NS 222

Major Substation Earthing Layout Design

November 2011

SUMMARY

Network Standard NS 222 sets out the objectives and basic configurations required of an earthing layout for major substations. It also specifies procedures and acceptable practice by which these shall be achieved.

ISSUE

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1 Scope

Major substation earthing layout shall be designed in accordance with this and other standards. The scope of the earthing layout standard is limited to the design with consideration of the connectivity between the following components:

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

Distribution substations are excluded from this standard (Refer to NS116). Earthing system performance issues such as feeder interconnectivity and system wide fault current distribution is covered in a separate process. Relevant design outputs from the earthing system performance design are inputs to the substation earthing layout.

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

1.1 Substation Layout Design Process

There are five phases in the overall earthing design process, including:

- Concept Design,
- Detailed Design, Materials and Equipment
- Commissioning, and
- Close out.

This standard will specify the detailed design processes in the second and third dot points required to achieve the substation earthing design layout objectives.

2 Definitions

Clearing Time	Time taken for the protective devices and circuit breaker to interrupt the fault current.
Earth Fault Current	The current flowing as the result of a line to ground 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 Grid Voltage Rise (EGVR)	See Earth Potential Rise.
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 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
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.
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).
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.

3 Objectives

Earthing systems are required to manage the transfer of fault energy via a low impedance path to limit the risk to people, equipment and system operation to acceptable levels. An earthing system is required to perform this 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 so as to continue to fulfil this function.

The energy which earthing systems must manage comes from a range of sources and system events, including:

- Generating plant,
- Conductively coupled earth fault current,
- Inductively coupled earth fault current,
- Lightning discharges,
- Transient discharges (e.g. switching surges)
- Capacitively coupled induction

Identification of these sources and any special considerations is part of the earthing system design and is outside the scope of this document. Any requirements that impact on the earthing layout design will be provided as an input to the earthing layout design.

The substation earthing must achieve the following objectives:

- Successful Protection Operation
- Safety Compliance
- Interference Minimisation
- Robustness
- Protection of Electrical Plant

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. It is intended to provide a potential reference for these devices and to limit the potential difference across these devices. The earthing system is required to achieve the desired level of system reliability through:

Facilitating the proper and reliable operation of protection systems during earth faults. This entails reliable detection of earth faults and either clearing the fault or minimising the resulting fault current.

Limiting equipment damage (by enabling protection systems to operate correctly and thereby limiting the duration of earth faults) and the consequent need for repair or replacement,

Limiting or reducing interference to substation secondary system equipment (e.g. SCADA).

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, associated with substations or equipment associated with power lines or cables, or even on non-power system plant items nearby (and not associated with) the electrical system. The soil potential relative to the metallic equipment needs to be carefully considered. For a hazardous situation to arise, a power system earth fault must be coincident with a person being at a location exposed to a consequential hazardous voltage.

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. Earthing systems, while not actively operating for the majority of time, are ‘safety critical’ systems in that under fault conditions they must operate to ensure safety of staff and the public as well as protection of system equipment.

As ‘constant supervision’ is not usually available on earthing system elements (as it is intrinsically for the phase conductors) deterioration or damage can remain latent. For this reason the design, installation and maintenance is all the more critical. Where an earthing system is inadequately designed, poorly installed, or not supervised through appropriate maintenance it will not reliably operate to provide safety when required to do so. This risk is not acceptable, as responsible management can generally ensure safety for a reasonable cost.

Earthing systems shall be designed and constructed to manage the risk of electric shock to people.

3.3 Interference Minimisation

Earthing systems shall be constructed such that the interference (e.g. 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 Section 3.6).

3.4 Robustness

Earthing systems shall be constructed such that they are adequate for the life of the substation and its condition can be monitored throughout its operational lifetime so that effective maintenance can be undertaken as required.

The earthing system, its components and earthing conductors shall 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.

Consideration shall also be given to the effect of corrosion on the lifetime of connections and conductors. No material, including copper and stainless steel, is immune to corrosion when buried in soil. Appropriate checks of local soil conditions are necessary to determine the impacts of the local soil on buried metals, and interaction between different interconnected metals (refer to Section5.4).

