not be located in high traffic areas (pedestrian or vehicular). A mechanical guard shall be installed where no option to relocate is available, or alternatively the conductor could be run in concrete.

5.3 Cable sizing and rating

Sizing of conductors shall be based on:

- the duration and magnitude of the current that the conductor is required to carry, and
- Its required level of redundancy as a component of the earthing for the associated item of plant.

5.3.1 Design inputs

- Connection criticality factor
- Conductor material
- Dimension of conductor
- Number of connections
- Protection details

Site specific earthing system design inputs (including expected fault levels) upon which the earthing system electrical design is based

5.3.2 Design outputs

- Connection type and selected conductor (dimension/s) as shown on earthing layout drawings
- Current reduction calculations shown in earthing design report
- Conductor size calculations shown in earthing design report
- Neutral conductor calculations shown in earthing design report and specified on drawings.

5.3.3 Protection details

Unless otherwise specified in a site specific earthing system design or protection report, current carrying elements of a substation earthing layout shall be capable of carrying the nominal system fault level (including X/R offset), for the Australian Energy Market Commission defined backup clearing time. This is summarised in the Table 5.

Table 5: Nominal System Fault Levels and Clearing Times

Voltage level	Fault rating	B Back up Protection Clearing Time
132kV	40kA	0.43s
66/33 kV	31.5kA	1.0s
11kV	20kA	1.0s

5.3.4 Optional current reduction for multiple connections

Where two conductors are required to bond equipment, they shall be terminated to separate sections of earth grid mesh, or else use of a direct earth conductor to adjacent equipment or to the source switchboard shall be considered.

Structures which have multiple connections to earth which share the current in the event of a fault, may reduce the current rating that each connection is required to carry.

N-1 redundancy may be interpreted as the ability to withstand either a failure of a single earth conductor or a failure of the primary protection, as shown in Table 6.

In the case of a single conductor failure the earth fault current is shared between N-1 conductors with a 70/30 split and the primary clearing time is used. In the case of a primary protection failure, the backup protection clearing time is used and the earth fault current is shared between N conductors.

Table 6: Current Reduction Factor for N-1 Redundancy

Prop Proposed No. conductors	No. of Damaged Conductors	Protection Operation (Primary or Secondary)	Current Reduction Factor
1	0	Secondary	1
2	1	Primary	1
2	0	Secondary	0.7
3	1	Primary	0.7
3	0	Secondary	0.5

Example:

A circuit breaker stand is evaluated with a criticality rating A. Two connections are made from different sections of the grid to the circuit breaker structure. The circuit breaker is operated at 132kV which equates to a 40kA fault rating. Each connection between the earth grid and the circuit breaker must be rated to 40kA for the primary clearing time. That is, if there is a mechanical failure of one bond to the grid, the other bond is required to carry the full fault current for the primary clearing time. If the backup clearing time is being considered, since the primary protection has failed and this is an electrical failure, then both grid connections are assumed to be in service with a 70:30 split of current between them. Thus, each conductor may be rated to 0.7 x 40kA = 28kA, rather than 40kA, for the backup clearing time.

5.3.5 Conductor size calculations

Appropriate formulae may be obtained from the ENA Substation Earthing Guide EG-1 or IEEE Standard 80. These formulae will calculate the required cross-sectional area to carry a certain current flow for a given conductor material and clearing time.

EG-1 also provides values for maximum temperatures to prevent annealing of hard drawn copper conductors (250°C). Ambient temperature shall be taken as 40°C. Both EG-1 and IEEE Standard 80 provide some further guidance regarding allowable temperature rise.

The result from this calculation is the minimum electrical requirement. The final conductor size selection shall also consider robustness (Clause 5.2) and normalisation (Clause 5.14).

5.3.6 Transformer neutrals

Transformer neutrals including earthing transformers are system and safety critical items of plant and are subject to the full earth fault current delivered in an event. Therefore, they shall have additional allowance of robustness which is normally achieved by:

- oversizing conductors;
- individually terminating neutral conductors; and
- Providing more mechanical support.

Neutral conductors shall be either:

- two conductors individually terminated to the neutral bushing and the earth bar; or
- A copper busbar of minimum outer diameter of 35mm which is redundantly terminated both ends (normally by two clamps each end of the busbar).

Every conductor in the neutral connection shall be rated to full fault current for backup clearing time. All bare copper terminations shall be tinned prior to final installation.

Consideration of the various fault scenarios shall be undertaken when determining the neutral earth terminations. Earth conductors shall be installed so as to ensure direct and redundant connections from the neutral conductors to the earth grid, the transformer and the cable screens of the associated power cables.

Where the transformer neutral is non-effectively earthed (e.g. via a bank of resistors) consideration shall be given to the insulation rating of the neutral cable between the transformer bushing and resistor bank for occurrence of neutral voltage displacement under earth fault conditions.

Voltage transformers in major substations represent a shock risk when open circuit and shall have consideration for redundant earthing so far as the equipment allows.

5.4 Connectivity

To achieve safety and performance requirements, conductive objects associated with a substation which are not specifically designed to carry load current during normal operation are generally connected to earth. Any requirements provided by a site-specific earthing system design supersedes the requirements presented here by this standard.

5.4.1 Design inputs

- Feeder and substation detail (including cable screens, overhead earth wires)
- Conductor material
- Site specific earthing system design inputs as specified.

5.4.2 Design outputs

- All required connections (with description) shown on earthing layout drawing

5.4.3 Components requiring earthing

Components critical to earthing system performance shall consider the following in the design:

Overhead earth wires

All overhead earth wires shall be terminated to the substation earth grid. Any conductor and connection hardware used to connect the earth wire shall meet or exceed the rating of the overhead earth wire it connects to. Connections to older or discontinuous earth wires should consider possible future upgrades/replacements to the earth wire when deciding the connection ratings. Typically, there shall be a continuous copper conductor bonding to the earth wire. Redundancy in earth terminations shall be provided at the base of the structure or pole.

Power cable screens

Provision should be made in the earthing layout design to terminate sub-transmission power cable screens and armouring where necessary, interfacing with the sub-transmission earthing design. The earthing design shall include consideration and design of link boxes, Radio Frequency (RF) bonds, surge arresters and screen terminations.

Cable screen terminations should be made robustly and redundantly, including the specification of long barrel (multiple crimps on barrel), long palm (double bolted), closed palm and sealed lugs where possible (11kV cable screens are single bolted unless specified otherwise). In certain cases, 11kV cable screens may be extended to reduce cable wastage, refer NS177. Any conductor and connection hardware used to terminate a cable screen shall meet or exceed the rating of a connected cable screen.

Cable screens terminating to an open point requiring a Sheath Voltage Limiter (SVL) device, shall be terminated at least as robustly as required for an earthed termination.

Outgoing 11kV feeders from the substation shall have their cable screens bonded at the substation earth grid unless specified otherwise in the design.

Sub transmission single point bonded cables within the substation

For cables that are single point bonded within the substation i.e. transformer to switchgear, no link box is required provided that the standing sheath voltage complies with NS260. Typically, the open point is terminated above the sealing end pedestal insulators at the transformer end.

For single point bonded cables between the main power transformer and switchgear, an Earth Continuity Conductor (ECC) shall be run in parallel with each primary voltage connection.

11kV single point bonded cables within the substation

The earthing requirements for single point bonded 11kV cables within new and brownfields zone substations are provided in Table 7 below. All other 11kV cables are to have the screens bonded at both ends. Exceptions to these requirements shall be listed on the design drawings.

