Snowy Technical Standards		
SHL-ELE-128	**Earthing**	
Subject Matter Expert Kapila Nanayakkara Principal Electrical Engineer		Version Date: 17 August 2020 Revision: Original

1. Executive Summary

This document describes the purpose and function of earthing systems within Snowy Hydro, and gives some guidelines in designing, installing, testing and maintaining earth connections. To this end it describes:

- The operation and function of earthing systems.
- How employees or contractors should work within, near or between electrical installations to minimise risks of earthing related electric shocks, when to exercise additional caution and when to seek further guidance.
- Safety targets for earthing system performance to be achieved by design and verified by test.
- Construction requirements for installations, both new and existing.
- Commissioning and maintenance targets, to ensure earthing systems remain compliant with operational requirements during their service lifetimes.
- Typical earth connections for equipment in power stations and in the vicinity.

Where works are to be entered into which could require staff to interface with the earthing of a high voltage installation, consideration needs to be made of potential circumstances which may lead to workers being exposed to earthing related risks.

The extent of an earthing system associated with a high voltage installation is not easily identifiable, so when these conditions exist is not readily apparent. To this end this document covers off on what the hazards are and how to come to a decision regarding the likelihood of working in these circumstances for a given set of working conditions.

It also describes the design and assessment compliance targets which are used in conjunction with the ALARP ('As Low As Reasonably Practicable') risk assessment framework.

2. Scope

This standard applies to earthing systems across Snowy Hydro's assets, particularly those which utilise, control or generate high voltage (electricity). Examples include power stations, pump stations, cable tunnels, depots and switching stations.

It also applies to other assets which may be impacted by proximity or exposure to electrical assets. Notionally impacted assets will be conductive, such as pipelines, pilot cables, remote hydraulic structures, medium voltage supplies and low voltage services.

2.1. Applicable Standards

[1] "IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations," *IEEE Std 1050-2004 (Revision of IEEE Std 1050-1996)*, 2005.

[2] "IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding," *IEEE Std 837 - Revision of IEEE Std 837-2002 (Revision of IEEE Std 837-1989)*, October 2014.

[3] "IEEE Guide for Safety in AC Substation Grounding," *IEEE Std 80-2013 (Revision of IEEE Std 80-2000/ Incorporates IEEE Std 80-2013/Cor 1-2015)*, pp. 1–226, May 2015.

[4] AS 2067-2016, *Substations and high voltage installations exceeding 1 kV a.c.*, 3rd ed. Standards Australia, September 2016, ISBN:978 1 76035 559 3.

[5] AS/NZS 1768:2007, *Lightning Protection*. Standards Australia, 2007.

[6] AS/NZS 3000:2018, *Electrical installations (known as the Australian/New Zealand Wiring Rules)*, 6th ed. Standards Australia/Standards New Zealand, 2018.

[7] AS/NZS 3835.1:2006, *Earth potential rise - Protection of telecommunications network users, personnel and plant, Part 1: Code of practice*. Standards Australia, 2006.

[8] *AS 4036-2006 Corrosion of metals - Dissimilar metals in contact in seawater*, Australian Standards Std., 2006.

[9] ENA EG1-2006, *Substation Earthing Guide*, Energy Networks Association Std., 2006.

[10] Energy Networks Association Limited, *ENA EG-0 (2010) Power System Earthing Guide, Part 1: Management Principles*, Energy Networks Association Limited Std., May 2010.

[11] IEC TR 61000-5-2:1997, "Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling ," IEC, Tech. Rep., 1997.

3. Definitions

3.1. Acronyms

Acronym	*Definition*
AC (or a.c.)	Alternating Current (in r.m.s. value unless stated otherwise)
AS	Australian Standard
EMF	Electromotive Force
ENA	Energy Networks Australia, formerly known as Energy Networks Association.
EPR	Earth Potential Rise
ESD	Electrostatic Discharge
HV	High Voltage

IEC	International Electrotechnical Commission
IRS	Inspection and record sheet
ISO	International Organisation for Standardisation
ITP	Inspection and Test Plan
JIRA	Snowy Hydro's Change Management process
kV	kilovolt(s)
LFI	Low Frequency Induction
MEB	Main Earth Bar
MEN	Multiple Earthed Neutral
MSB	Main Switchboard
NDE	Non-Destructive evaluation
PE	Protective Earth
PVC	PolyVinyl Chloride
QA	Quality Assurance
SHL	Snowy Hydro Limited
SPD	Surge Protection Device
SELV	Safety Extra-Low Voltage
V	Volt(s)

3.2. Jargon

The following words, acronyms and abbreviations are referred to in this document.

Word and/or picture	*Definition*
Bonding	The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed
Earthing	The effective connection to the general mass of the earth by means of a suitable earth electrode
Earthing Electrodes (earth rods or ground rods)	Buried vertical elements of the earthing system which provide connection deeper into the soil strata usually so that electrical contact can be made with layers of lower resistivity soil
Earth Potential Rise (EPR)	The increase in electrical potential of an earth electrode or earthed structure, with respect to remote earth, caused by the discharge of current to the general body of earth, through the impedance of that electrode or structure. [5, AS1768]
Earthing Resistance	The resistance of the earthing system to the general mass of earth, as measured from a test point.

Earthing System	The interconnection of all the earthing impacting the earthing performance of an installation, including local and remote buried elements, regardless of the nature of their metallic connection.
EPR Hazard Zone	The area around an earthing system bounded by a contour joining all points of EPR equal to the maximum acceptable voltage below which no special precautions need to be taken to protect telecommunications plant or personnel. [7, AS/NZS 3835.1]
Equipotential Bonding	Electrical connections intended to bring exposed conductive parts or extraneous conductive parts to the same or approximately the same potential, but not intended to carry current in normal service. [6, AS3000]
Grounded	Connected to earth or to some conducting body that serves in place of the earth
Grounding Conductor	A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes
Instrument Earth	Used to provide earthing for instruments, communication and metering equipment. Implemented using a single point bonded configuration as the equipment involved is relatively low power but is reliant on the earthing to provide equipotential bonding
Lightning Protection	A system of conductors and other components used to reduce the injurious and damaging effects of lightning
Prospective Touch Voltage	The potential difference between an earthed metallic structure, within 2.4m of the ground, and point on the earth's surface separated by a distance equal to a man's normal maximum horizontal reach (approximately one metre).
Remote Earth	The potential of the earthing system when no current passes through it. Under fault conditions it is considered to be the potential of the earth at location not affected by the passage of fault current through the earthing system under consideration [4].
Reticulated	Constructed, arranged, or marked like a net or network
Reticulated Earth	Power supply cable includes an earthed core, typical in 230V three core electrical cable
Step Voltage	Voltage appearing between the feet of a person, usually considered to be 1m apart
Soil Resistivity	The volume resistance of the soil, in practice the resistance between two opposite faces of a cube of soil. [7, AS/NZS 3835.1]
Touch Voltage	Voltage appearing between simultaneously accessible parts [6, AS3000]. The voltage across the body, caused by current flow through the body and other series impedances, when in a position described as for the prospective touch voltage
Transfer Voltage	A transfer voltage is a touch voltage created at a location distant from the earthing system by the transfer of potential through a conductive medium

4. Technical Requirements

4.1. Requirements

The fundamental requirements for effective earthing systems[1], in order of priority, are:

1. Provide safety for people;
2. Protection of equipment; and
3. Support of the operation and security of the power system.

[1] Discussed further in Appendix A

4.1.1. Earthing Philosophy

The effectiveness of an earthing system is highly dependent on the interface between the general body of earth and the system itself. The impedance of the system, which includes the resistance of the local earthing (including electrodes and mesh conductors), and the impedances of auxiliary earth paths (such as OHEWs, counterpoise conductors and cable screens) must be sufficiently low such that any voltages produced remain below acceptable limits of risk in the presence of earth fault or transient currents.

The rise in potential of the earthing system under earth fault or transient conditions with respect to a remote reference point, assumed far enough away to be at 'true earth' or zero potential, is commonly referred to as 'Earth Potential Rise' (EPR).Typically, the resistance of materials used to build an earthing system is negligible compared with the contact resistance of the buried earthing system, which depends primarily on the resistivity of the soil in the area. While earth potential rise (EPR) exists on an earthing system, hazardous voltages in the form of touch, step and transfer voltages may be present on and around the earthing installation, see Figure 1.

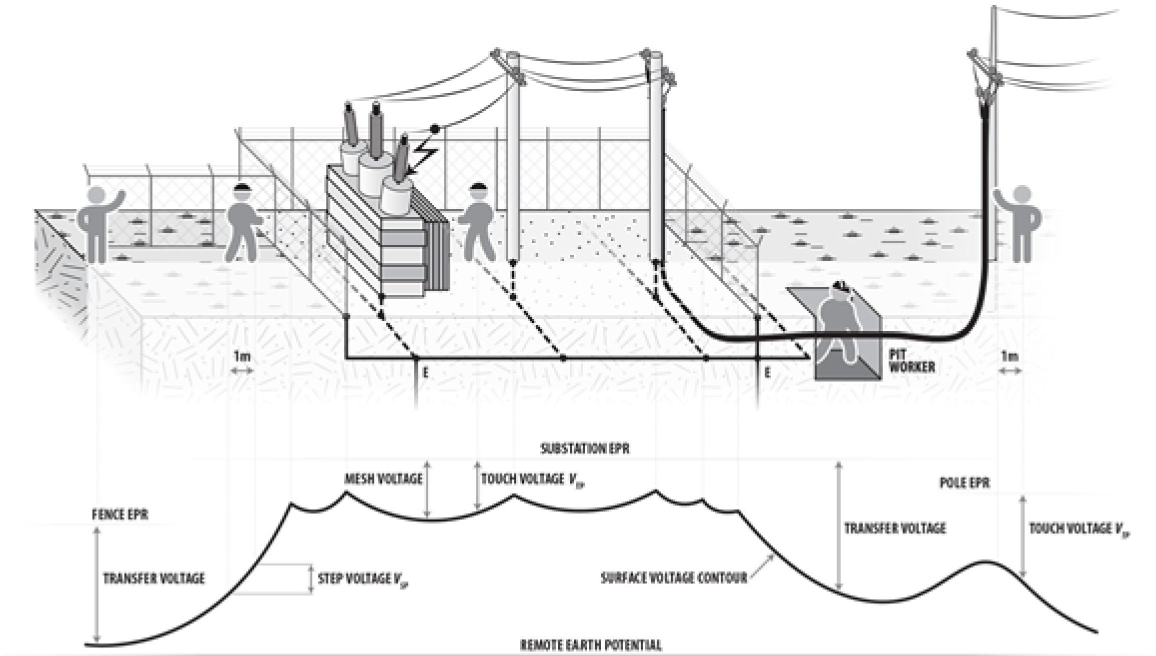

Figure 1: Potential circumstances of earthing related hazards around substations

The risk posed by an earthing system is measured in terms of the magnitude and duration of the voltage hazard created. The risk is also affected by a number of other variables including, but not limited to, the frequency that people may be in contact with the hazard, the soil conditions, protection clearing times, fault current, transient current and current path. Because the voltages produced are a function of the earthing system as a network of local and interconnected earthing, it has little dependence on the resistance of the local earthing. Targets such as 1Ω are no longer relevant as they have little direct bearing on individual safety. However, a target impedance may be set in design to achieve the required voltage based targets.

In design and assessment the ALARP process, where risk is reduced to As Low As Reasonably Practicable, is used to establish compliance in conjunction with negligible risk compliance curves, such as provided in EG-0 [10], which are quantitatively established and assessed.

The Quantitative Risk Assessment (QRA) process establishes whether the risk posed is below a negligible risk threshold. In some cases the risk will not be negligible, in which case the risk will be reduced by application of the ALARP process or the risk is considered intolerable, at which time the project feasibility is questioned.

The ALARP process extends assessment to include consideration of all reasonable practical industry accepted measures including likelihood, consequence, knowledge, utility, suitability of controls and whether the costs of controls are grossly disproportionate to the risk

4.1.2. Personnel Safety

With regard to the safety of people, earthing systems should be designed such that they pose a negligible risk to the maximally exposed individual, as recommended by EG-0 .[10]. Earthing hazard compliance curves, usually expressed as negligible risk (touch/step) voltage time curves, are based on:

- Clearing time of faults;
- Exposure of people to locations exposed to hazards created by a fault;
- The physical circumstances of persons likely to be exposed to the hazards e.g. public or electrical worker; and
- The frequency of faults and the presence of potentially exposed individuals.