The earthing system shall be designed and configured to enable the system to be tested at the time of commissioning and at regular intervals as required, and to enable cost effective monitoring of the key performance parameters and/or critical items.

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. System events/disturbances may otherwise cause extensive damage to equipment and associated ancillary equipment (e.g. insulation breakdown and thermal or mechanical damage from arcing, fires or explosions). This is achieved by adequately sizing conductors for the expected current levels, and durations.

3.6 Relevant Standards

The following Guides and Standards are considered particularly relevant to this Network Standard:

- ENA EG(0) Power Systems Earthing Guide – Part 1 Management Principles, February 2010
- ENA EG-1 Substation Earthing Guide 2006
- AS/NZS 3835.1:2006 : Earth potential rise - Protection of telecommunications network users, personnel and plant - Code of practice
- AS/NZS 4853:2000 : Electrical hazards on metal pipelines.
- AS 1768-2007/NZS/AS 1768-2007. Lightning Protection. Published jointly by Standards Australia & Standards Association of New Zealand.
- IEEE 837-2002 Standard for qualifying permanent connections used in substation grounding.
- Workcover NSW,"ELECTRICAL Practices for Construction Work: Code of Practice 2007".
- AS2758.7:1996 : Railway Ballast - Aggregates and rock for engineering purposes
- IEEE 998-1996 Lightning revised 2002.
- AS 2067:2010 'Substations and High Voltage Installations exceeding 1kV'. Standards Australia.
- AS/NZS 3000:2007 'Electrical Installations (known as the Australian/New Zealand Wiring Rules)'. Standards Australia.
- AS/NZS 7000:2010 – Overhead Line Design – Detailed Procedures
- IEEE80 - IEEE Std 80-2000 'IEEE Guide for Safety in AC Substation Grounding'. The Institute of Electrical and Electronic Engineers.
- AS 3007:2004 ' Electrical Installations – Surface Mines and Associated Processing Plant'. Standards Australia
- CAD Resources – e.g. DS111-E

4 Earthing Design Layout Overview

This section lists the specific tasks that the earthing layout designer shall undertake, the inputs required by the earthing layout designer in order to undertake the design task, and the outputs that the earthing layout designer shall produce. Each task will identify how to document the output from that task. There are six types of documentation that make up the earthing layout design:

- Earthing layout electrical drawing set – specifications, layout and construction detail.
- Earthing layout civil drawing set – specifications, layout and construction detail.
- Earthing layout report – calculations and justifications, addressing each of the design outputs listed in the following sections.
- 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 layout design is summarised in Figure 1 below.