Table 7: Zone Substation 11kV single point bonded cable earthing requirements

Equipment	New Zone Substation	Brownfields Zone Substation
Transformer panel	Cable copper wire screens shall be earthed at the transformer and shall not be earthed at the switchgear	Cable copper wire screens shall be earthed at one end only. They shall be earthed at the transformer wherever practicable; otherwise they shall be earthed at the switchgear.
Bus-tie panel (with CTs)	Cable copper wire screens shall not be earthed at this panel	Cable copper wire screens shall not be earthed at this panel
Bus-tie panel (without CTs)	Cable copper wire screens shall be earthed at this panel	Cable copper wire screens shall be earthed at this panel
Audio Frequency Customer Load Control (AFCLC)	Cable copper wire screens shall not be earthed at AFCLC, shall be earthed at source end	Cable copper wire screens shall not be earthed at AFCLC, shall be earthed at source end
Capacitor bank	Cable copper wire screens shall not be earthed at capacitor bank, shall be earthed at source end	Cable copper wire screens shall not be earthed at capacitor bank, shall be earthed at source end

Earth continuity conductors (ECC)

All ECC shall be terminated to an earth bar and appropriately labelled to facilitate testing and identification. ECC terminations should be made robustly and redundantly, including the specification of long barrel (multiple crimps on barrel), long palm (double bolted), closed palm and sealed lugs where possible. Any conductor and connection hardware used to connect an ECC shall meet or exceed the rating of the ECC it connects to. Provision should be made to terminate transmission earth continuity conductors where necessary, interfacing with the sub-transmission earthing design.

Sheath voltage limiters (SVL)

SVL and surge arresters require an earthed connection to correctly function. The sizing and any additional specifications of the arresters themselves shall be provided as an input to the substation earthing design and these specifications shall be incorporated into the earthing layout drawings and design documentation. Any standing voltage on SVL devices shall be considered and appropriate housing (including insulated, explosion proof and HV cage housing) shall be provided for in the design.

Trifurcating cable joints

Earth screen continuity shall be provided on all 11kV and 33kV trifurcating joints via cable screens or dedicated earth to the joint.

Metallic power cable trays and supports

All metallic supporting structures shall be earthed, except when the structure supports a single item of plant which has an enclosing earthed screen or sheath (e.g. Single uni-strut support for a single phase 132kV cable). However, any metallic tray supporting HV power cables or LV power cables would require earthing. Earthed cable trays shall have an earth bond across hinge joints. Earthed cable trays shall tighten pivot joints so that the trays are electrically continuous.

Metallic poles

All metallic poles (e.g. light poles, communication poles, and lightning spires) in proximity to live exposed equipment or which have the potential to receive a direct lightning strike shall be earthed.

Lightning poles with LV wiring should have the wiring installed internally and a non-conductive solid conduit provided to facilitate the underground entry/exit of the wiring to the pole. Lightning poles shall be earthed directly to the HV earth grid and to a lightning electrode. They should not be earthed via the LV wiring earth or neutral conductors, refer to NS264 for details.

Fences

All conductive fences associated with a major substation shall be earthed if overhead lines cross them or where they are in close proximity (within 15m) to live exposed conductors. Fences should be earthed at least every 30m and at gate posts. There shall be equipotential safety bonds installed across gates unless a site-specific design does not require them to be installed. Where personnel gates are installed with a concrete landing, a bond to the steel reinforcing of the landing shall be made.

Note that fences sometimes require additional design such as separated earth grids or isolation sections from third party or neighbouring fences for safety reasons. If additional design is required, the outcomes will be provided by a site-specific earthing design.

Other conductive infrastructure e.g. security installations shall take into consideration the fence earthing design to prevent bridging out fence isolation sections or introducing safety or equipment failure hazards under earth fault conditions.

Electrical Equipment

All equipment connected to the primary and secondary busbars shall be provided with at least one earthing connection, though most often a minimum of two (2) connections will be required to achieve redundancy requirements. Where only one earth tag is provided a second bond shall be made to an integral metallic member of the equipment structure (e.g. transformer tank strut, circuit breaker tank/stand). All equipment connected to the primary and secondary busbar shall be earthed, so as to fulfil the requirements set out in Clauses 5.2 and 5.3.

5.4.4 Optionally earthed components

The following are optional when specifying earth connections, unless they are nearby live exposed electrical equipment/conductors, in which case they must be earthed.

- Metal doors
- Short handrails

'Nearby' is defined here as within a radius equal to twice the busbar or live conductor height.

5.4.5 Components requiring segregation

No distribution voltages (e.g. street LV supply) shall be reticulated into a major substation without an earthing system design which addresses that specific issue. The earthing design would then have to incorporate any isolation, separation and insulation requirements.

No metallic pipework shall be brought into the substation which is not addressed by the specific earthing design. For instance, it is normal practice to include at least 6m of non-conductive (e.g. PVC) pipework (and 3m minimum radial measurement from the edge of the earth grid) in a water service to a substation.

All telecommunications brought into the substation shall be intrinsically isolated (for example fibre optic) or a telecommunications isolation device shall be used. The earthing design shall reference the telecommunications isolation method used and identify where it is located.

5.4.6 Staging

Where a new substation is being built next to an old substation, the need for bonds (temporary or otherwise) between the two sites shall be considered in the earthing design.

Where earth bars are installed provision shall be made for future earth connections and tee connections such that the need for disconnection of live earthing is minimised for future works.

5.5 Corrosion

Corrosion must be taken into consideration as it has the potential to adversely impact the earth system performance and to reduce the design life of an installation.

5.5.1 Design inputs

- Civil design, substation layout
- Geological report (soil evaluation), Soil Electrical Resistivity Test Analysis
- Identification of nearby DC traction systems and Cathodic Protected Plant (CP) (e.g. associated with pipelines and underground tanks)

5.5.2 Design outputs

- Results of soil evaluation documented in earthing design report.
- Minimum concrete cover identified on earthing layout civil drawings
- Corrosion mitigation measures included on earthing layout civil and electrical drawings

The earthing design shall address corrosion by specifying appropriate conductor sizes, redundancy, levels of concrete cover, sealing around earth connections to the embedded earth conductors and appropriate welding of the steel to form electrically continuous paths.

5.5.3 Specific earthing layout corrosion tasks

Identify minimum concrete cover on the earthing layout drawings for all concrete encased steel which is connected to an earthing system.

Undertake the soil-test evaluation outlined in Annexure A. Results shall be documented in the design report. If greater than 10 points are obtained while undertaking the soil evaluation, mitigation measures shall be incorporated in the earthing layout design drawings.

Identify DC traction systems within 200m of the substation and notify Ausgrid approved Corrosion Technologist within Network Test. Refer to NS270 for requirements related to management of stray direct current.

5.6 Embedded earthing

Embedded earthing is the reinforcing steel in concrete slabs, columns, walls or piers that forms part of the earthing system. The use of concrete reinforcement as a part of the earthing system adds electrical requirements to the traditional mechanical requirements associated with concrete reinforcement. These are generally satisfied via welding of the reinforcement together to form an electrically continuous mesh and providing connections between the mesh and the substation earthing system.

5.6.1 Design inputs

- Substation Civil Detail (Structural Design)
- Site specific earthing system design inputs as specified. This document will specify if embedded earthing is required.

5.6.2 Design outputs

- All required concrete reinforcement continuity weld locations and connection tag locations shown on the earthing layout civil drawing set.
- Earthing conductor terminations to connection tags shown on earthing layout electrical drawings.

Method used to identify embedded earthing conductors so as to:

- Facilitate 'as-built' drawings;
- Allow auditing and inspection of embedded earthing installation prior to placement of concrete grid (design compliance); and
- Provide for 'sign off' of approved ITP's.

5.6.3 Requirements

- An electrically continuous perimeter ring shall be formed via welding and inner reinforcement mesh shall be welded to that perimeter ring at a maximum spacing of 5 metres in one direction and by 10 metres in the orthogonal direction.