An earthing system design should take all of these circumstances into consideration. Should any of these circumstances change (particularly for the worse) then the earthing system performance will need to be reviewed. Assessment will need to be made of whether the earthing system remains at an acceptable or tolerable level of risk, or whether the risk posed by the new/changed/revised circumstances is such that redesign and additional works are required.

The applicable EG-0 earthing hazard compliance curves[2] for the Snowy Hydro Network, taken from Appendix E of EG-0, are summarised in Table 1 and Figure 2. Compliance with IEEE based curves, such as published in [3] & [9], is no longer appropriate as they are not constant probability curves. The appropriate curves or criteria should be based on the circumstances as outlined in EG-0 [10].

Table 1: Earthing Hazard Compliance Curves

EG-0 Curve	Application Description
TU	Contact with transmission asset in urban interface location
TDB	Contact with metalwork in a backyard affected by either transmission or distribution asset
TDMEN	Contact with MEN connected metalwork (around house) where MEN or soil is affected by either transmission or distribution assets.
MSPB	Backyard near major transmission installation with primary side fault.
TSI	Inside transmission substation, power stations, and switching stations

Notes:

- Most Snowy Hydro installations will need to comply with the TSI curve.
- For publicly accessible areas such as penstocks the TDB curve may be more relevant.

[2] Referred to as prospective touch voltage/clearing time curves in EG-0.

- Curve selection needs to based on the approach outlined in EG-0 [10].

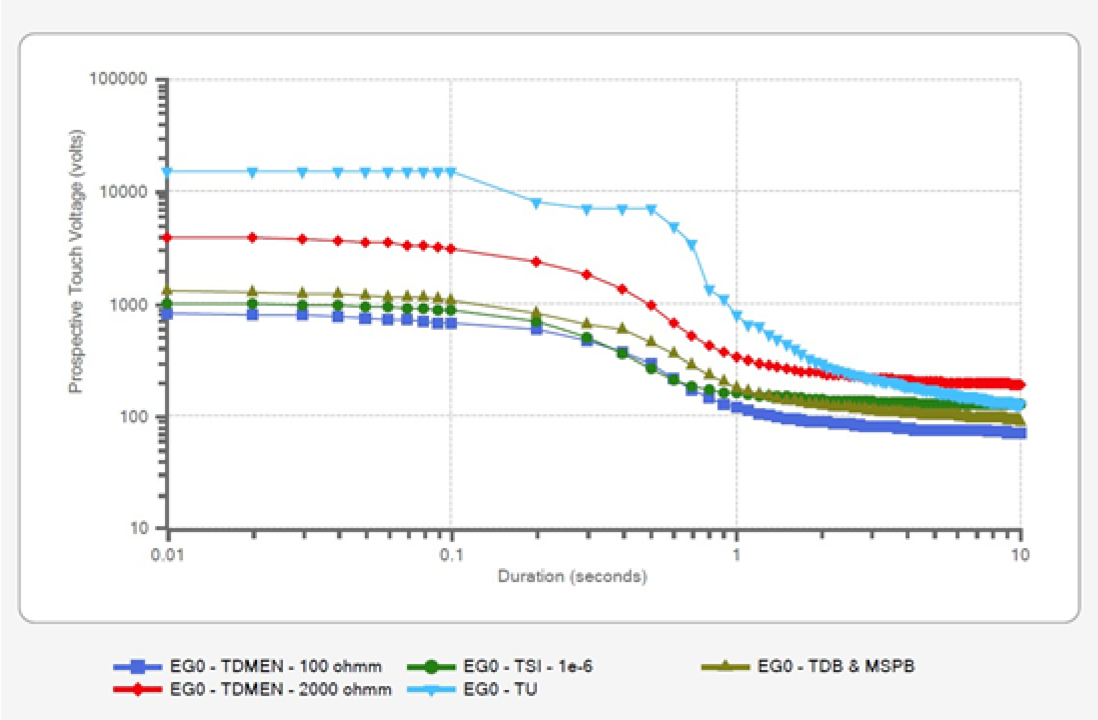

Table 2: EG-0 Earthing Hazard Compliance Curves - Transmission

Earthing hazard compliance curves for specific circumstances can be also be calculated using the ARGON[3] software tool which was published in support of EG-0 by the ENA. Compliance should include consideration for touch, step and transfer voltages to evaluate both personnel and public safety.

4.1.3. Protection of Equipment

To protect equipment the voltage levels imposed thereon need to be limited by safely providing a low impedance path for lightning discharges, switching surges, fault currents and other system disturbances. These disturbances may otherwise cause extensive damage to the main plant and ancillary equipment, such as communications cables. Equipment damage might include: insulation breakdown, thermal or mechanical damage, fires and electrically ignited explosions.

Under all reasonably foreseeable conditions the earthing system should provide for the expected operation without damage to any component. Equipment protection will typically include the following minimum functional requirements:

1. The earthing system, its components and bonding conductors shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on a single mechanical or protection failure.

2. The earthing system shall maintain its integrity for the expected installation lifetime with due allowance for corrosion and mechanical constraints. Where the earthing system will be subject to significant threats to its condition the design will need to consider supervision, maintenance and possible

[3] Or equivalent

replacement of the earthing system during the asset's lifetime.

3. The earthing system performance shall perform so as to avoid equipment damage resulting from excessive potential rise, potential differences within the earthing system and excessive currents flowing in auxiliary paths not intended for carrying a significant portion of the fault current.

4. The earthing system performance shall contribute to ensuring electromagnetic compatibility (EMC), in accordance with IEC/TR 61000-5-2 [11], among electrical and electronic apparatus.

4.1.4. Power System Operation

Under all reasonably foreseeable conditions the earthing system shall not, by action or inaction, negatively impact the operation of the power system other than where intended for the safety of people or the protection of equipment. Specific measures that support operational security include the following:

1. Maintaining a voltage reference for control, protection and communications systems, particularly to ensure the proper operation of protective devices such as protection relays and surge arresters.

2. Providing or assisting to provide electrical noise immunity for conductive and inductive hazards. Power-system over-voltages and fault current levels are influenced by the earthing system.

3. The design must be coordinated to achieve desired reliability levels. System outage rates are effectively reduced by the use of earthing systems which minimise phase to earth back flash-over and inductive interference, e.g. into protection pilot cables.

4. A continuous conductive (nominally metallic) earthing system provides a connection to earth for lightning, switching surges and 50Hz earth fault current. Therefore, every component of an earthing installation should be capable of carrying its expected proportion of the design maximum earth fault current. This current should flow through the component without causing hazardous voltages, interference to other systems, or damage until the fault is cleared.

4.2. Construction Design

To implement an earthing system it must be appropriately constructed. The service lifetime, and the ability of the physical earthing system to consistently achieve its expected performance and purpose, is dependent on the ongoing condition of the earthing system and its ability to respond to imposed conditions. Maintaining an acceptable level of ongoing physical condition is primarily dependent on the materials and installation practices used during the construction of the earthing system.

This section stipulates conductor and connection selection processes for earthing system construction to meet earthing system performance requirements.

The various layers of an earthing system, as illustrated in Figure 3, are used to perform various functions depending on the circumstances they will be expected to accommodate. These layers exist within different environments, specifically aboveground (facility), below ground (dissipative) and the transitional space between the two.

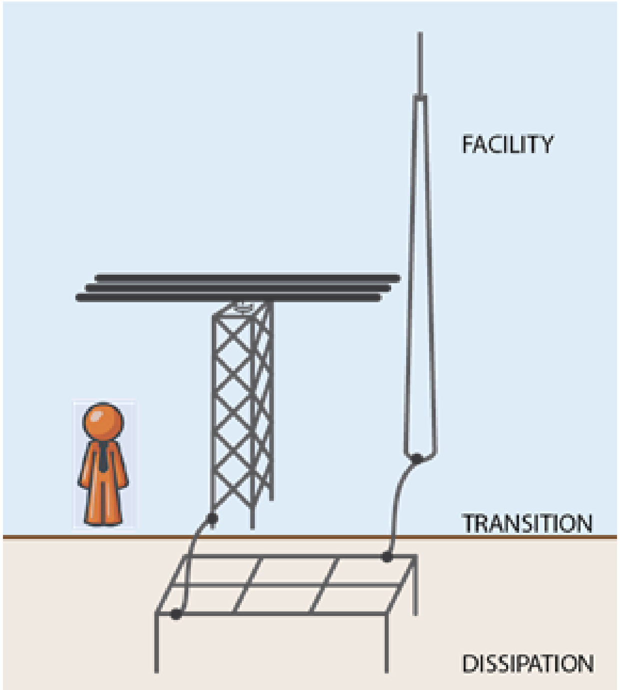

Figure 3: Earthing System Zones

Aboveground or Facility earthing provides connections between plants and the dissipative buried layer of the earthing system via the transitional layer in between. Whilst the purpose of the dissipative earthing components remains consistent, the purpose of facility changes with the equipment it services, as summarised in Table 3.

The below ground or dissipative layer of earthing is used to dissipate energy. During low frequency events, such as earth faults, it is usual that the buried elements dissipate the bulk of the voltage and power. In contrast whilst higher frequency events dissipate the bulk of the energy in the buried elements, the greatest voltage gradients may appear in the facility conductors.

Corrosion is the outstanding issue when selecting materials to construct an earthing system including conductors, connectors and fasteners. Threats from corrosion come from the materials themselves, through the action of dissimilar metals, and from the surrounding environments, in particular in the presence of water and oxygen. The below-ground/buried environment introduces the complexity of electrolytic (galvanic) corrosion. The aboveground/open-air environment introduces atmospheric corrosion due to the presence of water and oxygen. Conductors in the transitional space between the open-air and buried environments are subject to all the threats found in the other two environments.

Table 3: Functions of Facility Earthing

	Low Current	**High Current**
Low Frequency	Balanced power system operating condition	Earth Fault
High Frequency	Communications or Instrumentation	Transients/Switching

To select earthing conductors appropriate specification of the material, electrical and mechanical ratings, and the redundancy of connections is necessary. It is also necessary to consider the purpose of the conductor, nominally for power, transient or instrumentation earthing.

As a general rule, the fewer the number of metals used as earthing conductors in the grid the simpler the corrosion problem. Intermixing of materials should be avoided.

4.2.1. Installation

How earthing is installed has a bearing on its performance and on what materials are chosen for its construction. Snowy Hydro typically has both direct buried and embedded dissipating earths.

4.2.1.1. Dissipative Earthing - Direct Buried

Direct buried dissipative earthing is normally installed either horizontally or vertically. Horizontal buried conductors should be buried at a depth of 0.5 m below final ground level. The horizontal mesh conductors are placed according to a number of requirements, including controlling touch and step voltages and the provision of connections to facility earthing.

Vertical earthing or earth electrodes are often installed where the soil resistivity is conducive to reducing or stabilising the grid impedance; reducing touch and step voltages and the dissipation of transient energy. The depth of electrodes nominally depends on the depth of underlying lower resistivity soil layers.

Wherever possible dissipative earthing should be built using copper conductors. Where transient conditions are likely preference should be given to strap conductors due to its lower self inductance, particularly installations with GIS switchgear or exposed tall structures and small earthing footprints, such as communications towers.

Backfill material for horizontal conductors should be fine and of a resistivity no greater than the natural soil. In addition, backfill material for vertical conductors should be conducive to filling the long narrow void created by drilling whilst not subject to shrinkage during low rainfall periods.

4.2.1.2. Dissipative Earthing - Embedded

Embedded earthing is the term given to connection of the earthing system to reinforcing bar or structural steel within concrete that is in contact with the ground. Properly designed and prepared concrete slabs can perform well as a local earth grid to dissipate fault current and create equipotential areas. Embedded earthing can be used in conjunction with vertical and horizontal electrodes or in isolation.

Design of embedded earthing must ensure the temperature rise of concrete rebar does not increase risk of concrete damage due to steel expansion or creation of gasses (e.g. steam) internal to the concrete. Nominally a limit of 90oC is used. The selected reinforcement bars should be rated and welded to the current level expected in the embedded component of the earthing system.