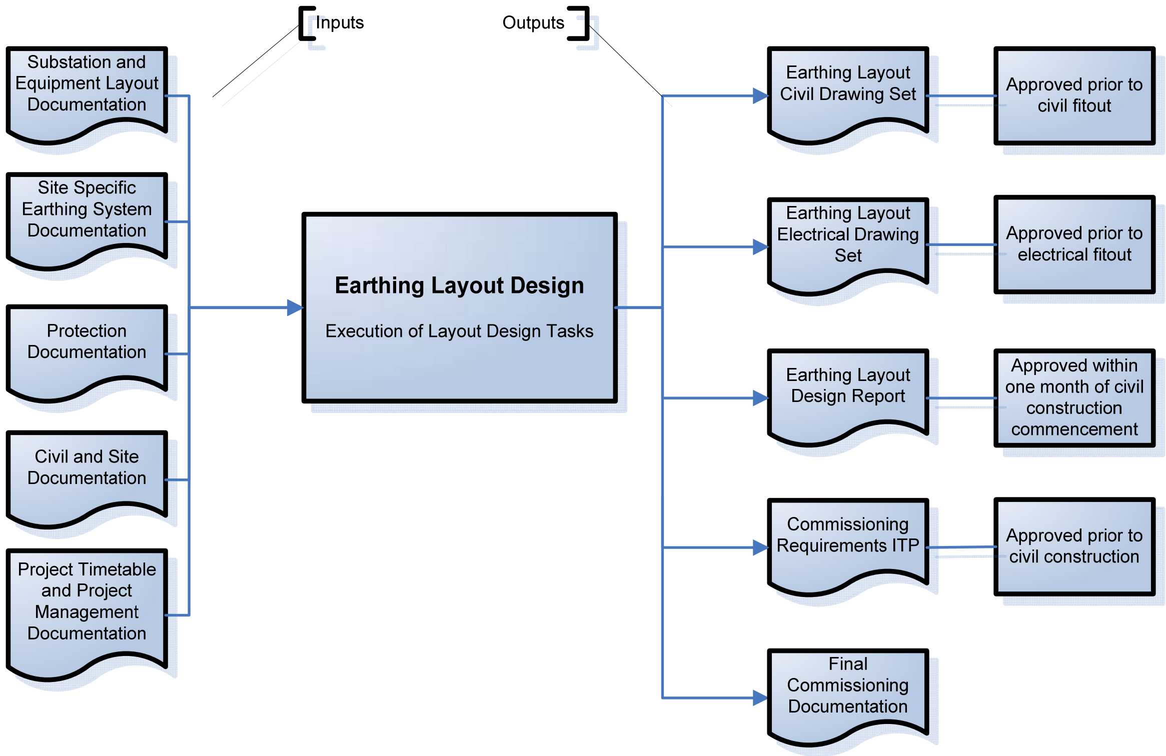

Figure 1: Earthing Layout Process

The earthing layout design is completed by undertaking the design tasks outlined in Section 5 and documenting the outcome of those tasks as required. Commissioning requirements are part of the layout design and require administrative and testing actions to be coordinated, assessed and signed off.

The considerations that are to be made to complete the earthing layout design are summarised in Table 1 below.

Table 1: Layout Design Considerations

Phases	Design Considerations	Section
Detailed Design, Materials and Earthing Equipment	Robustness, Reliability and Redundancy	5.1
	Cable sizing / rating	5.2
	Connectivity	5.3
	Corrosion	5.4
	Embedded earthing	5.5
	Grid and electrode layout	5.6
	Personnel Safety Equipment	5.7
	Crushed Rock	5.8
	Gas Insulated Switchgear (GIS)	5.9
	Lightning Protection Systems (LPS)	5.10
	Acceptable Interaction with Other Assets	5.11
	Future developments	5.12
	Standardisation and equipment normalisation	5.13
Commissioning	Commissioning	5.14
Earthing Construction Site Safety	Earthing Construction Site safety	6

5 Layout Considerations

Some details of the following material are open to alteration provided the alterations are consistent with Ausgrid's design outcomes. However, major and permanent alterations from this specification will be allowed only if prior approval has been given in writing by the manager responsible for standards and network guidelines.

DETAILED DESIGN, MATERIALS AND EARTHING EQUIPMENT

5.1 Robustness, Reliability and Redundancy

The components specified in the substation earthing layout design shall be of sufficient dimensions and construction to withstand the expected deterioration due to the environment for their required design life. The earthing of critical items of plant shall have N-1 redundancy (see Section 5.2.4). 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.

5.1.1 Design Inputs

Required redundancy level

Recommended equipment

Site specific earthing system design.

5.1.2 Design Outputs

Locations on drawings showing each required connection.

Connection criticality to be assessed and labelled in the earthing layout drawing set.

Justification for the connection criticality assessment shall be documented in the earthing design layout report.

Site specific requirements from the Earthing system design shall be included in the earthing layout drawing set and/or report.

5.1.3 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 layout 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 except where an alternate has been designed and authorised. A spring washer or Belleville washer is typically required. A maximum of one lug per bolt shall be used (ie. connections shall not be ganged on a single bolt).The bolts/nuts/washers shall not be installed in the current path ,ie the lug or copper bar shall make direct contact with the face to be earthed/bonded.

The bolt / nut threads and washer to bolt / nut surfaces are primary surfaces for corrosion, irrespective of the construction material (some will last longer). The electrical integrity of a bolted connection will diminish rapidly when subject to corrosion and quickly void the designed connection. Bolted connections are only suitable for above ground connectivity.