- The perimeter rings in adjacent slabs shall be solidly bonded (i.e. 75mm full penetration weld) as required in the site-specific earthing system design. Adjacent slabs which are not declared in an earthing system design may be solidly bonded together where practical. Connecting slabs together may involve welding a continuous path through vertical and horizontal reinforcing bars between the slabs, or by bonding across expansion/dowel joint in some structures.
- The embedded earth conductors that form the perimeter rings are generally located a nominal 300mm from the inside face of adjoining slabs.
- Where there are two layers of reinforcing in the slab (i.e. top and bottom), the embedded earth conductors shall be installed in the top layer to facilitate inspection prior to pouring concrete. The lower layer may be connected to the top layer if required, for instance at locations where a future sawn joint may compromise the concrete cover or may cut the top layer of reinforcing and therefore the perimeter earth ring.
- A method of identifying the embedded earth conductors shall be developed to ensure that the correct bars are connected to maintain electrical continuity. Methods may include marking designated bars with spray paint or welding identification tabs to the end of the nominated bar.
- The minimum weld length shall typically be 75mm in length, unless stated otherwise in the design.
- Where the reinforcement bars are to be bonded together at 90 degrees, a piece of reinforcement (not less than the size of the bars to be jointed) shall be bent at right angles and shall be welded as specified above to the bars to be bonded together.
- In-ground buried bonds to the embedded earthing system shall be achieved using a crimped structural steel earthing tail – ‘crimped tail’, (refer Ausgrid Drawing 236805).
- Above-ground bonds to the embedded earthing system shall be via bolted connections to protruding hot dipped galvanised mild steel earth tags solidly welded to the perimeter earth ring, (refer Ausgrid Drawing 236805).
- Electrical connectivity across expansion joints and across joints without continuity of steel reinforcing shall be provided at least every 30m using a minimum 70mm^2 PVC covered, stranded, copper conductor with an appropriate hexagonal crimp termination. The conductor is to be laid so that it does not suffer damage due to movement of the expansion joint, (refer Ausgrid Drawing 236805).
- To minimise the risk of corrosion, the minimum concrete coverage of embedded steelwork should be determined by following the process of Exposure Classification in AS3600 and/or AS2159. Additionally, where the exposed concrete surface is within 10m of a source of stray DC current, for greater durability, it is recommended that this coverage shall be increased by worsening the Exposure Classification one grade or as directed by Ausgrid. Refer NS270.
- Buried copper connections in concrete slabs shall be of a crimp type to minimise the risk of corrosion. No bolted terminations are permitted to be buried in concrete.
- Impermeable tanking or membrane layers should be avoided due to their impact on the performance of the embedded earthing system. Where significant areas of these layers are to be used the responsible earthing engineer should be consulted.
- The earthing layout drawings shall specify the number and location of all welds, expansion joint connections and connections between the embedded earthing conductors and the substation earthing system.
- Embedded steel earthing conductors shall not exceed 90 degrees Celsius under earth fault conditions.
- Embedded earthing shall be inspected, verified and signed off prior to concrete coverage. This requirement shall form part of the commissioning documentation and part of the ‘as-built’ documentation provided to Ausgrid.
- Witness and/or hold points shall be documented and agreed with civil construction staff prior to commencement of construction activities.

5.6.4 Detailed earthing requirements for Gas Insulated Switchgear (GIS) embedded earthing

- The minimum welded reinforcing size shall be 12mm diameter steel bar, or greater if required to ensure rating and temperature rise conditions are met.
- The GIS basement floor and GIS switch room floor shall be solidly welded to form a mesh size of not more than 5 metres in one direction and 10 metres in the orthogonal direction.
- The perimeter of the GIS basement floor shall be solidly welded.
- The perimeter of the GIS switch room floor shall be solidly welded.
- The perimeter of the GIS room and GIS basement floors shall be interconnected with vertical solidly welded reinforcement in the switch room walls and/or columns in each corner (where reinforcing exists) and at equally spaced distances not exceeding 10 metres.
- Parallel with the GIS trunking, a reinforcing bar 1 metre away from the control boxes shall be solidly welded across the GIS room floor (so as to be located beneath operators of the switch gear while they are in contact with the switch gear). It shall be integrated with the embedded earthing perimeter ring.
- Parallel with the GIS trunking, the first reinforcing bar on the trunking side of the penetrations shall be solidly welded across the GIS room floor and integrated with the embedded earthing perimeter ring.
- Welded reinforcing shall cross the GIS room floor at every bus section or intervals of not less than every 10m. Such an embedded earthing conductor shall be integrated with the perimeter ring.
- When the GIS switch room has a cable basement, ceiling mount earth tags shall be installed protruding from the basement ceiling. When the GIS switch room has no basement, vertical mounted earthing tags shall be installed protruding from the floor. Ceiling or vertical mounted earth tags shall be installed in each corner of the GIS switch room and in the following locations:
  - Earth tags shall be located along the welded reinforcing bar 1 metre away from the control boxes (i.e. operating positions). There shall be a minimum of one (1) earth tag per bus section of GIS equipment. Earth tags are also to be installed at both ends of the GIS switch gear.
  - Earth tags shall be located along the first reinforcing bar on the trunking side of the penetrations. Earth tags shall be installed at both ends of the GIS switch gear, so that there is a minimum of two earth tags per section of GIS equipment.
  - For discontinuous GIS bus sections, tags should be installed at each end of the group of panels.

5.7 Grid and electrode layout

The earth grid is comprised principally of a mesh of interconnected buried conductors and connected electrodes where required. The earth rods (i.e. electrodes) are either mechanically driven into the earth, or a hole is drilled with the electrode installed and the hole backfilled. The hole is backfilled to ensure contact is maintained between the electrode and the surrounding soil. The backfill material shall be an approved earthing compound from the Ausgrid stores. No earthing compounds with added salts are permitted to be used as they can accelerate corrosion to electrodes.

5.7.1 Design inputs

- Substation civil detail
- Substation Layout, including conduits, equipment, footings, fencing, oil containment, cable routes and cable tray layout.
- Site specific Earthing system design inputs: required electrode depth and maximum grid spacing dimensions.

5.7.2 Design outputs

- Earthing layout electrical drawings which show earth grid and electrode layout dimensioned in relation to the substation buildings, equipment and boundary.
- Earthing layout electrical detail drawings which show electrode dimensions and conductor dimensions and jointing details.
- Earthing layout electrical drawings which show the locations of all connections

5.7.3 Requirements

- The grid mesh, grading ring(s) and electrodes shall be spaced according to the grid dimension input from the site-specific earthing system design. The grid, grading ring(s) and electrodes shall be shown on the earthing layout drawings along with conductor size, material, electrode dimensions and connection details.
- The grid mesh shall accommodate substation equipment and facilitate connection of equipment to the grid. Where possible it shall take into consideration the installation of future equipment or connection thereof so as to minimise civil excavation in future projects.
- The electrodes shall not utilise inspection pits, but shall be terminated by direct PVC covered copper conductors to an accessible location for testing. Such locations are typically an earth tag on a fence (with an earth bond termination to small copper bars to facilitate the electrode termination) or equipment structure with earth bond.
- All electrode bonding conductors shall be labelled to identify them.
- All counterpoise earthing conductors shall be labelled where they are terminated.
- Grading rings shall be installed outside all perimeter fences unless otherwise specified by the site-specific earthing system design. All grading rings are to be located inside the property boundary.
- Grid and electrode earthing shall be inspected, verified and signed off prior to burial. This requirement shall form part of the commissioning documentation.
- Earth conductor terminations shall be labelled where the interconnection is not obvious.

5.8 Personnel safety equipment

Locations at which staff operate the network, such as operator handles on Disconnectors, Earth switches and Circuit breakers, shall be earthed such that the operator works within an area of equipotential. This shall be achieved by equipotential bonding the operator handle or control point to either a steel mesh mat or a concrete slab with embedded steel reinforced earthing.

The equipotential bonded handle and mat shall also be directly earthed at one point only to the copper earthing grid or copper earthing on the structure. Current flow through the earthing system (for instance, from an earth switch to the earth grid) shall have minimal effect due to the single point earthing of the operating handle and mat. This requirement for single point earthing overrides the redundancy requirement of Clause 5.2. It should be noted that the structure or equipment would still be expected to have two (2) redundant earth bonds.

5.9 Crushed rock

Crushed rock shall be installed in all areas of the substation switchyard, which are not concreted, in accordance with the following specification, unless specifically allowed for in the design:

- Rock type to be blue metal, granite or crushed river gravel. Conglomerate or shale is not acceptable.
- Aggregate size is to be 40mm single size concrete aggregate as per AS2758.1 Table B1.
- Electrical resistivity of the rock shall exceed 3kΩ.m when wet.
- The rough grade shall be prepared by mechanical compaction prior to installing the crushed rock.
- Rock depth shall be a minimum of 100mm and shall be laid on top of the finished ground level.
- Provide 2 x 15kg samples of crushed rock to Network Test (c/- Building 1, Abbott Street Depot) (Note: There is an after-hours drop box if required. Please label all samples with contact name and phone number, company, project and Ausgrid site on which it is intended to be used.)
- The crushed rock shall not be transported to site until the tested sample is approved in writing by the Ausgrid Earthing Engineer.
- Testing of the quality of the aggregate material and the depth of the surface layer shall be carried out during installation. The test results shall be recorded and submitted to the Ausgrid Earthing Engineer.