Depth of concrete cover to steel rebar must be > 25mm in normal environments and up to 75mm in aggressive environments - refer to AS3600 for specific guidance. Inadequate cover can lead to cracking, water ingress and corrosion. Higher concrete cover may be specified by civil or structural designs.

The use of under slab tanking or plastic membranes can impact the performance of embedded earthing used as an earth grid. For slabs of large areas these layers will not usually significantly impact performance. For small slabs such as pedestal or equipment footings, there can be substantial impact, and design guidance must be sought if embedded earthing is specified for such slabs.

Where the reinforcing of a concrete slab is used to provide an equipotential plane to mitigate step and touch voltages but not used for fault current dissipation or involved in the passage fault current, the reinforcing bars are not required to be welded.

4.2.1.3. Transitional Earthing - Direct Buried

Conductors transitioning between the buried underground to the aboveground environment should be protected from contact with the soil, due to the elevated risk of corrosion in this zone due to the near permanent presence of oxygen and water. This is commonly done using PVC covered conductors from 500mm below grade to a their termination on above ground equipment.

Connections should also be arranged to allow free draining of moisture to prevent trapping electrolyte. Example includes PVC covered equipment tail to buried grid, with tinned copper lugs fastened to galvanised steel structures arranged on vertical (per Figure 4a), not horizontal (per Figure 4b), steel faces.

(a) Vertical Arrangement (b) Horizontal Arrangement

Figure 4: Steel Structure Earthing Termination Arrangements

4.2.1.4. Transitional Earthing - Embedded

There are a number of suitable methods of making transitional earth connections to re-bar within concrete including:

- Stranded copper or strap penetrating concrete and connecting directly to rebar through clamping, cadweld or brazing.
- Earth bosses with a tail that connected to rebar, and a face that is flush with concrete finish surface. Care must be taken such that concrete or cement does not contaminate the thread or cover the boss.
- Earthing tags welded to the re-bar and protruding from the concrete face.
- Hold down bolts of vertical structural steel members that are made electrically continuous with rebar. This is preferred for columns between floors of multi storey buildings.

Where embedded earthing is relied upon for achieving earth continuity between different parts of a slab or levels of a structure, provision must be made for connections between concrete parts to achieve continuity at slab joints. This can be done by either:

- Connections between two rebar earthing points external to the slab.
- Flexible conductor installed from within one slab to another to connect across rebar discontinuities.

4.2.1.5. Facility Earthing

Instrumentation or Low Power Plant[4]

Equipotential bonding for instrumentation or low power plant is achieved by bonding all plant to the same earth bar with a single bond. This is known as single point bonding, as outlined in IEEE Std 1050 [1], and as shown in Figure 5.

[4] Can be protected by an RCD

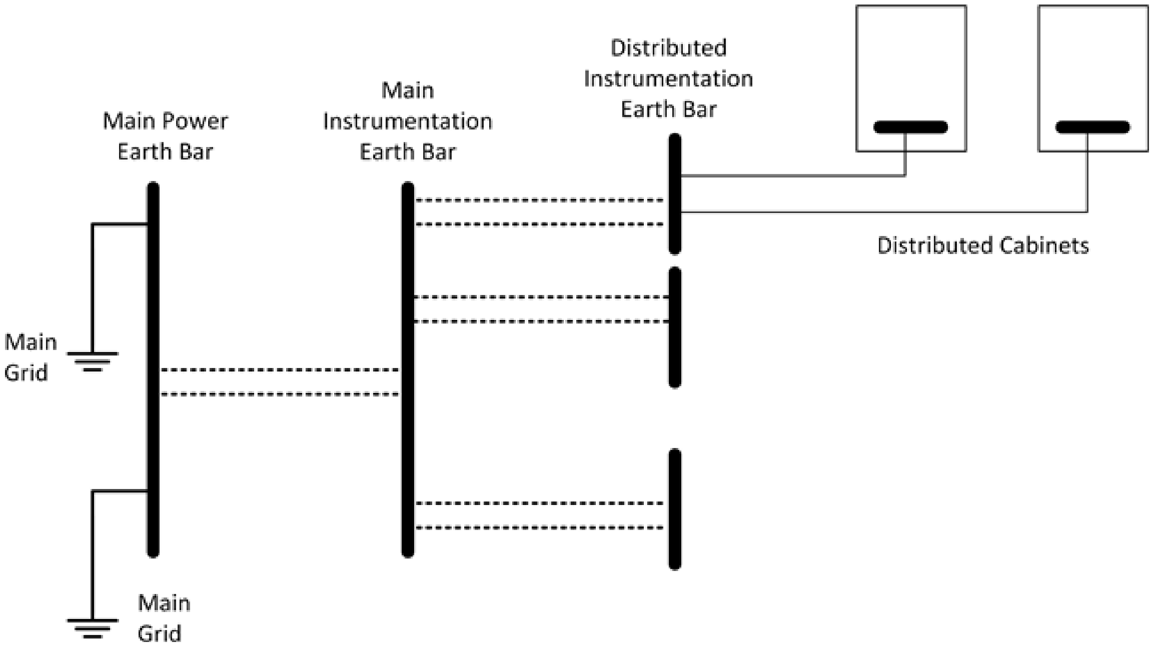

Figure 5: Instrumentation Single Point Bonding Scheme

Some notable features of the single point bonding scheme as described in Figure 5 include:

- Double bonds - Parallel double bonds can be used between earth bars for the purposes of redundancy. The conductors will need to be run along the same path and of the same conductor to minimise impedance differences.
- Single bonds - To be used in secured areas where redundancy is not an issue.
- If signal/instrumentation connections are common between cabinets the cabinets should be earthed to the same distributed instrumentation earth bar.

Transients

In general, the path of earthing conductors should be as short as practicable to minimise the impacts of transients.

4.2.2. Conductors

There are a number of competing requirements to consider when determining the conductor type and sizing. Once all the following requirements are considered the most significant requirement becomes the determining factor.

4.2.2.1. Material

The earth conductors and connections should be of sufficient conductivity to minimise voltage drop across the installation. This requirement is usually fulfilled when conductors meet other electrical and mechanical constraints.

Dissipative Earthing:

The corrosion of buried conductors occurs due to the electrochemical reaction between dissimilar metals, enhanced by the presence of an electrolyte such as soil, as discussed in Appendix B. The choice of main grid earthing materials to minimise corrosive activity has resulted in mostly copper conductors (wire, strap, or copper covered steel) being used. Stainless steel should be used with caution as it will corrode in soils where there is no oxygen to allow formation of the protective passive layer. Stainless steel is not recommended for electrodes unless the soil type is known. Aluminium conductors are not acceptable for below ground use due to the formation of a non-conductive passivation coating[5]. Galvanised steel can be used where required for material coordination to minimise corrosion and where the dissipative system will not be subject to significant transient currents.

Where copper covered earth rods are used the preference is to use copper coating which remains adhered to the steel core, such as electroplated rods. The alternative, copper-clad rods, allow moisture into the interface between the copper and the steel, which causes eventual failure of the rod. The clad rods have also been noted to delaminate when bent. Copper or stainless steel electrodes may be considered as alternatives. In many applications structural foundation reinforcing can be used in place of buried conductors as the primary earth grid.

Where embedded earthing is used, consider the use of the steel reinforcing. Most civil structures have sufficient reinforcing to make the addition of other conductors superfluous.

Transitional Earthing

To minimise corrosion transitional conductors are chosen to match the material used in the dissipative layer, which is nominally copper. Changes in material are only made aboveground at the connection to the facility earthing. Transitional conductors should be PVC insulated to minimise corrosion by restricting exposure to water and oxygen.

Facility Earthing

Stranded copper conductor or strap may be used in covered cable ducts or as above ground connecting leads to framework and apparatus.

Aluminium may only be used with the approval of Cooma Engineering.

Material preparation such as tinning shall be used to reduce galvanic potentials between different metals in contact. Where above ground conductors are exposed to running water it may be necessary to paint the conductors to minimise corrosion. Oil based/enamel paint is preferable in this circumstance due to the exposure to water.

Embedded earthing may be used as facility earthing conductors provided the steel conductors and connections within the reinforcing have been identified and rated. Connections between facility earthing and the embedded earthing should be made outside the concrete so steel is the only metal internal to the concrete.

4.2.2.2. Conductor Sizing

Once the material of a conductor is established the minimum required cross sectional area can be determined.

Electrical Rating - Power

Due to the energy which can be injected into an earthing system by a power system, nominally during fault conditions, power systems can place the greatest requirements on the facility earthing system. The electrical rating of earth conductors for power system faults is determined by: fault current magnitude and duration, material conductivity, ambient and permissible final temperature, and thermal breakdown limits.

<u>Fault Current Magnitude</u>

The conductor should be of sufficient current carrying capacity to withstand the maximum currents expected under any operational condition, including: Solidly earthed fault conditions; Impedance earthed conditions; and

[5] Nominally Aluminium Oxide Al_2O_3

Load conditions. For design purposes the sub-transient current magnitude is considered.

- Solidly Earthed Fault Conditions

  Most of Snowy Hydro's substations have solidly earthed neutrals or star points. In establishing the maximum current for rating earth conductors the projected increases in fault levels across the substation lifetime need to be taken into account. If a fault level increase is associated with the installation of new transmission line(s), consideration should be made of the associated earthing, such as OHEWs or cable screens. These additional earthing elements will carry a proportion of the fault current, reducing the expected earth grid current increase, depending on the fault scenario.

- Impedance Earthed Fault Conditions

  For plant in the Snowy Hydro network with the neutral earthed via a high impedance, such as the main generators and some standby diesel generators, there are few difficulties in mastering earthing problems if the only consideration is single phase to earth faults. When a poly-phase fault occurs in a network earthed through a high impedance, depending on the actual network impedances, short-circuit currents of the same order of magnitude as those for a single-phase earth-fault in a solidly-earthed network can occur.

  A polyphase earth fault means that two or three different phases in the same system have simultaneous earth faults. Such faults within the substation or generator yard will cause the greatest fault level. Therefore, conductor size is chosen to meet this maximum expected fault current flowing until cleared by the protection scheme. Single phase equipment will need to be rated for the polyphase fault level if this circumstance is likely.

- Load Conditions

  In some situations circulating currents in earth conductors resulting from induced voltages due to load current can result in excessive temperature rise. In these situations, the spatial and geometric arrangement of earthing conductors, as well as consideration of earthing connection points can reduce induced emf and circulating currents such that they do not dictate conductor sizing requirements.

<u>Current Splitting</u>

- Transitional Earthing

  Bonds (or risers/tails) between equipment and the earth system should be sized in consideration of redundancy level, see Section 4.2.2.3, and current distribution between available conductors. It may be assumed that the fault current will travel in two directions at the point where the bond (tail) connects to the main earth system. Rather than assuming equal current split, a value of 70/30 is usually used (i.e. rate the bond for 70% of the fault current). Note that single pole bonds, such as exist on single pole earth switch contacts, must be rated for the maximum of either the full three phase earth fault or the single phase earth fault.

- Dissipative Earthing

  If the earth fault current, upon entering the buried section of the earth grid, travels in two directions, it is assumed that the current divides on a 70/30 basis. Thus, such buried conductors do not require full fault rating, unless the portion of the grid to which HV equipment connects is a radial conductor not forming part of a closed mesh (for example, buried earthing around reactive[6] plant).

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[6] Particularly air inductors.

The number of available conductors and clearing time must consider the most onerous of the permissible number of failures (redundancy level) of conductor and/or protection.

Fault Duration

The malfunction of protection relays or other equipment will cause the fault current to persist until the backup protection operates. As the failure of protection, control or operating equipment may remain unnoticed until requested to operate, backup clearing times shall be used for earth conductor sizing.

The fault current duration for conductor rating is often specified to correspond to the total clearing time defined as the greater of either the:

- Clearing time assuming the failure of one primary protection system element or associated operational equipment (i.e. circuit breaker, tripping coil).
- Total clearing time of the primary protection system and subsequent reclosers.
- ‘Stepped’ Fault Currents - In instances where the fault current magnitude changes, as protection schemes isolate the faulted section, the individual magnitudes and times are summated according to EG-1 [9].