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 layout design to achieve the required redundancy. Generally this should 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. Earth bar size shall form part of the earthing layout design to achieve the required equipment rating and robustness.

Fasteners: All fasteners including bolts, dyna bolts, saddles, 'knock-ins', and clamps to be stainless steel grade 304 or 316. Fasteners to be secured at least every 1000mm and more frequently where required.

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 2 where label size requires the description to be abbreviated.

Table 2: 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 UPVC sheathed above ground so as to protect the conductor. Black UPVC 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. The size and number of conductors and bolts per lug shall form part of the earthing layout design to achieve the required equipment rating and redundancy.

Tinned Copper Braid: Tinned copper braid shall be used on all equipment subjected to movement with infrequent use, such as operating arms and handles. Size and number of conductors shall form part of the earthing layout design to achieve the required equipment rating and redundancy. Adequate length of braid shall be allowed to ensure no undue stressing of the conductor. The braid shall be installed so as to ensure that 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. The length and number of welds required shall form part of the earthing layout design to achieve the required 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. Size and number of conductors shall form part of the earthing layout design to achieve the required equipment rating and redundancy. Where the cable terminates in the barrel of a lug heatshrink (heavy duty) 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.

5.1.4 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. The earthing layout design shall identify required spacing between conductor terminations and placement to facilitate testability.

5.1.5 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 3.

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

Table 3: 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:

An equipment support stand would receive a criticality rating of A (it could be part of the primary fault current path).

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.

A single phase busbar support would receive a criticality rating of B while a triple busbar support would receive a criticality rating of A.

5.1.6 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.

5.2 Cable Sizing and Rating

Correctly sizing the earthing conductors is an essential part of ensuring that the earthing system will perform as intended during an earth fault event. Sizing of conductors is 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.

5.2.1 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.

5.2.2 Design Outputs

Connection type and selected conductor (dimension/s) shown on earthing layout drawings.

Current reduction calculations shown in earthing layout report.

Conductor size calculations shown in earthing layout report.

Neutral conductor calculations shown in earthing layout report and specified on drawings.

5.2.3 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 AEMO defined backup clearing time. This is summarised in the Table 4.

Table 4: 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

5.2.4 Optional Current Reduction for Multiple Connections

Structures which have multiple connections to earth (that is, to different mesh conductors) which will share the current in the event of a fault, may reduce the current rating that each connection is required to carry in accordance with the following table. Refer to Section 5.1.5 for details on assessing the criticality rating. Selecting the appropriate conductor size depends on the level of redundancy, number of proposed conductors, as well as the clearing times for the primary and backup protection.

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 5.

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.

It should be noted that 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.

Table 5: 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.

5.2.5 Conductor Size Calculations

Appropriate formulae may be obtained from the ENA Substation Earthing Guide EG-1 (Section 10.2.2.2) or IEEE Standard 80. These formulae will calculate the required cross sectional area to be able 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). PVC covered conductors should not exceed a maximum temperature of 160°C to avoid damaging the insulation. Ambient temperature shall be taken as 45°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 (Section 5.1) and normalisation (Section 5.13).

5.2.6 Transformer Neutrals

Transformer neutrals are system and safety critical items of plant and are subject to the full earth fault current that it delivers 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).

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 i.e the 11kV neutral shall be directly interconnected to the 11kV switchboard and feeder screen terminal earth bar.

Earthing transformer neutrals shall adhere to the requirements of this section, even though they are not the neutral on a power transformer, they do form the system neutral- earth connection.

5.3 Connectivity

In order 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.

5.3.1 Design Inputs

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

5.3.2 Design Outputs

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

5.3.3 Components Requiring Earthing

The following components are key to the earthing system performance and require the following considerations:

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. Conductor termination size and termination connection type shall form part of the earthing layout design. Typically there shall be a continuous copper conductor bonding to the earth wire. Full redundancy in earth terminations shall be provided at the base of the structure or pole.