5.10 Gas insulated switchgear (GIS)

The substation earth system shall be designed to mitigate hazards associated with Transient Earth Potential Rise (TEPR) originated by GIS switching and earth fault conditions.

5.10.1 Design inputs

- Substation slab floor civil design
- GIS manufacturers requirements

5.10.2 Design outputs

- Slab reinforcement bonding locations shown on earthing layout civil and electrical drawings
- GIS connectivity requirements shown on earthing layout electrical drawings

5.10.3 General requirements

Copper earth bars shall be installed so as to facilitate interconnection between the GIS connection points provided by the manufacturer, the steel reinforcing connection points and the substation earthing system. The connection between the GIS connection points and the earth bar shall be installed as per the manufacturer’s requirements. Due to the nature of GIS transients, connections between GIS connection points and copper earth bars shall be as short as possible (refer to Clauses 5.6.4 and 5.10.4 for detailed earthing requirements).

The earthing arrangement associated with the GIS must facilitate interconnection between the transmission earthing system and the substation earthing conductors. Specifically, transmission cable screens, surge arresters, link boxes and earth continuity conductors shall be installed and terminated so as to minimise the TEPR. The connections between the GIS and the transmission cable screens, arresters shall be installed in such a manner as to not compromise the GIS switchgear manufacturers’ requirements.

5.10.4 Detailed earthing requirements for GIS electrical earthing

- The GIS earthing shall satisfy the minimum requirements set by the GIS manufacturer.
- The GIS manufacturer may provide earthing elements such as bonds between the trunking and the cable glands or cable plugs. These are referred to as RF or Radio Frequency bonds. The need for the RF bonds to be earthed via SVLs shall be considered in the earthing design.

- As a minimum requirement, the electrical earthing for GIS equipment shall be rated according to Clause 5.3 however standard conductor sizes are to be used according to the fault rating of the GIS equipment.
- For 132kV GIS equipment, the minimum earth bar size for earthing on the GIS floor, GIS basement ceiling earth bar and interconnections must be at least 50x6.3mm HD copper bar. This is referred to as the 'Main GIS earthing'.
- For voltages equal to or less than 66kV, the minimum main GIS earthing bar size maybe reduced to 50x3.18mm HD copper bar depending on the results of design undertaken to address Clause 5.3.
- The following earthing associated with the GIS equipment shall be at least 50x3.18mm HD copper bar.
  - Basement earth bar
  - Connections between the main GIS earthing and the basement earth bar
  - Connections to earth tags
- The GIS floor earth bar shall be installed on the GIS floor, as close as possible to the penetrations on the trunking side of the penetrations. Care shall be taken not to obstruct the penetrations with the bar.
- For double banked feeders, an additional ring around the second penetration shall be installed on the trunking side of additional penetration.
- Basement ceiling earth bar: There shall be an earth bar installed on the basement ceiling in the same configuration as the bar on the GIS floor.
- For double banked feeders, the additional ring on the basement ceiling is not required, and only one bar shall be installed in-between the two penetrations.
- GIS floor earth bar and basement ceiling earth bar shall be interconnected.
- Bonds between the GIS floor and basement ceiling earth bars shall be made at each end of the GIS bus section and at evenly spaced intervals of not more than every 4th power cable penetration. Conduits are not required at either end of the GIS as cable penetrations shall be used.
- If the RF bonds are not installed, the GIS floor earth bar and basement ceiling earth bar interconnections must be made at every penetration.
- Bonds between the GIS cable module and the GIS floor mounted earth bar shall be made with 1 x 185mm^2 (min) stranded copper conductors with long barrel lug and double bolted palm connections. This is to replace the manufacturer's stranded copper conductors which have both cables crimped in one (1) specialised lug.
- GIS earth switches shall be bonded to the GIS floor earth bar using floor mounted earth bars to the connection point on the earth switch. An 'Earthing Plan' drawing should be issued by the manufacturer showing the locations for the earth switch bonds.
- There shall be a bond to each of the 'C' section base frame rails that the individual bays of GIS equipment are mounted on at the end closest to the GIS floor earth bar. For long sections of rails (>20metres), other interconnections shall be made at intervals of at least every 4th penetration or at each GIS earth switch bond crossing.
- GIS surge arresters shall have a single earth bar connection to the GIS floor earth bar via the most direct route. The earth bar shall be adequately mounted and supported.
- Cable screens for the 132kV transformer cables shall be connected to the GIS floor earth bar.
- The transformer 300mm^2 ECCs shall be connected to the GIS basement ceiling earth bar with a double bolted palm connection (Refer to Drawing 236804 General Earthing Details – Standard Construction).

- The 132kV link box earth bar shall be bonded via a 300mm^2 stranded copper PVC covered conductor to the GIS basement ceiling earth bar with a double bolted palm connection
- The 132kV link box metal casing shall be connected via a 120mm^2 (minimum) stranded copper PVC covered conductor to the GIS basement ceiling earth bar with a double bolted palm connection (Refer to Drawing 236804 General Earthing Details – Standard Construction).
- A basement earth bar shall be mounted on the basement wall at a height between 1.5metres from the floor to 0.3metres from the ceiling. The height shall be selected to minimise interaction with other services and to maximise accessibility to the earth bar.
- Bonds from basement ceiling earth bar to basement earth bar shall be made at each end of the basement ceiling earth bar and at intervals of at least every 4th penetration via the most direct route.
- Bonds to each earth tag shall be made to the nearest earth bar via the most direct route.
- Bonds from the basement earth bar to the external earthing systems (e.g. the buried substation earth grid) shall be installed with 120mm^2 stranded copper PVC covered conductor through conduits in each corner of the GIS basement. The external earth system bonds shall be installed at intervals not greater than 20metres between bonds unless otherwise specified in the layout design to address site limitations.

5.11 Lightning protection systems (LPS)

All substations should be adequately protected against lightning events. This is achieved through a combination of elements such as feeder overhead earth wires, surge arresters, lightning spires, lightning shield wires and the earthing system – these combine to form the lightning protection system. The substation earthing design shall identify lightning spire and lightning shield wire placement whilst maintaining required access and safety clearances in consultation with the substation layout designer.

5.11.1 Design inputs

- Substation equipment layout detail
- Site specific Earthing system design inputs

5.11.2 Design outputs

- Lightning protection details shown on earthing layout drawings.
- Lightning protection analysis shown in earthing layout report.

5.11.3 Requirements

Refer to NS264 for substation lightning protection requirements.

5.12 Acceptable interaction with other assets

The earthing design shall take any site-specific earthing requirements regarding interaction with other assets and incorporate the information onto the layout drawings and reports.

The substation earthing system shall not produce unacceptable levels of interference in other assets. Examples of asset types that are most likely to be affected include:

- Pipelines
- Telecommunications
- Conveyors
- Underground mines
- Railway Systems (e.g. signalling, drainage bonds and tunnels)
- Swimming Pools

The site-specific earthing system design will make appropriate assessment and mitigation recommendations taking into consideration the standards governing third party assets.

5.12.1 Design inputs

- Site specific design requirements where the earthing system interacts with other assets

5.12.2 Design outputs

- Mitigation requirements noted on earthing layout drawings and in earthing design report as required.

5.13 Future developments

The substation earthing design should consider the effect of future developments. Some typical examples include future transformers (additional or increased capacity) and additional equipment (e.g. future capacitors). Where possible the need for excavation should be avoided or minimised for future equipment by careful allowance during the design stage. Earthing conduits and earth grid mesh shall facilitate future development wherever possible.

5.13.1 Design inputs

- Site specific earthing system design requirements regarding possible future developments

5.13.2 Design outputs

- Requirements documented on the earthing layout drawings and in report as required.