Final Temperature

The earth conductors and connections must be sized such that maximum permissible final temperature is not exceeded under nominated fault currents and durations. Permissible final temperatures will usually be determined by conductor material, conductor insulation or connection method [9].

Minimum Cross Section Calculation

Minimum conductor sizes for a range of bare conductor types are given in Table 4 and Figure 6. These sizes are based on an ambient temperature (T_a) of 40ºC and a maximum allowable temperature (T_m) of 250ºC. Figure 7 shows the minimum conductor sizes for a range of PVC insulated conductor types (T_a = 40ºC, T_m = 160ºC). These conductor ratings are calculated using Onderdonk’s equation [9, 3].

Table 4: Minimum Conductor Size (mm^2/kA)

Fault Clearing Time t_c(s)	**Copper**		**Aluminium Cable**	**Zinc Coated Steel**	**Stainless Steel (No. 304)**
	(100%)	**(97%)**			
0.1	1.87	1.89	2.79	5.79	9.92
0.2	2.64	2.67	3.95	8.18	14.03
0.5	4.17	4.22	6.24	12.94	22.18
0.75	5.11	5.16	7.65	15.84	27.16
1.0	5.90	5.96	8.83	18.29	31.36
1.5	7.23	7.30	10.82	22.40	38.41
2.0	8.34	8.43	12.49	25.87	44.36
3.0	10.22	10.33	15.30	31.68	54.32

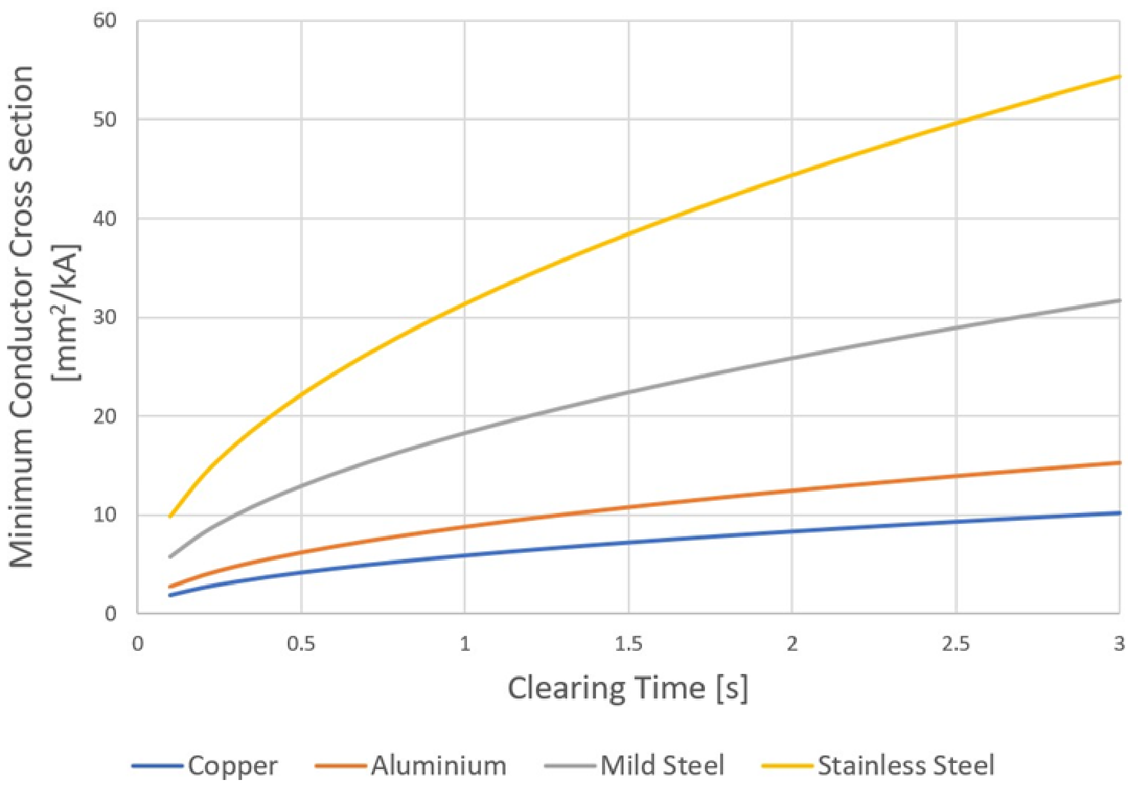

Figure 6: Bare Conductor Minimum Cross Sectional Area (T_a = 40ºC, T_m = 250ºC)

Guidelines for maximum conductor temperatures are usually limited by jointing/connection methods and insulation as follows:

- Embedded Earthing $T_m \leq$ 90ºC
- Soft soldered joints: $T_m \leq$ 240ºC depending on solder filler
- PVC insulation $T_m \leq$ 160ºC
- Brazed joints: $T_m \leq$ 450ºC
- Compression connections compliant with [2] $T_m \leq$ 250ºC [3].

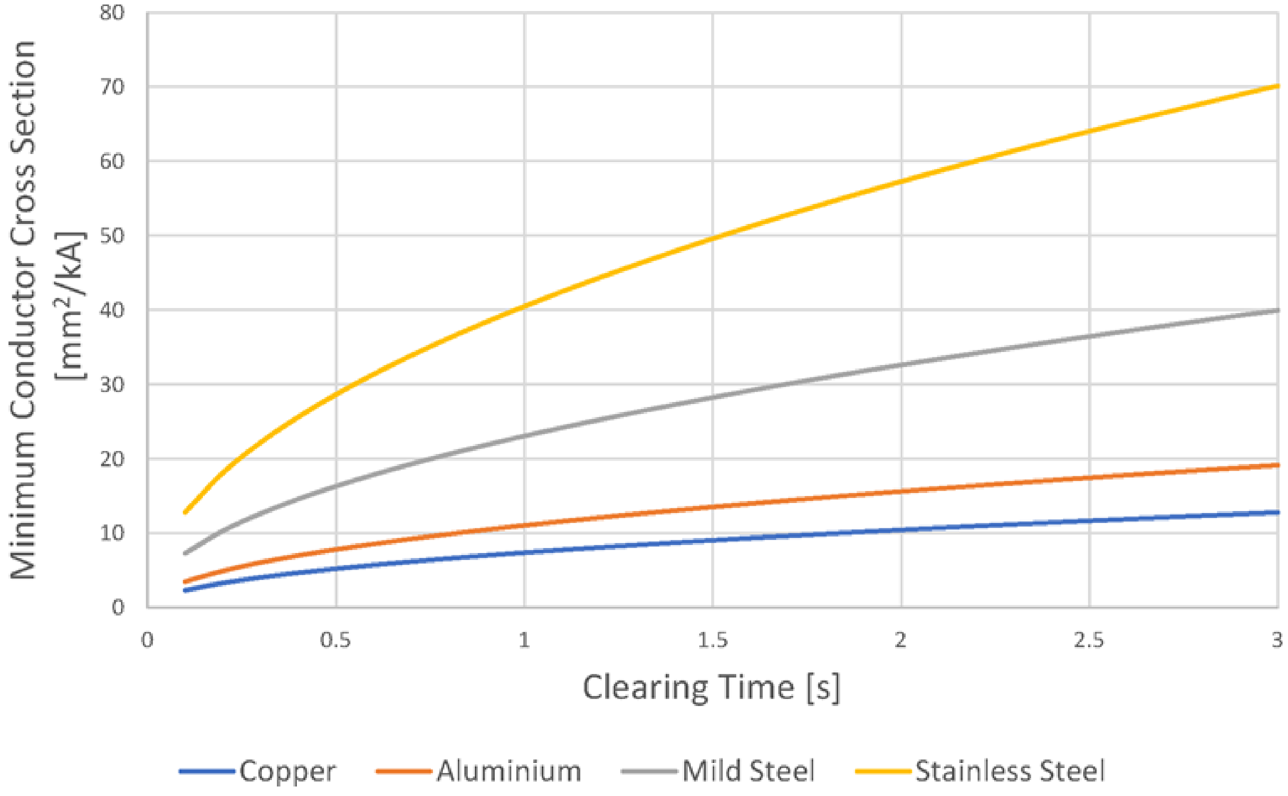

Figure 7: PVC Insulated Conductor Minimum Cross Sectional Area (T_a = 40°C, T_m = 160°C)

- HDC where mechanical strength needs to be retained Tm ≤ 250oC [3]
- Fully rated (ie. Fusing Temperature): Tm (copper) ≤ 1050o [3]

Transients

Faults of a transient or high frequency nature are associated with lightning spires, surge arresters, and GIS installations.

- Lightning Spires

  Lightning spire downleads, and overhead shield wires acting as lightning protection over substations, will usually only conduct lightning surge currents. As these are of very short duration the following minimum areas are typically used [5]:

  - 35mm^2 copper
  - 50mm^2 steel
  - 107mm^2 aluminium

  Care should be taken to ensure that power frequency fault currents may not flow in such conductors if these minimum areas are chosen. Typically a minimum of 60mm2 copper is specified where conductors are susceptible to mechanical damage.

- Surge Arresters

  Although the minimum conductor areas suggested above apply to the high frequency surge current, the power frequency ‘follow-through’ current is of full fault rating, unless the arrester has special current limiting characteristics. If fault current flows through an arrester it can fail, generally open circuit, if they are not rated for power frequency fault energy dissipation. To ensure protection operation arrester earth conductors are usually fully fault rated.

Mechanical Rating

Where earth conductors are not mechanically protected and are susceptible to damage the mechanical strength requirement may determine the minimum conductor size. A conductor size, with the mechanical strength and rigidity to minimise the possibility of mechanical damage that is commonly used for an unprotected conductor is $60mm^2$ copper.

- Additional 'Safety' Factor - In most cases an additional 'safety' factor is applied by specifying the next largest standard conductor size. This often occurs for economical reasons where a standard size is used to minimise multiple stock holdings of cable, joints and tools.

4.2.2.3. Redundancy - Power

All connecting conductors which will carry earth fault current are to be of adequate mechanical strength and current carrying capacity. If a metallic structure, e.g. transformer tank, steel or aluminium support structure, forms part of the conductive path for fault current, attention should be given to joints or transition points, e.g. provision of bonding conductors.

The connection of metalwork associated with probable fault current sources, e.g. arresters, transformer tanks, earthing switches, is often made with additional security by using a minimum of N-1 redundancy.

The N-1 specification will achieve required integrity for a single contingent failure. This can be either:

- One conductor failure and current flow for the primary protection clearing time, or
- Primary protection failure with all earthing intact. All conductors must share (in a 70/30 split) the full fault current for backup clearing time.

Where multiple or redundant equipment connections are used care should be taken to ensure:

- Connections are placed on different sides of the equipment and foundation to avoid simultaneous damage to both conductors;
- The connection to the earth grid conductor is such that current can flow in at least two directions, so that the breaking of one earth grid conductor does not render the bonding ineffective.

Example 1: A new panel to be installed within a power station should be connected to the station earth by two copper conductors with a minimum cross sectional area of 60mm2. The conductors should preferably be connected near to the two ends of the earth bar. The two connections should connect to the station earth grid at different segments of that system to maximise current distribution.

4.2.3. Connectors and Connections

Connections or joints must also meet the criteria for conductivity, thermal capacity, mechanical robustness and long term reliability [2]. The connections are usually the most vulnerable point in the earthing system, and must continue to withstand the electrical/thermal and mechanical stresses even in a corrosive environment.

International standards exist that specify functional performance type test requirements for earthing connectors, one of which is IEEE 837 [2]. It is acknowledged that some of the conditions tested for in performance testing standards do not occur in Australia (e.g. below ground freeze-thaw cycles). Connector selection should be made on consideration of the following criteria:

- Demonstrated performance in type test conditions relevant to the operating conditions, environment or installation location.
- The connectors must adequately achieve the thermal and mechanical requirements of the design.
- The connectors must be able to be reliably installed in the prevailing site conditions to the quality specified by the manufacturer and earthing designer. This includes consideration of contamination, water, access to conductors and available tooling.

Connections to equipment should be made in such a way as to avoid the use of intermediate materials in the fault current path that can de-rate the connection. Examples of unwanted materials include nuts or washers between an earth lug and the equipment to be earthed.