Power Cable Screens and Earth Continuity Conductors (ECC)

All cable screens or sheaths and all ECCs shall be terminated to an earth bar or surge arrester. Any conductor and connection hardware used to terminate a cable screen or ECC shall meet or exceed the rating of the cable screen it connects to. Conductor termination size and termination connections shall form part of the earthing layout design. Provision should be made to terminate transmission power cable screens and armouring and associated earth continuity conductors where necessary, interfacing with the transmission earthing design. The earthing layout design shall include consideration and design of link boxes, RF bonds, surge arrestors and screen terminations.

Cable screens and 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.

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

All Earth Continuity Conductors (ECC) shall be terminated to an earth bar and appropriately labelled to facilitate testing and identifying the termination. Any conductor and connection hardware used to connect an ECC shall meet or exceed the rating of the ECC it connects to. Conductor termination size and termination connections shall form part of the earthing layout design.

Surge Voltage Limiter (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 layout 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

Trifurcating cable joints should be located as close as practical to the cable termination. The cable sheath bond should be made as near as possible to the phase conductor terminations and labelled so as to facilitate testing. Earth screen continuity shall be provided on all 11kV and 33kV trifurcating joints.

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 (eg. 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.

Separation shall be maximised between buried services (including power or control cables, conduits, pipes etc) and lightning pole earthing equipment (including electrodes, HV earth grid connections and down conductors). Two (2) metres separation shall be achieved where possible. Where less than one (1) metre separation is able to be achieved, then the services shall be installed in conduit so as to increase the Basic Insulation Level (BIL) of the service within the ionisation zone of the lightning earthing equipment.

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 system design and shall be incorporated into the earthing layout design.

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 (eg. transformer tank strut, circuit breaker tank/stand). All equipment connected to the primary and secondary busbar shall be earthed in an appropriate manner, that is, so as to fulfil the requirements set out in Sections 5.1 and 5.2.

5.3.4 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
- Bollards
- Short handrails

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

5.3.5 Components Requiring Segregation

No distribution voltages shall be reticulated into a major substation without an earthing system design which addresses that specific issue. The earthing layout design would then have to incorporate any isolation, separation and insulation requirements provided by the earthing system design.

No metallic pipe-work shall be brought into the substation which is not addressed by the specific earthing system design. Any requirements from the earthing system design shall be incorporated into the earthing layout design. For instance, it is normal practice to include at least 6m of non-conductive (eg, 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 layout design shall reference the telecommunications isolation method used and identify where it is located.

5.4 Corrosion

Corrosion considerations must be taken into account as they have the potential to adversely impact the earth system performance and to reduce the design life of an installation.

5.4.1 Design Inputs

- Civil design, substation layout
- Geological report (soil evaluation)
- Soil Electrical Resistivity Test Analysis

5.4.2 Design Outputs

Identification of nearby DC traction systems and Cathodic Protected Plant (CP) (for instance pipe lines and underground tanks)

Results of soil evaluation documented in earthing layout report.

Minimum concrete cover identified on earthing layout civil drawings

Corrosion mitigation measures included on earthing layout civil and electrical drawings.

Substations shall be designed such that the effects of corrosion do not compromise the substation earthing equipment design lifetime.

The earthing layout 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.

5.4.3 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 Appendix A. Results shall be documented in the layout report.

If greater than 10 points are obtained while undertaking the soil evaluation, notification via the commissioning documentation shall be undertaken. Mitigation measures resulting from that notification shall be incorporated in the earthing layout design drawings.

Identify DC traction systems within 100m of the substation.

Where required corrosion mitigation and testing facility measures shall be incorporated into the earthing layout design drawings and documentation. Some typical examples include

- Installation of conductors or conduits during distribution works or zone development to facilitate drainage bond installation if required.
- the installation of earth bars either side of a rail easement to allow bridging out of a buried counterpoise conductor if required.
- Providing test facility at a cable tunnel entrance so that all collected stray DC traction current could be assessed during a single measurement.

Notification of DC traction systems within 100m of the substation shall be given to the manager responsible for network earthing. Mitigation measures resulting from that notification shall be incorporated into the earthing layout design drawings.