5.14 Standardisation and equipment normalisation

In the process of undertaking an earthing design, a range of equipment will be specified from conductors to spires and connectors.

An overall equipment list shall be generated and each piece of equipment normalised to those commonly stocked or uniform sizes. Where a customised part is required because no standard component is suitable, it shall be highlighted on the respective layout drawing and approved prior to installation.

5.14.1 Design inputs

- All previous earthing layout design tasks

5.14.2 Design outputs

- Normalised equipment lists.

5.15 Commissioning

5.15.1 Design inputs

- All previous earthing layout design tasks.
- Construction schedule.

5.15.2 Design outputs

- Proposed commissioning inspection and test plan (ITP).
- Final commissioning documentation.

The ITP is to be approved prior to construction commencement.

The earthing commissioning ITP report shall identify:

- Where inspection, verification and any significant testing is required and shall specifically identify which earthing elements must be checked.
- When the earthing elements shall be checked in accordance with the construction schedule. Many earthing elements such as concrete embedded earthing must be inspected prior to concrete coverage. The commissioning documentation shall include scans of the signed ITPs and photographic evidence of these inspections.
- How the earthing components are to be checked.
- The documentation required to demonstrate compliance and signoff.

The final commissioning documentation shall demonstrate compliance of the installation with design requirements. It shall include scans of completed ITP's (with photographic evidence) and also 'as-built' drawings. The following components shall specifically be included in the commissioning documentation:

- Earthing connections installed as per specified size/type
- Overhead earth wire (OHEW) connectivity
- Cable screen connectivity
- Earth Continuity Conductor (ECC) connectivity
- Neutral Terminations
- Metallic supporting structures
- Metallic poles (e.g. security cameras or lighting)
- Conductive fences
- Sheath voltage limiters / arrester configurations
- All electrical equipment earthing connections
- Distribution feeder earthing arrangement and terminations
- Conductive pipe work (bonds and isolations)
- Telecommunications isolation
- Embedded earthing welding strength, and continuity and connectivity
- Grid electrodes and mesh connectivity and continuity
- Lightning spire/terminal installation and connection to earth
- Site specific mitigation requirements (corrosion, future considerations, site safety, lightning, fences, crushed rock)
- Site safety – site shed location, power, conductive material handling.

6.0 EARTHING CONSTRUCTION SITE SAFETY

6.1 General

Earthing construction site safety requirements shall be specified as part of the design. Earthing safety requirements may address hazards such as Touch (or Step) Voltages or Transferred Touch Voltages, Capacitive Coupling and Critical Earth connections to be managed during project staging. Substation construction work methods (in practice and documentation) shall incorporate any required earthing related risk mitigation measures in order to manage those risks to an acceptable level. Refer to Annexure C for typical hazards and possible controls.

Consideration shall be given to site shed location, transfer hazards, LV power supply, storage of conductive materials, use of vehicles/plant, personal protective equipment, staging of construction works, temporary fencing earth configuration and temporary bonding requirements. These requirements shall be implemented to eliminate earthing hazards as far as practically possible especially in site establishment.

6.2 Design inputs

- Substation layout
- Feeder energisation status
- Site specific earthing system performance detail
- Civil work site establishment details
- Allowable touch voltages

6.3 Design outputs

- Site safety requirements documented on earthing layout drawings.
- Site safety requirements documented in earthing construction safety report or in separate format to facilitate implementation on site.

6.4 Applicable safety criteria

Special assessment is required for construction work where in-service earthing is located. During construction activities the frequency and duration of contact is high, and the impressed voltage (%EPR) is also often higher due to transfer hazard mechanisms. The contact profiles in Clause 4.2.3 do not apply to construction work in this instance.

Where risks assessments are undertaken, the coincidence shall be assumed to be 1 as a first pass assessment with more emphasis on site specific earthing safety suite of controls outlined in the earthing construction safety report and Safety In Design documentation. Where there are non-compliances the assigned project Earthing Engineer shall be consulted for advice in refining contact profiles or alternate controls.

6.5 Specific site safety tasks

6.5.1 Site Shed

Identify a location for the site shed and source of LV power (if required). This location shall be provided on the earthing layout drawings or documentation. Unless otherwise documented in the site-specific earthing system report a site shed shall:

- Be located inside the earth grid or more than 5 metres outside the earth grid.
- Be located such that there is a minimum clearance of 1.8 metres around it to any conductive material.
- Be powered by a standalone generator located within 3 metres of the site shed or via an isolation transformer located within 3 metres of the site shed (If located more than 5 metres outside the earth grid).
- Be powered by a temporary construction supply fed from the substation auxiliary if located inside the earth grid.
- Any pipework coming into the site shed shall be non-conductive.
- Alternatively, the site shed may be located 20 metres or more from the new and existing substation earth grids and be powered by a temporary builder’s supply from the Ausgrid LV network.

6.5.2 LV Power for equipment

The earthing construction safety requirements shall document the use of LV power including:

- Where LV power can be sourced when operating equipment within the substation grid.
- Where LV power can be sourced when operating equipment outside the substation grid (including within a construction area and/or within a storage or preparation area).
- Exclusion zones for power supply.
- Earthing configuration of isolation transformer LV supply if relevant.

6.5.3 Trailing earth leads

Where plant is working on the edge of the earth grid perimeter (e.g. just outside the substation fence) or across the earth grid perimeter precautions such as trailing earths or exclusion zones may be required. Earthing the plant may introduce hazardous potentials to the portion outside the earth grid necessitating other measures such as barricading and the use of gloves by operators. Requirements for such situations shall be specified in the earthing construction safety report.

6.5.4 Conductive Materials

Any construction using conductive materials (such as temporary fencing, scaffolding or steel reinforcing bar) with an assembled horizontal length of longer than 5 metres shall consider the following:

- Temporary bonding arrangements (e.g. equipotential bonding and temporary earth electrodes)
- Isolation requirements (e.g. earth breaks)
- Personal protective gear requirements (gloves, shoes, mats) and inspection regime.
- Transport arrangements (storing and carrying conductive materials)
- Clearly specified and delineated construction 'lay down' and metallic equipment storage areas

Where equipment is in the vicinity but does not have potential to come into contact with HV equipment, then there is still potential for nuisance shocks. Some examples are given below:

Scaffold

- Metallic Scaffold: The location and size of scaffolds varies so specific advice should be sought once the configuration is known.
- Note that personnel working on metallic scaffolds, whether earthed or not, may still experience small nuisance induction shocks depending on proximity to high voltage conductors due to varying potentials e.g. insulated body in proximity to HV field discharging via earthed metallic scaffold.

Possible mitigation measures include use of fibreglass scaffolding, installation a trailing earth lead if the scaffold is conductive and/or wear construction or riggers gloves for additional insulation.

"Linear / Long" type equipment

- Camera survey vehicles with long leads,
- Pneumatic lines (where permitted), hydraulic or other hoses.
- Concrete line pumps
- Aqueous pumps
- Temporary water pipes (non-metallic). Note that the substation water supply is earthed.

If entirely within the substation grid, a trailing earth is typically required, especially if linear/long equipment is metallic and run parallel to HV busbar it may be subjected to inductive coupling and may require earthing depending on the scenario. Avoid running long metallic lengths parallel to HV busbar. If unavoidable, contact the assigned project Earthing Engineer for advice.

Note: temporary construction fences outside a substation are special cases as they often adjoin an earth grid and so are a touch potential risk. Such fences require assessment by the assigned project Earthing Engineer.

6.5.5 Where Earthing is not required

Unless noted in earthing construction safety requirements, earthing is not required for the following situations where located more than 6m horizontally from exposed live HV equipment (unless nuisance shocks are in issue in which case a trailing earth or the use of construction or riggers gloves may be used):

- Shoring regardless of material type is not required to be earthed as it is at ground level in contact with the earth
- Un-powered sheds
- Skip Bins
- Road plates

6.5.6 Temporary Earths

Where part of the substation earth grid is required to be cut away to make room for an excavation, Ausgrid technicians then need to attend to remove the required earths and to place any required temporary earths.