Within the dissipative layer of the earthing system there shall be no buried threaded connections. Preference is given to the use of two compression lugs per joint.

The use of compression lugs is the preferred method of jointing within facility earthing. Lugs should be tinned when connecting between dissimilar metals.

4.2.4. Fasteners

As fasteners (nuts, bolts and washers) have a smaller cross sectional area than the conductors to which they are applied, corrosion can be minimised by following the guidance of the noble metals chart [8]. Fasteners and connectors/lugs should have a mating face (not including the method of attachment i.e. the bolt) no less than the CSA of the conductor.

Typically fasteners made from stainless steel, bronze and brass are acceptable. Mild steel is less preferable due to its reactivity with copper.

Fasteners shall be selected and installed to ensure they do not loosen in-service by applying correct torques for the material.

4.3. Works Around In-service Earthing

The precautions required when working on earthing systems depend on the context of that earthing system relative to other earthing and the power system. To that end circumstances are considered in terms of working within, between and remote from earthing systems. These circumstances are outlined in the following sections. The general process is described in Figure 8. How to apply these ideas are outlined in Section 4.3.4 which discusses typical circumstances found on and around Snowy Hydro sites. Should work be entered into where it is not clear what work practices or precautions should be used contact Cooma Engineering.

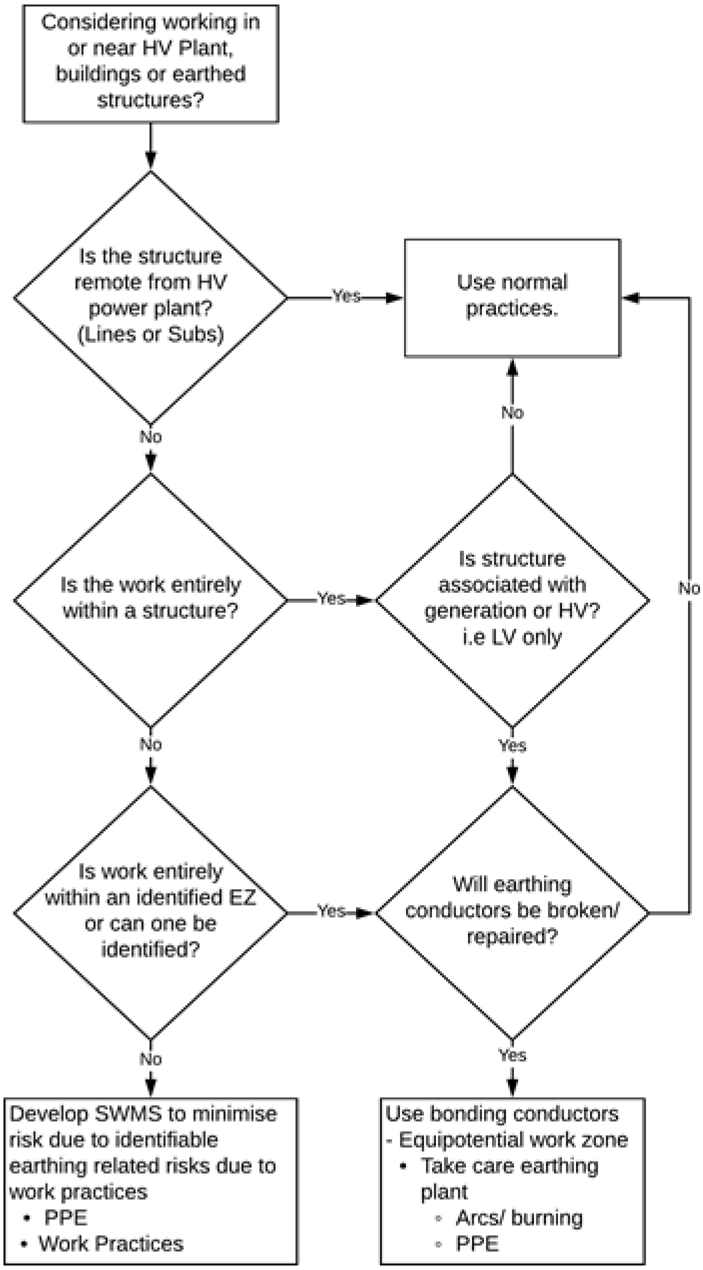

Figure 8: Work Practices Flowchart

4.3.1. Within

Earthing systems for installations such as power stations allow work within those installations to be conducted with negligible threat from earthing related hazards, except in the following circumstances due to potential exposure to harmful voltages:

- Work is conducted within the earthing system of the power station with access to remote earthing as provided through metallic services.
  - Example 1 - Working on remotely earthed pilots within the power station.
  - Example 2 – Earthing of out-of-service transmission lines – phase conductors.

While the provision of an equipotential area nominally allows work to be conducted safely within the installation, the following circumstances require special care and in some circumstances work permits:

- Breaking or repairing earthing conductors or bonds; and
- Terminating or working with conductive services entering the area.

It is important to do a risk assessment before any work commences to ensure no persons are exposed to harmful voltages during the work.

Coordination of all services entering a building, installation or area serviced by an equipotential plane must be coordinated with the earthing system design.

Equipotential planes are provided by dedicated earthing conductors, structural reinforcing and other structural conductive elements which are appropriately rated for that purpose.

4.3.2. Between

Works that involve work between earthing system may require specific strategies to be implemented to minimise the earthing related risk. This is particularly true when conductive materials are involved. Strategies include: Insulation, Isolation and Bonding.

Examples of work between earthing systems include:

- Installing electrical services between buildings where one of the buildings contains HV plant.
- From the example case when work is conducted between the power station and another earthing system, which is not bonded to the power station earthing system, such as works near the substation requiring the installation of metallic fencing.

4.3.3. Remote

Works located remote from any electrical asset will not be subject to any risk from power system earthing related risk unless connected by metallic services such as cables or pipes which may act as sources of transfer voltage. The definition of remote is site dependent but for most HV sites of 15m from the external perimeter of the earth grid is adequate.

Lightning risks may require consideration depending on the nature of the work e.g. maintenance work on above ground pipeline or out of service power lines with significant separation from any other power line.

4.3.4. Case Studies

Snowy Hydro sites can be quite extensive and involve multiple earthing systems, such as exemplified in Figure 9. Deciding what approach to take to earthing depends on where in site the work is to be conducted. Consider the examples provided in this section.

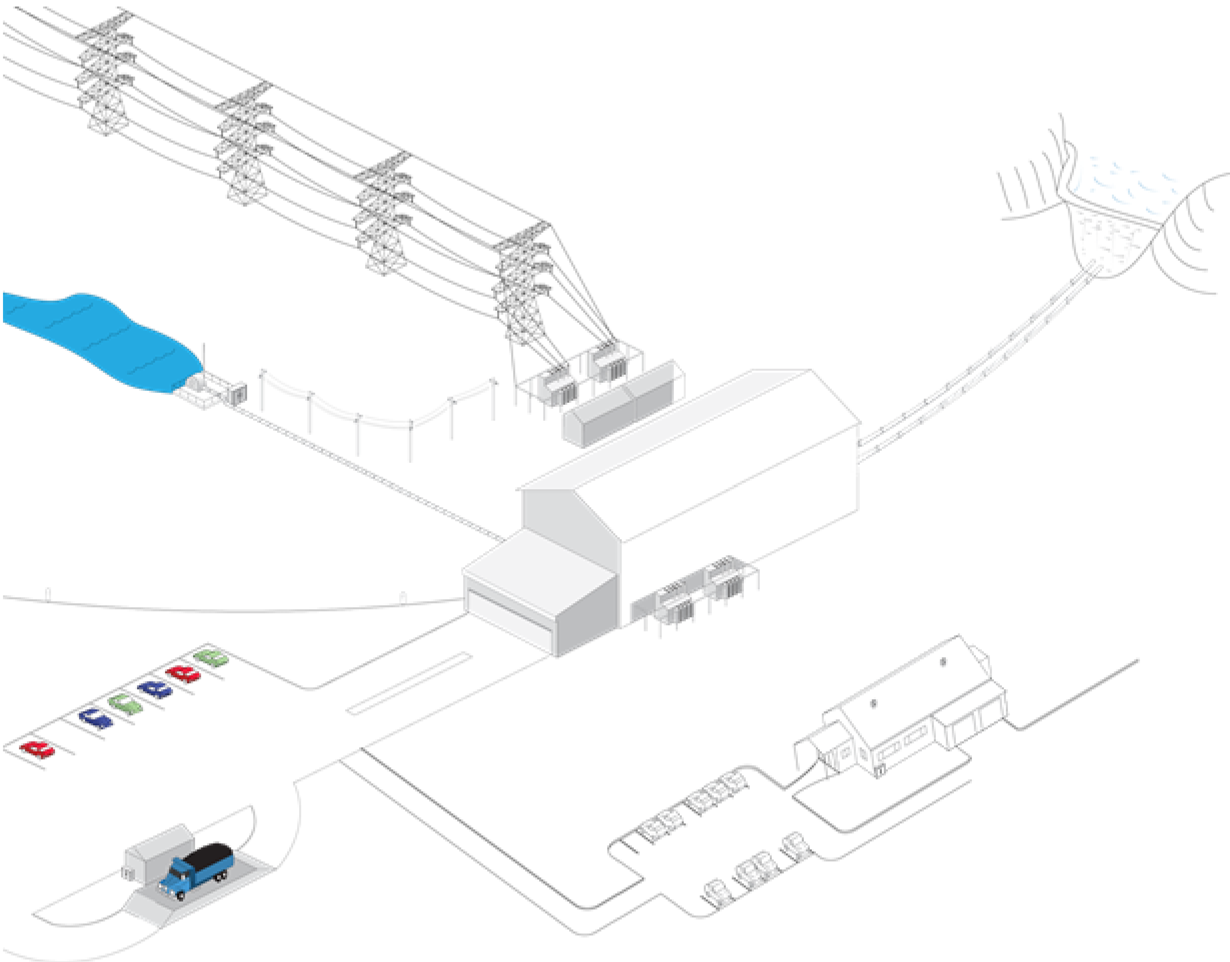

Figure 9: Example Snowy Hydro Site

Within the example scenario, and at any Snowy Hydro site, there will be earthing within all structures providing or using electrical power. In the example provided in Figure 9 this includes the HV substations, power stations, transmission lines, pump station office buildings and the gatehouse. What is less obvious is that other structural elements will contribute to the earthing system. In Figure 9 the water pipelines are an example of this.

Hazards are created when faults occur on any of the power systems associated with the site. As power systems contained entirely on site can be constructed to direct current flow during faults the hazards produced are not as significant as systems which introduce energy from remote locations. Within the Snowy Hydro network this is usually the 220kV or 330kV network. The presence, therefore, of 330kV or other transmission assets at a site implies the likelihood of potentially significant hazard levels.

4.3.4.1. Within the Office Building

Works contained entirely to the office building will only be required to comply with the requirements of AS3000 and the Snowy LV Earthing Standard SHL-ELE-156 Annexure K.

Should the office provide, or be provided with, metallic services from other buildings or structures in the area, such as the power station, consideration of transfer hazards must be made when work involves these services. Services that may require these considerations in Risk Assessment and work method statements include: HV & LV cabling, metallic pilot cables, telecommunication lines and water piping.

4.3.4.2. Within the Power Station

Working on the earthing within the Power Station will not be as simple as the working other areas such as within the office building. Whilst the design should keep the hazardous step and touch voltages at negligible risk level within the power station through equipotential surfaces, being directly associated with sustained large currents will probably mean large circulating currents in the power station earthing system due to magnetic induction.

In addition to the normal facility earthing functions earthing within a power station may also have to cope with the circulating currents produced in the earthing conductors when generating due to the high current levels in the generator buses. As a consequence:

- Earthing should be arranged to minimise the magnitude of these circulating currents, whilst rated for the maximum sustainable circulating current;
- Breaking of conductors may require live line processes when performed whilst generators are running; and
- Earthing of other equipment may produce sparking/arcing, particularly when multiply earthing a piece of equipment as it will form another path within the earthing system for circulating currents to flow.

In the risk assessment before work commences, hazards as a result of potential circulating currents shall be considered.