5.5 Embedded Earthing

Embedded Earthing is constructed using the reinforcing steel in concrete slabs, columns, walls or piers as part of the earthing system. Embedded Earthing is installed to ensure an equipotential plane is created and also provides a path for lightning and earth fault current to dissipate into the soil. Its usage is common practice in large indoor installations but the same concept is often applied to outdoor footings or slabs.

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.

5.5.1 Design Inputs

Substation Civil Detail (Structural Design)

Site specific earthing system design inputs as specified. This document will specify if embedded earthing is required.

5.5.2 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 drawing set.

Method used to identify embedded earthing conductors so as to:

- Show design compliance,
- Facilitate as building of drawings,
- Allow auditing and inspection of embedded earthing installation prior to placement of concrete grid, and
- Provide for ‘sign off’ of approved ITP’s.

5.5.3 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 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 (ie 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 to 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 together 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 method used shall be documented in the Commissioning Requirements document with signoff provided via the ITP document.
- The minimum weld length shall typically be 75mm in length however, consideration of the cross sectional area shall be made if the fault level or current carrying requirement of the embedded conductors is particularly onerous.
- 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 Cell Library Cell C21).
- 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 to the Cell Library 'EW, 'EH', 'ES', 'EV' or 'EC' connection details as appropriate).
- Electrical connectivity across expansion joints and across joints without continuity of steel reinforcing shall be provided every 30m, unless more frequent bonds are required to achieve redundancy or rating.
- Electrical connectivity across expansion joints and across joints without continuity of steel reinforcing shall use a minimum of 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 to Cell Library D2).
- To minimise the risk of corrosion, the minimum concrete coverage of embedded steelwork recommended by the civil/structural design should be strictly observed. Typically the minimum concrete cover would be 40mm. Where the exposed concrete surface is subject to direct contact with soil, increased salt levels, or both, this coverage may need to be increased, to typically no less than 75mm, as directed by the responsible civil or structural engineer. In addition to minimum concrete cover, buried copper connections in concrete slabs or in soil shall be of a crimp type to minimize the risk of corrosion. No bolted terminations are permitted to be buried (in soil or concrete). This requirement needs to be included in the structural design.
- 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.
- Cable sizing shall satisfy conductor sizing requirements and redundancy requirements 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.

5.5.4 Detailed Earthing Requirements for 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 and at equally space 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 intervals of less than every 4th penetration. 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). The minimum spacing shall be the intersections of the welded reinforcing 1 metre away from the control boxes and the welded reinforcing crossing the GIS room floor in-between the penetrations, so that there is 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. The minimum spacing shall be aligned with the intersection of the welded reinforcing next to the penetrations and the welded reinforcing crossing the GIS room floor in-between the penetrations. Earth tags are also to 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.

The embedded earthing associated with the GIS switch gear complements the electrical earth bars associated with the equipment

5.6 Grid and Electrode Layout

A buried metallic earth grid may form one part of an interconnected substation earthing system. 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. As such 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.

5.6.1 Design Inputs

Substation civil detail

Site specific Earthing system design inputs: electrode and grid dimensions.

5.6.2 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.

5.6.3 Requirements

Conductor size for the earth grid shall be calculated as outlined in Section 5.2. Calculations shall be shown in the earthing layout report.

The grid mesh shall be maximally spaced according to the grid dimension input from the site specific earthing system design. The grid shall be shown on the earthing layout drawings along with conductor size and material.

The electrodes shall be spaced according to the grid dimension input from the site specific earthing system design. All electrode locations shall be shown on the earthing layout drawings along with 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 so as to facilitate the electrode termination) or equipment structure with earth bond.

All electrode bonding conductors shall b labelled to facilitate identifying 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 shall be shown on the earthing layout drawings. 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.

5.7 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 mat or slab shall be situated so that the operator would stand on the mat to operate the equipment.

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 Section5.1, but shall be installed robustly. It should be noted that the structure or equipment would still be expected to have two (2) redundant earth bonds.

5.8 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 ungraded (straight) 40mm as per AS2758.7 Table 1.
- 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 Earthing (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 Authorised 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 Authorised Earthing Engineer.

5.9 Gas Insulated Switchgear (GIS)

In addition to the earthing requirements associated with power system frequency faults, 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.