7.0 STORES & MATERIALS

Only approved materials and equipment may be used in the construction of infrastructure which ultimately forms part of Ausgrid's electrical network. The approved materials and equipment contained in this Network Standard are detailed in Ausgrid's Approved Material List (AML) with manufacturer and supplier information and Ausgrid stockcodes where appropriate. Ausgrid will consider adding alternative materials and equipment to the AML in accordance with NS181 - Approval of Materials & Equipment and Network Standard Variations.

ASPs may obtain approved materials and equipment items as listed in the AML from any source. Where an ASP wishes to use alternative materials and equipment, application to have the materials or equipment considered for approval is to be made in accordance with NS181. Alternatively, where approved materials and equipment are held as stock in Ausgrid's stores system, ASPs may purchase them from Ausgrid. All enquiries and requests for quotations should be directed by email to aspsales@ausgrid.com.au.

All materials used on Ausgrid's network must be new.

8.0 AUTHORITIES AND RESPONSIBILITIES

For this Network Standard the authorities and responsibilities of Ausgrid employees and managers in relation to content, management and document control of this Network Standard can be obtained from the Company Procedure (Network) – Production/Review of Network Standards. The responsibilities of persons for the design or construction work detailed in this Network Standard are identified throughout this standard in the context of the requirements to which they apply.

9.0 RELATED DOCUMENTS

All work covered in this document shall conform to all relevant Legislation, Standards, Codes of Practice and Network Standards. Current Network Standards are available on Ausgrid's Internet site at www.ausgrid.com.au.

ASPs and other persons external to Ausgrid are responsible for sourcing any required manufacturer's instructions and manuals.

9.1 Ausgrid documents

- Electrical Safety Rules
- Electricity Network Safety Management System Manual
- NS116 Design Standards for Distribution Equipment Earthing
- NS212 Integrated Support Requirements for Ausgrid Network Assets
- NUS181 Approval of Materials and Equipment and Network Standard Variations
- NS260 Sub-Transmission Feeder Earthing
- NS264 Major Substation Lightning Protection and Insulation Coordination
- NS270 Stray Direct Current Management

9.2 Other standards and documents

- AS 1768-2007/NZS/AS 1768-2007. Lightning Protection. Published jointly by Standards Australia & Standards Association of New Zealand.
- AS 2067:2016 'Substations and High Voltage Installations exceeding 1kV'. Standards Australia.
- AS 2159:2009 Piling – Design and Installation
- AS 2758.7:2015: Railway Ballast - Aggregates and rock for engineering purposes
- AS/NZS 3000:2018 'Electrical Installations (known as the Australian/New Zealand Wiring Rules)'. Standards Australia.
- AS 3007:2013 'Electrical Installations – Surface Mines and Associated Processing Plant'. Standards Australia
- AS 3012:2010/Amd 1:2015 'Electrical installations – Construction and demolition sites'
- AS 3600:2018 Concrete structures
- AS/NZS 3835.1:2006: Earth potential rise - Protection of telecommunications network users, personnel and plant - Code of practice
- AS/NZS 4853:2012: Electrical hazards on metal pipelines.
- AS/NZS 7000:2016 – Overhead Line Design – Detailed Procedures
- IEEE 80 - IEEE Std 80-2013/Cor 1-2015 'IEEE Guide for Safety in AC Substation Grounding'. The Institute of Electrical and Electronic Engineers.
- IEEE 837-2014 Standard for qualifying permanent connections used in substation grounding.
- ENA Doc 001-2008 National Electricity Network Safety Code
- ENA EG (0) Power Systems Earthing Guide – Part 1 Management Principles, February 2010
- ENA EG-1 Substation Earthing Guide, Latest Revision

9.3 Acts and regulations

- Electricity Supply (General) Regulation 2014 (NSW)
- Electricity Supply (Safety and Network Management) Regulation 2014
- Work Health and Safety Act 2011 and Regulation 2017

10.0 DEFINITIONS

Accredited Service Provider (ASP)	An individual or entity accredited by the NSW Department of Planning, industry and Environment, in accordance with the Electricity Supply (Safety and Network Management) Regulation 2014 (NSW).
Clearing Time	Time taken for the protective devices to sense and interrupt the fault current.
Client	An individual or entity who is the proponent of a project; a client could be a developer, or customer, or Ausgrid. For Contestable Works, any reference to the Client includes Accredited Designer(s) and Accredited Service Provider(s) working under agreements/contractual arrangements for the Client. For contestable works, the client is not Ausgrid. For projects which are not Contestable Works, Ausgrid is the Client.
Contact Profile	The information required to define the contact being assessed as part of the risk assessment e.g. current path, footwear type, soil resistivity, surface layer, number of contacts and contact duration.
Document control	Ausgrid employees who work with printed copies of document must check the document repository regularly to monitor version control. Documents are considered “UNCONTROLLED IF PRINTED”, as indicated in the footer.
Earth Fault Current	The current flowing in the earthing system as the result of an earth fault on the power system.
Earth Grid	A connection to the greater mass of the earth, usually made by burying metallic conductors in the soil.
Earth Potential Rise (EPR)	The maximum voltage that a station earth grid will attain relative to a distant earthing point assumed to be at the potential of remote earth.
Earthing System Compliance Assessment	The combination of all identified risk assessments to determine compliance with the applicable safety criteria for each individual.
Earthing Layout Design (ELD)	Earthing design relating to the layout and placement of earthing equipment and infrastructure.
Earthing System Design (ESD)	Earthing design relating to the electrical safety performance of the substation and interconnected network.
Embedded Earthing Conductors	Steel reinforcing embedded in concrete, welded to ensure electrical continuity and provided with a connection facility to interconnect it with the earth grid
Hazard Voltage	The open circuit voltage for a current path being considered as part of the contact profile. Hazard voltages include touch voltage, step voltage and hand to hand voltage.
Induced Voltage	The voltage on a metallic structure resulting from the electromagnetic or electrostatic effect of a nearby power line.
Inspection Test Plan (ITP)	Document specifying and recording required actions to provide compliance with design for elements and interconnections for the installed earth grid and embedded earthing system.
Network Standard	A document, including Network Planning Standards, that describes the Company's minimum requirements for planning, design, construction, maintenance, technical specification, environmental, property and metering activities on the distribution and transmission network. These documents

are stored in the Network Category of the document repository and available externally on Ausgrid's website.

Prospective Step Voltage The open-circuit voltage difference between two points on the earth's surface separated by a distance equal to a man's normal step (approximately one metre).

Prospective Touch Voltage The open circuit voltage difference between an earthed metallic structure (within 2.4 metres of the ground), and a point on the earth's surface separated by a distance equal to a man's normal horizontal reach (approximately one metre).

Review date The review date displayed in the header of the document is the future date for review of a document. The default period is three years from the date of approval. However, a review may be mandated at any time where a need is identified due to changes in legislation, organisational changes, restructures, occurrence of an incident or changes in technology or work practice.

Risk Assessment A combined assessment of various contact profiles pertaining to a particular hazard (e.g. utility worker within a substation or member of the public living adjacent to substation). Each contact profile is assessed against all identified faults in the analysis for a single risk assessment.

Step Voltage The difference in surface potential experienced by a person's body bridging a distance of one metre with his feet without contacting any other grounded object.

Touch Voltage The voltage across a body, under fault conditions, in a position described as for the Prospective Touch Voltage but allowing for the voltage drop caused by a current in the body.

Transfer Voltage A special case of Prospective Touch Voltage where the metallic structure is connected to a remote point or alternatively is connected to the station grid and is touched at a remote location.

Transient Earth Potential Rise An earth potential rise (EPR) originating from a transient source such a lightning strike or switching of fast circuit breakers or Gas Insulated Switchgear.

11.0 RECORDKEEPING

The table below identifies the types of records relating to the process, their storage location and retention period.