4.3.4.3. Pumping and Transfer Stations

Work on the pumping or transfer stations may appear to be remote their earthing can be impacted as follows:

- The power at the transfer station could be supplied from the power station making it subject to the hazards linked to the power station. Whilst works entirely within the transfer station can be considered ‘within’ an earthing system, work to the outside of the station involving metallic services should be considered ‘Between’. Such work scenarios will need to consider transfer hazards. An example of such work would be working outside the Transfer Station using earthed electrical appliances powered by an extension lead.

- The power at the pumping station could be supplied by a HV three phase without an earthed connection to the Power Station. However, the metal pipeline between the two locations may result in hazards on the transmission network and the power station being transferred to the pumping station.

4.4. Construction Practices

This section provides general guidelines when working on earthing systems and their components.

4.4.1. Greenfield Construction

A greenfield site in terms of earthing is a site which has no conductive systems which connect that site to sources of electrical power. At such sites earthing hazards rarely exist. Examples of a greenfield site are civil construction sites with LV power supplied by the local distribution network or a generator.

However, as metallic services are connected to the site as part of its construction the site transitions from a Greenfield site to a Brownfield site, particularly HV services. Milestones associated with this transition include the termination of the first HV power line.

4.4.2. Construction around in-service Earthing (Brownfield)

A Brownfield site is any site with an in-service earthing system or connections thereto. Examples include:

- Work on a substation or power station,

- Work on a pipeline which terminates at a power station.

Brownfield sites need a staged plan for building the interconnecting earthing into (existing) in-service earthing.

4.4.2.1. Connections to existing Conductors

Connections to existing earth grid conductors should follow the following guidelines:

- Wherever possible use like for conductors.
- Below grade connections should use double C-crimps wherever possible. If C-crimps cannot be used, particularly when connected to bar, exothermic welds (cadweld) or brazing[7] should be used.
- Above ground connections should use tinned copper crimp hex lugs to terminate conductors wherever possible. Fasteners should be made of high quality stainless steel.

4.4.2.2. Working with In-service Earthing

Exposed buried earthing conductors must always be regarded as live in the first instance. Earthing conductors may be carrying current even under normal operating conditions, or where the connected asset is de-energised.

Workers must:

- Seek advice if you are unsure of the hazards related to earthing systems.
- Avoid contact with exposed/unrestrained bare buried earth grid conductors unless appropriate controls and authorisations are in place.
- Cordon off the area around the broken or exposed conductor to prevent contact by personnel and public.
- Remove the equipment that damages the earth conductor only if safe to do so. For example, if an excavator has damaged an earth conductor and remains in contact with the conductor, consideration must be given to hazards at the machine. If a machine operator is required to board or alight the machine, an insulating mat and LV rated insulating gloves must be used.
- Utilise appropriate safety equipment including bonding leads, equipotential mats or isolating mats when working on exposed earthing conductors.

4.4.2.3. Broken Earths

Workers must not intentionally break an earth grid conductor without specific authorisation. Care must be taken to avoid unintentional breakage of in-service earth conductors. Workers must not disconnect or break an earthing system conductor or cable screen bond without specific authorisation and risk assessment.

If an earth conductor is broken or identified broken while work is being undertaken:

- Stop work activity
- Report the incident immediately to supervisor
- Treat the earth conductor as live, make the area safe and maintain clearances[8] from the earth and connected equipment. Treat equipment associated with the broken earth as if it live.
- Under no circumstances attempt a repair until the situation is assessed.

4.4.2.4. Construction Hold Points

As much of an earthing system is buried in either soil or concrete it is critical in construction to implement hard hold points in the construction programme. Continuity tests need to verify that connections and conductors to be buried meet the standards required by the design. Experience indicates that regular inspections prior to hold points minimise the time impact on the programme.

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[7] Brazing may reduce the maximum operating temperature.
[8] Minimum clearances will depend on the largest system voltage associated with the installation.

4.4.3. Neutral Conductors

Neutral conductors are the most important connection of an earthing system. It is via this connection that fault current returns to the supply point to ensure protection operation and continued normal supply conditions.

- Additional redundancy is often specified for neutral conductors and care must be taken to ensure compliance with design.
- Neutral conductors are often equipped with double holed lugs. Where installed both holes in the lug must be utilised.
- Neutral conductor fasteners must be marked after being tightened to specified torque to indicate completion.

4.4.4. Use of Civil Structures as Earthing Elements

It is commonplace within the Snowy scheme to use civil structures and elements of the earthing system. Examples include concrete reinforced slabs, pipelines and penstocks. The use of civil structures as earthing elements requires some assessment of those elements ability to conduct current in the worst case scenario.

Connecting reinforcement slabs within HV installation is advisable to ensure equipotential bonding and that there are sufficient dedicated conductive paths to handle the level of current that may be present in that location. In some instances it may be necessary to install additional copper conductors to supplement the steel conductive paths.

4.5. Testing

Earthing system testing is the process undertaken to verify the state and performance of an earthing system at some designated stage of its service lifetime.

4.5.1. Purpose

Testing is essential as the validation step for the design, installation and maintenance of earthing systems. In most cases tests will measure the performance outputs of the earthing system in terms of resultant voltages and current distributions rather than solely earth resistance or impedance. Testing is nominally undertaken for one of the following purposes:

- Routine - Conducted over the lifetime of the asset to ensure the ongoing condition and state of the asset.
- Commissioning - Used to verify the design.
- Pre-design - Used to gather information about existing earthing systems at a site.
- Specific - Used to assess specific hazards to conditions e.g. LFI assessment.

The testing should consider the key performance criteria identified in the hazard identification and treatment analysis phases. Measurements are also affected by mechanisms such as interference, non-linearity errors and physical obstacles.

Earthing system testing normally consists of the following six core activities. In some instances, not all activities are required.

- Visual inspection.
- Continuity testing.
- Earth resistivity testing.

- Earth potential rise (EPR) measurement.
- Current distribution measurement.
- Transfer, touch and step voltage testing.

It is not always possible to foresee all hazard mechanisms at the design stage. Some hazards will only become evident at the testing stage. Consequently, testing should be used to identify the need for any secondary mitigation and any additional requirements for telecommunication coordination, pipeline interference coordination, other metallic infrastructure coordination or mitigation.

4.5.2. Assessment Tests

An earthing system is assessed for its physical condition and its electrical performance.

4.5.2.1. Physical Inspection

Physical inspection is the verification of the appropriate condition of some or all of the following earthing system components:

Design Layout

- Grid conductors should be installed in compliance with the design drawings and standard construction practices.
- Design layout drawings should be changed to reflect any ‘as-built’ variations.

Earth Connections

- Inspection of earth connections should be made to ensure that all joints and connections are sound and secure. This check is best undertaken during construction, prior to grid burial.

Neutral Connections

- Verify that neutral links are tight, that the neutral earth connection is intact and, where appropriate, that the resistance of the connection is correct.
- In substations where the neutral connection and cable sheaths are isolated from the substation earth, check that this isolation is not short circuited.

Bonds to Structures and Equipment

- Check that earthing and bonding connections to equipment such as: transformers, switchgear, cable sheaths, support frameworks, pillars, cubicles, metal clad chambers, bases of insulators and bushing and their associated metalwork are intact.
- Inspect flexible bonding braids or laminations for fracture and corrosion and change as required. A protective compound may be applied to flexible braids where corrosive conditions exist.
- Verify that earth mat connections are secure and that buried installations have not been disturbed.
- On switchboards fitted with frame leakage protection, verify visually that the insulation which segregates the switchgear frame from the main earth bar and the cable sheath is not short-circuited by spurious paths.
- Inspect connection points for portable safety earths to ensure they are accessible, in good condition and of an approved type (ie. adequately rated).

Power Asset Surface Condition

If the crushed rock layer is 'filled' with soil and grit its insulating properties may be negligible.

- The condition of any crushed rock inside the substation and around the perimeter, if present, should be inspected for thickness and cleanliness.

Only useful where there is a difference between crushed rock resistivity and that of the underlying strata!

Transfer Potential Hazard Check

The configuration of conductive infrastructure in the vicinity of the substation should be checked by maintenance programs for any new transfer hazards, including:

- Identify any conductive infrastructure such as pipelines, communications lines, or fences that have changed since commissioning.
- If a hazard is identified, e.g. fence connected to yard perimeter fence, urgent action should be taken.
- If the metal work is part of a major installation, e.g. industrial complex pipeline, a calculation of the hazard level is suggested as the first step in deciding a mitigation program.

4.5.2.2. Continuity Testing

To ensure that the grid conductors and connections are still intact and offering a low resistance it is recommended that a continuity test be undertaken at regular intervals. The continuity test is usually made between the main earth bus, e.g. neutral point, and each structure earthing point. This test is critical for high fault energy dissipation points, in particular portable earth and surge arrester earthing points. The resistance of joints should be less than 100μΩ. The resistance across a grid will depend on its size and interconnectivity.

4.5.2.3. Electrical Performance

Electrical performance tests investigate grid impedance, step, touch and transfer voltages, and current distributions, to verify compliance of the installation with safety criteria, and the physical design specification.

For smaller systems, e.g. distribution substations or smaller isolated zone substations, where a node or local assessment of compliance is to be used, a portable resistance meter may be used to measure grid resistance. The values should be compared with the initial and other previous tests results to detect any possibility of below ground conductor breakage or theft. This comparison is complicated by the resistance fluctuations that occur due to seasonal variations in soil resistivity. Care should be taken when deciding upon lead lengths and positioning if metalwork may 'short circuit' the earth return path.

For larger or more complex systems where a network assessment is required a full current injection test becomes necessary to obtain any useful grid performance results. In such cases grid impedance is often well below 0.5Ω and is not significantly affected by individual conductor breakages.

If the initial installation had performed safely then it is reasonable to assume continued electrical performance if no changes occur to the internal metalwork configuration. Therefore, careful physical inspection should be conducted, as described in the previous section, whenever electrical performance is assessed.

4.5.3. Monitoring Activities

Investigations of substation earthing system conditions are required so that an asset manager can determine the extent of any required maintenance, modification or refurbishment. Such investigative tasks include commissioning tests, condition assessments and performance reviews.

4.5.3.1. Commissioning Tests

A substation earthing system should be checked and inspected immediately after construction. This is required to:

- Validate that construction is in compliance with the system design;
- Statutory safety requirements are met; and
- Baseline performance established for future comparison.

Commissioning tests should check both physical condition and electrical performance as outlined in Section 4.5.2.

The results of commissioning investigations and tests will be used to calculate the expected EPR, voltage gradients and touch and transfer potentials associated with the substation. Calculations will be made to verify the validity of test results and to design any required alterations to ensure system security.

Care should be taken to investigate transfer potential problems e.g. fences, pipelines, railway lines.

4.5.3.2. Condition Assessments

The performance of an earthing system may progressively degrade, as its conductors and connectors deteriorate because of corrosion, mechanical fatigue, vandalism or inadvertent breakage, e.g. digging or vehicle impact. It is not reasonable to assume that an earthing system will maintain its initial condition indefinitely. Therefore, periodic integrity tests are required to detect damaged or corroded conductors of the earthing system.

Condition assessment results should be used to make asset management decisions regarding the allocation of capital to remediate earthing systems. Such decisions include relative assessment of other competing programs of work that also reduce risk to the business.

The frequency and type of periodic checks required are determined by: statutory requirements, earth system size and vulnerability i.e. degradation by aggressive soils, or vandalism. The following guidelines are provided to assist in the determination of the frequency and type of periodic integrity checks.

Above-ground Inspection

- A physical inspection of all above-ground conductors and connections, as outlined in Section 4.5.2.1, is recommended as the minimum maintenance requirement.
- It should be undertaken at frequent intervals, typically 1-3 years.

Below-ground Inspection The integrity of buried conductors and connectors is difficult to determine. In small systems a periodic resistance check will highlight any breakages. In larger systems a d.c. continuity check is more effective at identifying poor connections.

- It is also recommended that a physical inspection of the condition of the buried conductors be undertaken by exposing a grid joint at an infrequent interval e.g. 5-12 years.
- Frequency of inspections should be increased where the corrosion is a significant concern.
- Other risk factors include:
  - Fault level changes
  - Construction work over time (excavation)
  - Soil condition and type (corrosion)
  - Time

- Changes in design or construction philosophy e.g. use of steel components compared to copper strap.
- Activity and changes around the outside of the site.