5.9.1 Design Inputs

Substation slab floor civil design

GIS manufacturers requirements

Ausgrid Network Earthing detailed earthing requirements

5.9.2 Design Outputs

Slab reinforcement bonding locations shown on earthing layout civil and electrical drawings

GIS connectivity requirements shown on earthing layout electrical drawings

5.9.3 General Requirements

The steel reinforcing in the slab under the GIS shall be welded to provide an earth plane under the switchgear. A high level of interconnection shall be provided between the GIS trunking and the steel reinforcing in the floor under the switchgear. Refer to Section 5.5.4

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 sections 5.5.4 and 5.9.4 for detailed earthing requirements).

The earthing arrangement associated with the GIS switchgear 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, arrestors shall be installed in such a manner as to not compromise the GIS switchgear manufacturers' requirements.

5.9.4 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. Some RF bonds may be earthed via surge arrestors.
- As a minimum requirement, the electrical earthing for GIS equipment shall be rated according to Section 5.2, however standard conductor sizes are to be used according to the rated voltage 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 Section 5.2.

- The following earthing associated with the GIS equipment shall be at least 50x3.18mm HD copper bar.
- Basement perimeter earth bar
- Connections between the main GIS earthing and the basement perimeter 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 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 185mm2 stranded copper conductors with long barrel lug and double bolted palm connections. This is to replace the manufacture's 2 x 95mm^2 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 arrestors 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 Cell Library Detail PC).
- 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 (Refer to Cell Library Detail PC).
- The 132kV link box metal casing shall be connected via a 120mm^2 stranded copper PVC covered conductor to the GIS basement ceiling earth bar with a double bolted palm connection (Refer to Cell Library Detail LB).
- A basement perimeter earth bar shall be mounted on the basement wall at a height between 1.5metres from the floor to 0.3metres from the ceiling to form a ring around the entire switch room basement. 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 perimeter 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 perimeter 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.

5.10 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 diverters, lightning spires, lightning shield wires and the earthing system – these combine to form the lightning protection system. The substation earthing layout design shall identify lightning spire and lightning shield wire placement whilst maintaining required access and safety clearances in consultation with subs design.

5.10.1 Design inputs

Substation equipment layout detail

Site specific Earthing system design inputs

5.10.2 Design outputs

Lightning protection details shown on earthing layout drawings.

Lightning protection analysis shown in earthing layout report.

5.10.3 Requirements

The earthing layout designer shall undertake a lightning design using the rolling sphere method or alternative approved method. The rolling sphere size shall be 20m unless otherwise specified in an earthing system design. The earthing layout drawings shall show placement and height of lightning spires, and any lightning shield wires, and all connections to earth. The earthing layout report shall show the calculations that demonstrate compliance with the 20m rolling sphere. All substation buildings and equipment shall be protected unless designed to intercept lightning strikes, in which case the interception and strike conditions shall be specified.

The rolling sphere approach is documented in AS1768 and IEE998-1996 (Revised 2002). Calculations shall be provided in the earthing layout report.

Where a component of the lightning protection system (LPS) has an alternate function, (eg a roof), it is not acceptable to incorporate it into the LPS if its alternate function is adversely impacted by being bonded to the LPS. For instance, a roof being punctured due to lightning strike would be unacceptable if it were the only weather proofing above electrical equipment.

Where a power line provides shielding to a building or substation equipment, lightning masts are not required to be installed. However, equipment such as down conductors and lightning electrodes (which may be difficult to install once civil construction were finalised), should be installed against the scenario that the power line were to be relocated.

Refer also to Section 5.3.3 for additional earthing requirements for metal poles.

5.11 Acceptable Interaction with Other Assets

Assessment and design of electrical and safety impacts of an earthing system on other assets is outside the scope of the earthing layout design. This assessment will be done as part of the earthing system design.

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

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

- Pipelines
- Telecommunications
- Conveyors
- Underground mines

- Railway Systems (eg Signalling,drainage bonds and tunnels)
- Swimming Pools

The site specific earthing system design will make appropriate assessment and mitigation recommendations.

5.11.1 Design Inputs

Site specific earthing system design requirements which shall specify mitigation activities where the earthing system interacts with other assets.