Table 8 – Recordkeeping

Type of Record	Storage Location	Retention Period*
Approved copy of the network standard	Document repository Network sub process Standard – Company	Unlimited
Draft Copies of the network standard during amendment/creation	Records management Work Folder for Network Standards (HPRM ref. 2014/21250/232)	Unlimited
Working documents (emails, memos, impact assessment reports, etc.)	Records management Work Folder for Network Standards (HPRM ref. 2014/21250/232)	Unlimited
Electrical Earthing Drawing Suite/Set	Vault	Life of asset + x years
Civil Earthing Drawing Suite/Set	Vault	Life of asset + x years
Earthing Layout Design Report	Trim	Life of asset + x years

Earthing Commissioning requirements, including Inspection and Test Plan	Trim	Life of asset + x years
Final Commissioning Documentation	Trim	Life of asset + x years
Earthing Construction Safety Documentation	Project File + Trim	Life of Project Construction
Safety in Design (SiD) designer's safety report	Trim	Life of Project + x years

* The following retention periods are subject to change e.g. if the records are required for legal matters or legislative changes. Before disposal, retention periods should be checked and authorised by the Records Manager.

12.0 DOCUMENT CONTROL

Document Owner : Head of Asset Risk & Performance

Distribution Coordinator : Manager Asset Standards

Annexure A – Corrosion Assessment

The following soil test corrosion evaluation shall be included in the corrosion assessment. Soil characteristics based on samples taken 100mm below surface. Take care to include an assessment of the impact of industrial landfill or acid sulphate soils (> 100mm depth) if present. Points in each section are to be added up to give an overall total. Refer to Clause 5.5.3.

Resistivity (Ω.m)

<15 10

≥15–18 8

>18–21 5

>21–25 2

>25–30 1

>30 0

pH:

0–2 5

2–4 3

4–6.5 0

6.5–7.5 .... 0 †

7.5–8.5 0

>8.5 3

Sulphides:

Positive.. 3.5

Trace 2

Negative 0

Moisture:

Poor drainage, continuously wet 2

Fair drainage, generally moist... 1

Good drainage, generally dry 0

* Greater than 10 points means further investigation required.

† If sulphides are present, add three points for this range.

Annexure B – Exposure Assessment

A risk profile is required for locations at which staff or the public are in contact with metalwork and able to receive an electric shock during an earth fault occurrence. The exposure parameters are outlined in the following table:

Table 9: Exposure parameters

Contact Information	Measure
Contact voltage	%EPR
Contact configuration	Touch, step, hand to hand voltage
Series impedance* **	Crushed rock, asphalt, concrete slab, footwear (impedance, voltage withstand)
Contact frequency /duration	Number and duration of contacts, how distributed over time

* Natural surface soil resistivity shall be based upon test measurements with allowance for seasonal and/or test result variations.

**Wet body option is not applicable for worker exposure, as is only applicable to bare feet. If a wet area is part of normal inspection work consideration is to be given to the use of 'Safety Gumboots'.

The following sections provide guidance on selection of exposure frequencies for people affected by assets grouped into typical scenarios. If a unique scenario exists where a custom contact scenario is deemed to be required, the scenario selection reasoning and justification should be documented as part of the design report and its use must be approved by the assigned Ausgrid Earthing Engineer reviewing the design.

B.1 Utility Worker Exposure

Utility workers frequently interact with metalwork that may present a hazardous contact voltage during earth fault events. The following table provides recommended exposure rates for workers to manage the cumulative risk exposure:

Table 10: Utility worker typical contact profiles

Contact Profile	Description	Footwear	Surface Layer	Contact Scenario Details
1. Inside and near Major Substation	Contact with metalwork with no equipotential mat, voltage control, asphalt, or gloves. Note: assumes that operating points and gate openings are not included in contact count (gates configured to open inwards only, operator mats deployed)	Electrical (as per EG-0)	Crushed rock (if present)	Individual 1000 contacts/yr for 4s Societal 750 contacts/yr for 4s, for 2 people
2. Major Substation Construction	Work in or on substation that involves changes to earthing configuration (e.g. fence movement) or greater exposure than the 'normal contact' case, shall be subject to a separate study, and a Working Instruction required to cover process (see notes following)	May need special boots (e.g. 'safety Gumboots')	Usually no crushed rock remaining	Requires special assessment
3. Transmission Tower Work	Contact with transmission asset (≥66kV) for normal access. E.g. ground line maintenance and inspection	Electrical	None	Individual Additional analysis required to define contact frequency
4. Transmission Cable Asset Interaction	Cable link box inspection or oil reservoir checks	Electrical	None	Individual Additional analysis required to define contact frequency
5. Distribution Assets	Contact with distribution asset (<66kV)	Electrical	None	Individual 1000 contacts/yr for 4s Societal 750 contacts/yr for 4s, for 2 people

Notes:

Contact scenarios assume the typical maximum exposed contacts for individuals and the average contacts for societal analysis.

Construction work: Table 10 only applies for normal operation such as inspection and testing that does not require staff to reconfigure equipment. It does not apply to construction work where earthing system effectiveness is compromised and/or the exposure rate is much higher for a shorter period.

Special assessment is required for work practices such as: cable jointing, line or cable pulling, substation extension or fence replacement. In these instances, the frequency and duration of contact is high, and the impressed voltage (%EPR) is also often higher due to transfer hazard mechanisms.

The project Construction Safety Plan and/or Safety in Design documentation will be required to cover off on construction safety aspects.

B.2 Public Exposure

Table 11 provides guidance on typical contact scenarios the public may be exposed to. For a given person exposed to more than one hazard scenario the effect of each scenario needs to be combined to determine a cumulative resultant risk.

Table 11: Public typical contact profiles

Contact Scenario	Description	Footwear	Surface Layer	Contact Scenario Details
1. Access near perimeter of major substation	Contact with perimeter fence of substation	Standard (as per EG-0)	None	Urban Interface Individual 100 contacts/yr for 4s Societal 75 contacts/yr for 4s, for 2 people
2. House with transmission structure nearby	Contact with transmission asset (≥66kV) in urban interface location (<100m from residences or where people congregate and move)	Standard	None	Urban Interface Individual 100 contacts/yr for 4s Societal 75 contacts/yr for 4s, for 2 people
3. House with transmission structure on property	Contact with transmission asset (≥66kV) in backyard location (e.g. combination of gate, fence and back tap contacts)	Standard	None	Backyard Individual 416 contacts/yr for 4s Societal 350 contacts/yr for 4s, for 2 people
4. Distribution – Urban Interface	Contact with distribution asset (<66kV) in urban interface location (e.g. UGOH, PT earthing, kiosk)	Standard	None	Individual 135 contacts/yr for 4s Societal 75 contacts/yr for 4s, for 2 people
5. Distribution - Backyard	Contact with metalwork in a backyard	Standard	None	Backyard Individual 416 contacts/yr for 4s Societal 350 contacts/yr for 4s, for 2 people
6. Distribution - MEN	Contact with MEN connected metalwork (around house) where MEN or soil is effected (e.g. combination of contacts including showering, laundry, kitchen contacts)	None	Concrete	MEN Individual 2000 contacts/ys for 4s Societal 1500 contacts/yr for 4s, for 2 people
7. Backyard swimming pools	Backyard pools may sometimes present voltage hazards at locations such as entrance gates, pool ladders, pool surrounds to	None	N/A	Backyard Individual 416 contacts/yr for 4s Societal

	metallic fence contacts (above ground pool)			350 contacts/yr for 4s, for 2 people
8. Aquatic Centre (open 5 months/yr)	Contact with metalwork (e.g. hand rail for water slide line)	None	N/A	Aquatic Centre (5 months) Societal Population size of 50 Av contacts / hr / Person 5 Av contact duration 2s Average group duration 10hrs Average No. gatherings per year 150
9. Aquatic Centre (open all year)	Contact with metalwork (e.g. hand rail for water slide line)	None	N/A	Aquatic Centre (12 months) Societal Population size of 50 Av contacts hr / Person 5 Av contact duration 2s Average group duration 10hrs Average No. gatherings per year 365
10. Societal Distribution - MEN	Contact with MEN connected metalwork (around house) where MEN or soil is effected (e.g. combination of contacts including showering, laundry, kitchen contacts)	None	Concrete	MEN 1500 contacts/yr for 4s, for 10 people
11. Other cases	Certain cases do not fit the categories already specified and require an individual assessment. Such sites include industrial sites, commercial sites near major substations or transmission structures (e.g. car parks), schools, bus stops, hospitals, parks, sporting venues and cattle sale yards	As required (refer to EG-0)	As appropriate	As assessed

Notes:

Remote locations: locations where the coincidence probability presents a negligible incremental risk to members of the public (e.g. <60 contacts/yr for 4s for clearing times <= 1s; or <75 contacts/yr for clearing times <=0.2s).