4.5.4. Inspection and Test Intervals

The following points are made with respect to inspection and test intervals:

- Measurement of the earthing system performance should be carried out periodically or following major changes to the installation or power system which affect the fundamental requirements of the earthing system. Such measurements should generally follow the commissioning program. Continuity tests should also be undertaken.

- The asset owner or user should determine appropriate inspection and test intervals based on knowledge of their earthing installations and design standards, and on their understanding of the relevant threats. Establishing intervals for installations where conditions are not considered typical, such as high susceptibility to corrosion, high likelihood of mechanical damage or theft, should be based on a risk assessment of the specific circumstances.

- When work has taken place that may have interfered with the earthing system, the system in that area should be inspected and checked. All parts of the earthing system exposed by excavation should be inspected for damage or deterioration.

- Typical intervals between performance assessments of earthing systems for major substations is between 10 and 15 years. Continuity and visual inspections of earthing systems have typical intervals of 1-3 years.

4.6. Education

Avoiding issues with earthing systems is either a matter of prudent avoidance or statistical improbability. To ensure that staff, particularly non-electrical field staff, do not innocently venture into tasks which may expose them to earthing related hazards the following actions are recommended:

- When new staff are inducted earthing related hazards are discussed at least at a conceptual level; and

- A discussion revising earthing related hazards is held with staff on an annual basis.

APPENDIX A: The Function of Earthing Systems

Despite the earth being dominantly constituted of rock and other similar materials, the bulk of the earth is conductive and forms an important component of most power systems. The earth is intimately involved in power system faults. Faults where a live transmission conductor falls to the ground; when a lightning strike strikes powered equipment or structures; or even when a bread crumb gets between the toaster element and the frame of the toaster, are all examples of electrical faults involving earth.

Earthing systems are designed to manage the flow of fault currents to protect people and equipment and to limit risks to the operation of the electrical system, from low voltage residential wiring to power stations. Fault currents, including lightning currents, are safely transferred into the earth via earth conductors and earthing systems.

It is the purpose of this section to describe how earthing works and how to identify work outside the protection afforded by an earthing system and measures to take in those instances.

A1. Purpose

The purpose of an earthing system is to protect people and equipment from direct and indirect contact with electrical hazards during normal and abnormal conditions. When currents flow in the ground between equipment and remote earth, a potential difference, which is called earth potential rise, is generated, and as a result:

- People are endangered by the possibility of indirect contact with parts at different electric potential, resulting in dangerous currents through the body.
- Equipment can be affected by earth potential rise exceeding the insulation withstand capability.

The fundamental requirements for effective earthing systems, in order of priority, are:

1. Provide safety for people;
2. Support of the operation and security of the power system; and
3. Protection of equipment.

To understand how earthing systems function we need to understand their primary purpose in supporting power systems and how that relates to people. That leads us into a discussion on how earthing systems create hazards and what level of hazard represents an acceptable risk.

A2. System Operating Requirements

Power systems throughout the world, including Australia, use the potential of the earth to reference those systems. This is done for two reasons:

- It is available everywhere; and
- It is the potential that people live at.

As a consequence:

- All electrical infrastructure that people could interact with is earth referenced and has an earthing system of some description.
- Faults on the power system return current to the location where the power system is earthed allowing faults involving earth to be detected and isolated.

This behaviour of the power system is considered normal and allows the power system to be operated in a safe manner for those of us working at earth potential. It allows for power systems, which may be many kilometres long, to detect dire situations which cannot be observed by any person or device with sight or communication with the incident. This is a highly desirable outcome for all those involved, from the unfortunate person who crashed their car into a power pole, the power system operator and the many consumers connected to the impacted network who would prefer that the network remain on during the passage of the storm which contributed to the accident.

In a more formal sense the following is required of an earthing system. Under all reasonably foreseeable conditions the earthing system shall not, by action or inaction, negatively impact the operation of the power system other than where intended for the safety of people or the protection of equipment. Specific measures that support operational security include the following:

- Maintaining a voltage reference for control, protection and communications systems, particularly to ensure the proper operation of protective devices such as protection relays and surge arresters.
- Providing or assisting to provide electrical noise immunity for conductive and inductive hazards. Power-system over-voltages and fault current levels are influenced by the earthing system.
- The design must be coordinated to achieve desired reliability levels. System outage rates are effectively reduced by the use of earthing systems which minimise phase to earth back flash-over and inductive interference, e.g. into protection pilot cables.
- A continuous conductive (nominally metallic) earthing system provides a connection to earth for lightning, switching surges and 50Hz earth fault current. Therefore, every component of an earthing installation should be capable of carrying its expected proportion of the design maximum earth fault current. This current should flow through the component without causing hazardous voltages, interference to other systems, or damage until the fault is cleared.

A3. Earthing Related Hazards

Hazardous earth voltages can be produced by power frequency and transient earth currents as a result of power system earth-faults and switching and lightning over-voltages.

- Power Frequency Voltages
    - Conduction of Fault Currents

      The majority of safety problems are associated with voltage rises resulting from the conduction of power frequency earth fault currents into the ground. All metalwork forming or connected to the earthing system will conduct current, either directly into the ground, or to another part of the system and then to ground. The three basic hazard situations are due to step, touch and transfer voltages, see Figure 1. These hazards are associated with electrical substations, transmission lines and distribution lines, and metallic infrastructure near these components.

    - Electromagnetic Induction

      Voltages may be electromagnetically induced in fences, pipelines, conveyors, railway lines, telecommunication cables, trailing cables whether above or underground due to the flow of fault current in high voltage power lines and buried insulated cables. Induction is usually associated with long parallel exposures of metallic infrastructure to transmission and distribution lines, particularly subject to fault conditions.

- Electrostatic Induction

  If an item of equipment runs parallel to or approaches a transmission line for any distance, tests should be undertaken to determine the voltages existing in the steady state. Problems have been experienced with fences, parallel power lines and conveyors near to transmission lines. These issues can be present under normal operating conditions.

- Transient Voltages

  Transient voltages are either of atmospheric or man-made origin.

  - Atmospheric Origin

    Potentials due to lightning strikes to ground, or discharges between clouds, can affect any plant at the surface, but can also be transferred conductively and/or inductively to distant parts of installations (even underground). Following a lightning strike to a line or substation, although the initial lightning surge to earth may be of short duration, a power frequency 'follow-through' current may occur. This secondary effect, due to insulation 'flashover' may present a greater safety hazard than the initial transient surge.

  - Man-made Origin

    Transient currents enter the earthing system, due to arcing between isolator or disconnector contacts during switching operations or breakdown of insulation, or faults in inductive/capacitive circuits. The short rise times of the wave combined with the high speed of travel creates high voltage differences over short distances in the earthing system. Whilst this does not present a great safety hazard to personnel, the overall reliability of substations may be reduced. Therefore, special measures should be taken to avoid or minimise disturbances due to high frequency earth potential rises. As an example earthing designs for gas-insulated substations (G.I.S.), which can create extremely high frequency voltages.

There are several potentially hazardous conditions routinely found on equipment connected to the electrical network including earthing conductors and interconnected structures. Hazardous conditions may also exist where equipment is in close proximity to, but not connected to the supply network. These hazardous conditions include:

- Earth potential rise (EPR) and resulting step and touch voltages during system faults;
- Induced voltages, including magnetic induction and capacitive charging; and
- Transient voltages from lightning and some high voltage (HV) switching surges.

While these conditions are more likely to be found during a fault somewhere on the electrical network, they can also occur during normal working conditions. Earth faults can result where and when the insulation of the electrical system breaks down.

Possible causes of faults include bush fires, wires falling down, cables damaged during excavation, animals such as birds and possums climbing or approaching the network, or by tree branches touching wires during a rain or wind storm. These events occur regularly on the network, as frequently as once a week - more in some locations.

Fault related hazards exist even though the fault can be at an entirely different, even remote, location.

Certain parts of the electrical network, such as cable screens, earth continuity conductors and neutral conductors, must remain earthed whenever in service. They should not be disconnected from earth unless required as part of replacement or planned work.

In most cases earthing engineering design ensures touch voltage and induced voltage hazards at and around the electrical network are kept to acceptable levels. Certain work practices, network augmentation and construction works can cause excessive hazards to arise. Taking appropriate precautions and ensuring that you have the correct network access requirements before working on or adjacent to the electrical network is critical to minimising the risks posed by earthing related risks.

A3.1. Earth Potential Rise

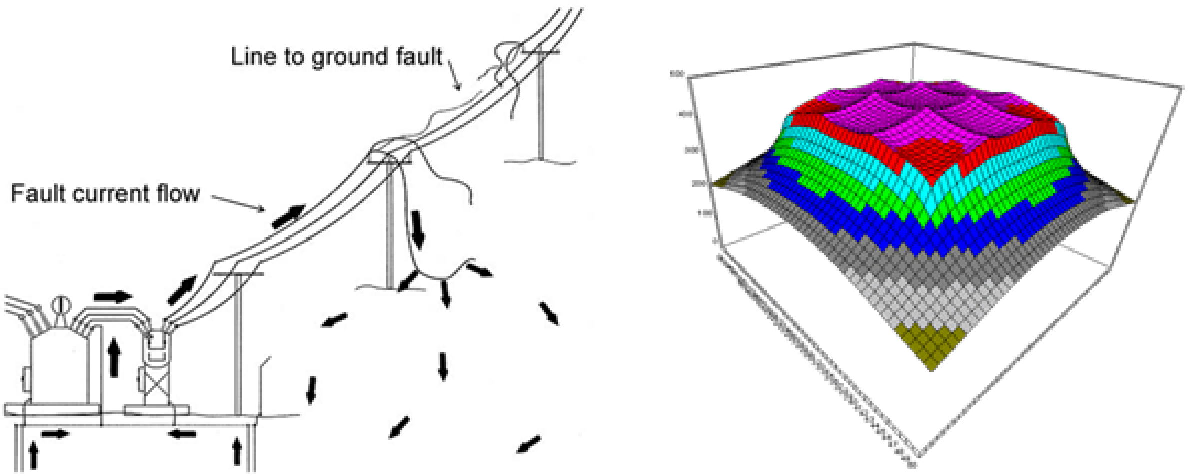
Earth Potential Rise (EPR) occurs when electrical current enters the ground. The voltages produced by earth potential rise can be hazardous to personnel and equipment. The earth potential is highest at the point where the current enters the ground, and declines with distance from the source. The earth fault circuit and the response of the soil around an earthing system due to current flowing through it are described in Figure A.1.

The earth potential rise also occurs at a number of other locations during a fault:

- The substation to which the earth fault current returns;
- Where circuits supplying the fault transition from overhead to underground; and
- At earthed intermediate poles or towers connected by an earthwire or MEN.

A3.2. Step and Touch Voltage

Step and touch voltages are electric shock hazards resulting from earth potential rise. Step voltage occurs when an individual's feet are located at different points on the soil potential gradient. The resulting potential difference can cause an electric shock.



(a) Earth fault current flow

(b) Soil voltage response due to earthing system, at point of fault or supplying substation, passing current

Figure A.1: Earth Fault Effects

Example 2: A step voltage can be produced next to a tower that is connected to a faulted substation via an earthwire.

Touch voltage is the potential difference between the ground on which you are standing and a metal object which might be touched, such as a fence, a water tap or earthed equipment in the electrical network.

Example 3: Touch voltages can be produced on a pipe located near a faulted power station.

A transfer voltage is a touch voltage created at a location distant from the earthing system by the transfer of potential through a conductive medium.

Example 4: A property fence connected to the fence of a HV substation will transfer voltage (EPR) away from the substation. The soil potential will drop away from the substation creating a transfer voltage on the property fence, particularly when the fence leaves the vicinity of the substation.

A3.3. Lightning and Switching

Lightning poses threats to the personal safety of all people outdoors when a storm is in the local area. Australian Standard 1768 'Lightning Protection' defines a local lightning event as one where thunder is heard within 15 seconds of a lightning strike - meaning the lightning is within 5km.

During a lightning strike and during some switching operations on the electrical network, large voltages and currents can be transferred onto other equipment and to remote locations of the network.

Where a switching surge or lightning energy enters a powerline, it can be transmitted many kilometres on the power system. Lightning can cause harm to power system workers on large networks even when there is little evidence of local storm activity. Site warning systems involving system controllers can be an effective way to manage lightning hazards across the power system.