5.11.2 Design Outputs

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

5.12 Future Developments

The earthing layout design shall take into consideration any site specific earthing system design requirements in regards to possible future developments. The earthing layout design shall incorporate the information onto the layout drawings and reports as specified in the earthing system design. Substation earthing layout design should consider the effect of future developments that may adversely affect the earthing system or be adversely affected by it. Some typical examples include future transformers (additional or increased capacity) and additional equipment (eg future capacitors). Where possible the need for future 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.

5.12.1 Design Inputs

Site specific earthing system design requirements regarding possible future developments.

5.12.2 Design Outputs

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

5.13 Standardisation and Equipment Normalisation

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

In many cases standard equipment and standard sizes are stocked by Ausgrid.

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.

5.13.1 Design Inputs

All previous earthing layout design tasks

5.13.2 Design Outputs

Normalised equipment lists.

5.14 Commissioning

5.14.1 Design Inputs

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

5.14.2 Design Outputs

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

The ITP is to be approved prior to construction commencement.

The earthing layout 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
- Earthwire connectivity
- Cable screen connectivity
- Earth Continuity Conductor (ECC) connectivity
- Neutral Terminations
- Metallic supporting structures
- Metallic poles (eg security cameras or lighting)
- Conductive fences
- Voltage limiters / arrestor 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 Earthing Construction Site Safety

Earthing site safety requirements are to be specified in addition to standard construction site safety requirements. 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.

This additional earthing site safety requirement may not apply to Greenfield Substations or Substations that are not energised. However, all HV feeders on site must be assumed energised unless proven otherwise.

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. The earthing layout design shall detail earthing safety related considerations and any required mitigation measures. 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. Any site specific requirements from the earthing system design shall be incorporated into the earthing layout design. These requirements shall be implemented so as to eliminate earthing hazards as far as practically possible especially in site establishment.

If the requirements presented here are not fully understood then the issue shall be raised and a resolution documented prior to any work commencing.

6.1.1 Design Inputs

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

6.1.2 Design Outputs

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

6.1.3 Specific Site Safety Tasks

- Identify a location for site shed and source of LV power (if required). This location shall be provided on the earthing layout drawings or documentation. Unless otherwise allowed 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 1.8m 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 pipe-work 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 builders supply from the Ausgrid LV network.

Any construction using conductive materials (such as temporary fencing or steel reinforcing bar) with an assembled horizontal length of longer than 5 metres shall be identified and documented in the earthing layout report and a site specific work policy shall be documented in the earthing layout report. This shall include:

- Temporary bonding arrangements (eg. equipotential bonding and temporary earth electrodes)
- Isolation requirements (eg. 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

The earthing layout report 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.

7 Appendix 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 Section 5.4.

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.

8 Appendix B – Standard Constructions

Network Earthing utilises a number of CAD Resources to support the development standardised suites or earthing drawings for each project. These include:

The library includes the following cells:

1. DS111-E Network Earthing CAD Drawings Guidelines and Procedures
2. Network Earthing

   General Electrical and Embedded Earthing Standard Cell Library. A library of standard earthing cells detailing earthing construction methods with corresponding Earthing Materials lists and standard earthing construction notes (e.g. E53 Copper bar (50 x 6) – T-Joint).
3. Standard Linestyle Symbology and Font Files

   A library of standard linestyles useful for detailing and differentiating various earthing conductors and sizes.
4. Substation Master Setout Model

   A standard set of CAD files with general setout layouts and links to Aerial photos, Scout GIS Data and site survey information.
5. Projectwise Citrix Document Management System

   A network system that provides access to a range of Standard Earthing Drawings and CAD models and templates which utilises a Citrix Network Interface and Benley Project Wise Document Management System Software.

All resources can be provided on request either on CD or preferably through the ProjectWise Citrix Online Interface for Alliance partners

	Revision History
Initial issue:	November 2011
Last issue:	November 2011
Current issue:	November 2011

	Document Control
Authorised By: T.Lampard	Date: 09/11/2011
Manager, Standards & Comunications	
Document Number:	NS 222