B3 Typical Contact Profiles for Risk Assessment Analysis

Tables 10 and 11 outline the typical contact profiles used in a risk assessment for the public and utility workers. Individual contact profiles may be removed from the analysis after consideration of the specific risks associated with the earthing system under assessment. The contact profiles are shown in Table 12 below, each combination of profiles forming a separate Risk Assessment.

Table 12: Standard Contact Profiles for Risk Assessments

Risk Assessment	Contact Profiles
Workers inside the Substation	Table 10 Profile 1
Public outside Substation fence(s)	Table 11 Profile 1, 2, 4
Public resident inside the worst case EPR local residential property	Table 11 Profile 1, 2, 3, 4, 5, 6
Public at the local urban distribution asset location/s, particularly UGOHs	Table 11 Profile 4
Public at the local urban sub transmission asset location/s, particularly UGOHs	Table 4 Profile 2
Public inside the worst case EPR local business/commercial property	Table 4 Profile 6
Other (as deemed appropriate for installation)	As required

Additional contact profiles may be added to the Risk Assessment where the profiles in Table 12 are inadequate.

B4 Pipeline Utility Staff Exposure

Pipeline utility staff make contact with a range of equipment attached to metallic pipelines, as well as the pipeline itself during maintenance and construction. The public make limited contact with transmission pipelines, but more regular contact with metallic pipelines within their homes. Appendix K of AS4853 provides guidance regarding contact exposure scenarios for different workers.

Pipeline worker tasks include: CP system routine inspection, maintenance, valve inspection and operation, repairs (usually require use of special safety provisions).

B5 Telecommunications Staff Exposure

Telco staff make contact with earthed cable pairs. The current AS3835 provides prescriptive voltage targets (i.e. 430V, 1000V, 1500V) and guidance regarding when each should be applied. AS3835 mentions the probabilistic nature of the hazard mechanisms that create the risk profiles but does not provide a framework for assessment.

Annexure C – Typical Construction Earthing Hazards and Controls

Earthing Hazards	Controls
Excavation	
● High resistance surface layer removed resulting in increased touch and step voltage hazards (e.g. crushed aggregate removed). ● Grid Conductors Excavated ● Equipotential grading conductors no longer in contact with soil and are no longer effective resulting in increased touch and step voltage hazards. ● Wet Conditions: Excess water in hole resulting in an increased electric shock hazard under an EPR event	● Safety boots in good condition and less than 12months old. ● Leather (riggers) gloves in good condition for general construction work. ● LV Insulation gloves are to be used when handling earth grid conductors in the live substation. ● Wear rubber safety gumboots in excavated areas if crushed rock removed ● LV Insulation gloves are to be used when handling earth grid conductors in the live substation. ● Pump out the excess water. ● Wear rubber safety gumboots in excavated areas in wet conditions
Temporary Fencing	
Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation via metallic fencing. ● Capacitive and Inductive hazards due to overhead power lines.	● Temporary fence bonded to earth grid where it is entirely inside the earth grid. ● The temporary fencing is to have 3 metre isolation sections (ply-timber) installed to isolate it from substation fence where it joins to the outside of a live yard fence. ● The temporary fencing located outside the earth grid is to be earthed at each end with a 1m earth electrode. ● Work in accordance with the Electrical Safety Rules, ensuring that the minimum clearance requirements are met.
Scaffolding	
● Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation via metallic Scaffolding. ● Capacitive and Inductive hazards due to overhead power lines.	● Scaffolding entirely within the earth grid is to be bonded to earth grid. ● Work in accordance to the Electrical Safety Rules, ensuring that the minimum clearance requirements are met. ● Scaffolding located outside the earth grid is to be earthed at each end with a 1m electrode.
LV Power Supplies, Power Tools, Site Sheds & Workshops	
● Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation via power leads or other metallic paths.	**Construction Area** ● Portable RCDs are to be used on ALL LV power supply points in accordance with the Electrical Safety Rules. ● Where possible, tools should to be double insulated. ● The substation LV supply is to be used for work when entirely within the substation earth grid. LV Supply is not to be taken out of the substation earth grid area. ● The construction site LV supply to be sourced from a temporary builder’s supply where work remains 20m from the substation earth grid. The distribution board earthing must satisfy AS3000. **Site Shed Area** ● Site shed located inside the earth grid area shall be earthed to the grid with a minimum 70mm^2 PVC covered earth grid conductor.
Power Excavation, Cutting or Drilling Tools	
● Puncturing energised cables. ● Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation via an earthed tool ● Power Excavation, Cutting or Drilling Tools are required to work in or nearby live yards	● Work in accordance with NS165 ● Locate cables. ● The operator is to wear rubber safety gumboots when operating power excavation, cutting or drilling tools as per NS165

Water Supplies, Dewatering Pumps, Aqueous Waste Services	
● Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation via conductive pipes or hoses.	● Use the existing substation water supply and take care near live electrical equipment. ● Use non-conductive water pipes and hoses wherever possible ● Use LV supply for dewatering pump from inside the earth grid if the pump is inside the grid.
Cranes / Concrete Booms / EWPs	
● Crane, Concrete Booms or EWP could contact exposed HV power lines. ● Transfer of dangerous fault voltages out of the substation or transferring remote earth into the substation. ● The operator is required to touch the machine while standing next to it.	● Work in accordance with NS209. ● Maintain clearances in accordance with Electrical Safety Rules. ● When the Crane or Concrete Boom truck is setup within the earth grid; it is to be bonded to the substation earthing system via a trailing earth lead. ● When the CRANE is setup OUTSIDE the earth grid AND will be lifting/pumping into the substation earth grid, the CRANE earth point or chassis is to be bonded to the substation earthing system via a trailing earth lead. While in this configuration: - Temporary non-conductive barriers are required to limit contact with the CRANE while bonded. - Operation of the CRANE requires either: 1. wireless remote control OR 2. equipotential mat (Ref Dwg: 508610) OR 3. operation from within the crane/plant/vehicle OR 4. the operator to wear rubber safety gumboots. ● Use non-conductive hoses to pump / place concrete, where possible
Carrying Equipment	
● Transfer of dangerous fault voltages out of the substation.	● Carry conductive equipment parallel to the earth grid when external to the earth grid. ● Maintain clearances in accordance with Electrical Safety Rules.
Storing Equipment	
● Transfer of dangerous fault voltages out of the substation.	● Where storage sheds are inside the earth grid area. They are to be bonded to the substation earthing system via a 70mm^2 trailing earth lead connected to the metal frame of the shed. ● When storing equipment inside the earth grid, the equipment must not cross the boundary of the substation earth grid. ● When storing metallic equipment outside the earth grid area, the equipment shall be placed parallel with the earth grid and more than 20m away from the earth grid.

Annexure D – Drawing Format and Standard Constructions

Earthing and Insulation Coordination Group of Ausgrid utilises a number of CAD resources to support the development of standardised suites of earthing drawings for each project. These include:

1. General electrical and embedded earthing standard constructions. To provide a level of consistency and confidence in the earthing design and construction, the techniques contained within the below drawings shall be used for all earthing connections. All earthing drawings shall reference these standard construction drawing details as applicable. Refer to drawings:
    a. Ausgrid drawing 236804 – General earthing details - standard construction
    b. Ausgrid drawing 236805 – General embedded earthing details – standard construction
    c. Ausgrid drawing 236806 – Earth bar mounting and connection details – standard construction
2. Standard line style, symbology and font files – To provide a level of consistency across earthing drawings a standard set of line styles, line weights, colours, symbols, fonts and font sizes are used. All earthing drawings shall use the Ausgrid Earthing & Insulation Coordination supplied standard line style, symbology and font files.
3. Drawing borders and numbers – All earthing drawings shall use the Ausgrid standard drawing borders and drawing numbers sourced from Ausgrid's drawing management system (Vault).

    All Ausgrid supplied resources can be provided on request.