A4. Safety of People

Maintaining safety for both utility staff and the public in the event of an earth fault is the primary purpose of an earthing system. In the past this was achieved using what was considered deterministic[9] design processes. Existing practice has adopted quantified risk targets which allows for design optimisation and comparison of different hazards and exposures. Under all reasonably foreseeable conditions the earthing system should not impose on any person or group of people an unreasonable risk. An unreasonable risk is one that is considered intolerable or a risk that whilst 'tolerable' is not negligible and can be further lowered at a cost that is not grossly disproportionate to the change in risk achieved. This is further discussed in EG-0 [10].

To ensure these aims are met an earthing system design must ensure that:

- Accessible metallic structures and equipment are maintained at or near equipotential;
- No unreasonable hazardous step, touch and transfer voltages exist during fault conditions (50Hz or transient);
- A common earthing point is provided to reduce or eliminate static build-up;
- The design targets are revised over the life of the installation, reflecting the state and reliability of the power network; and
- Compliance with the design criteria can be maintained over the life of the installation despite additions or modifications.

All these hazards can present dangerous conditions to staff accessing the electrical network, and working on

[9] A *deterministic* system is a system in which no randomness is involved in the development of future states of the system. A *deterministic* model will always produce the same output from a given starting condition or initial state.

equipment impacted by the electrical network. The risks can be managed by using the following:

- Network access and safety rules governing appropriate use of safety controls;
- Access permit earths;
- Working earths at the worksite;
- Sequencing of work activities and worksite design; and
- Appropriate work methods, such as:
    - Considering the specific hazards to the specific task/job;
    - Developing task or job specific work procedures to mitigate the hazards; and
    - Conducting a job discussion and hazard assessment.

Even where appropriate mitigation options are employed, some risk of shock remains when working on overhead lines, underground cables/conductors, or in electrical substations.

There is no single solution to address induction and earth potential hazards on all electrical assets for all types of work. It is important to address the risks to ensure safety and this must be done considering the specific hazards to the task/job at each worksite.

These hazards (and the subsequent risk) are partially addressed by isolating and earthing the network prior to access. Task or job specific work procedures are also usually required to mitigate the hazards. These work procedures should be included in the job discussion and hazard assessment. The work procedures do not form part of the network access requirements but are essential to addressing shock risk while undertaking the work.

For complex or high risk work on or near the electrical network, expert advice should be sought.

A4.1. Performance Targets

With regard to the safety of people, earthing system should be designed such that they pose a negligible risk to the maximally exposed individual, as recommended by EG-0 .[10]. Negligible risk targets are based on:

- Clearing time of faults;
- Exposure of people to locations exposed to hazards created by a fault;
- The physical circumstances of persons likely to be exposed to the hazards e.g. public or electrical worker; and
- The frequency of faults and the presence of potentially exposed individuals.

An earthing system design should take all of these circumstances into consideration. Should any of these circumstances change (particularly for the worse) then the earthing system performance will need to be reviewed. Assessment will need to be made of whether the earthing system remains at an acceptable or tolerable level of risk, or whether the risk posed by the new/changed/revised circumstances is such that redesign and additional works are required.

The applicable EG-0 standard compliance curves for the Snowy Hydro Network, taken from Appendix E of EG-0, are summarised in Table A.1 and Figure A.2.

Table A1: Standard Compliance Curves

EG-0 Curve	Application Description
TU	Contact with transmission asset in urban interface location
TDB	Contact with metalwork in a backyard affected by either transmission or distribution asset
TDMEN	Contact with MEN connected metalwork (around house) where MEN or soil is affected by either transmission or distribution assets
MSPB	Backyard near major substation with primary side fault
TSI	Inside transmission substation

Safety compliance curves for specific circumstances can also be calculated using the ARGON[10] software tool which was published in support of EG-0 by the ENA.

A4.2. Modes of Protection

An earthing system reduces the risk of shock through equipotential bonding, insulation and separation. Equipotential bonding ensures that all metallic objects are electrically bonded or connected together via a low impedance to each other and to earth [6]. This minimises any potential differences from developing.

Separation minimises faults currents from flowing in certain structures avoiding potential rise. Barriers such as fences, shields or insulation may be used to prevent personnel and the public contacting equipment that may suffer a potential rise.

[10] Or equivalent

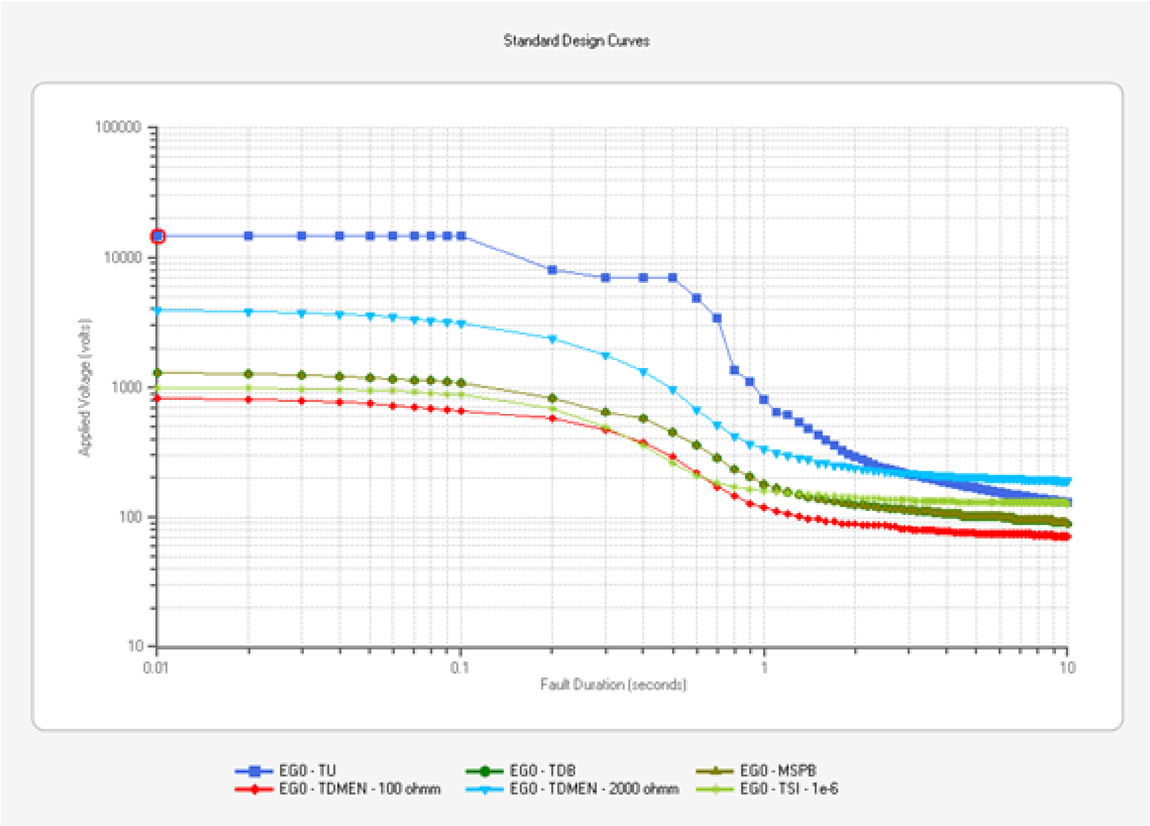


Figure A.2: EG-0 Transmission Standard Design Curves

A5. Protection of Equipment

To protect equipment the voltage levels imposed thereon need to be limited by safely providing a low impedance path for lightning discharges, switching surges, fault currents and other system disturbances. These disturbances may otherwise cause extensive damage to primary substation plant and ancillary equipment, such as communications cables. Equipment damage might include: insulation breakdown, thermal or mechanical damage, fires and electrically ignited explosions.

Under all reasonably foreseeable conditions the earthing system should provide for the expected operation without damage to any component. Equipment protection will typically include the following minimum functional requirements:

- The earthing system, its components and bonding conductors shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on backup protection operating time.
- The earthing system shall maintain its integrity for the expected installation lifetime with due allowance for corrosion and mechanical constraints. Where the earthing system will be subject to significant threats to its condition the design will need to consider supervision, maintenance and possible replacement of the earthing system during the substation's lifetime.
- The earthing system performance shall perform so as to avoid equipment damage resulting from excessive potential rise, potential differences within the earthing system and excessive currents flowing in auxiliary paths not intended for carrying a significant portion of the fault current.
- The earthing system performance shall contribute to ensuring electromagnetic compatibility (EMC), in accordance with IEC/TR 61000-5-2 [11], among electrical and electronic apparatus.

APPENDIX B: Corrosion of Conductors

The corrosion of buried conductors occurs due to the electrochemical reaction between dissimilar metals, enhanced by the presence of an electrolyte such as soil. The current which flows causes loss of material on the anodic surface. Corrosion problems are exacerbated when the anodic action is concentrated in a small area (e.g. hole in pipeline covering). In this case the full current density is focussed on the small area, potentially removing material at an accelerated rate.

Certain soil conditions can accelerate corrosion. These include:

- Low resistivity soils (< 20 Ωm).
- Acidic soil including acid sulphate soils.
- High moisture and soils with high total dissolved solids content.

The solution to such problems lies in a combination of the following preventative measures:

- Correct choice of materials, see noble metal chart [8];
- Careful installation procedures;
- Calculation or measurement of hazard magnitude; and
- Installation of special protection (e.g. active or passive cathodic protection system).

The latter two steps are required if a threat is still suspected, once the former two steps have been considered. In these conditions, alternate materials (such as stainless steel) or installation method (such as embedded earthing) should be considered to resist corrosion and extend the life of local grid elements.

APPENDIX C:

This Appendix is giving easy reference material to cover frequently asked questions.

General Earthing Requirements:

The following guidelines need to be considered in making earth connections, however it is important to consider site specific issues, relevant Australian Standards and SHL-ELE-156 Annexure K before finalising the design. The reference list given below directs to additional information. Some information is given here for easy reference.

1. Motors

Motors terminal board earth terminal should be earthed at supplying switchboard using the supply power cable earth core and the frame to the nearest earth grid. Two earth connections are recommended for redundancy. Due to the potential high circulating current sometimes the earthing is done only to the motor frame. At T1 and T2 power stations only one earth connection is made due to this reason. The supply cable earth should be only terminated at the switchboard earth bar, where the motor end must be removed and insulated with heat shrink.

The motor frame should be bonded to local facility earth with the same size phase conductor, minimum size frame earth is 25mm^2 copper for mechanical strength. Motor holding down bolts should not be used for earth connection to the frame.

If there is an armour and/or screen for the supply cable they should be bonded and earthed at one end or both ends depending on the possibility of circulating current.

2. HV, MV and LV Cable screens and armour

The cable screens and armour should be bonded and earthed at least at one end as per the earthing design depending on potential for circulating current and development of higher voltages on screens/armour..

3. Electrical Panels [5][6]

- Earth connection to the Panel to be done to the nearest main earthing conductor via 25mm x 3mm (or larger depending on fault current) annealed copper strips.
- Where multiple components or devices terminate, a copper earth bar must be provided within the board/panel to facilitate earthing of these items. This bar must be fabricated (drilled) to accommodate a facility earth grid connection.
- All steelwork including hinged doors and panels, should be earthed using separate bolted connections.
- Welded studs should be installed within enclosures for earthing purposes. Studs should be provided on doors, panels, gland plates and other fixed metal work.
- Paint must be removed from around connection points before a connection is made; once this is completed, the surface must be repainted to provide surface protection against corrosion.

4. Cable trays[12]

Metal cable trays should be earthed as follows.

- The cable tray should have a single point of attachment to earth, due to the high probability of circulating currents in underground power stations. Other places consideration should be given for two connections for redundancy.The minimum earthing conductor size for the point of attachment to earth shall be 70mm^2 unless determined to be greater by the largest supply cable as per Table 5.1 in AS/NZS 3000-2018.
- Each ladder section should be bolted together using the appropriate splicing plate, additional to this each section must be bonded using a 35mm^2 cable (unless a larger cable is specified by design). A 35mm^2 or greater conductor is to be also run in the tray, where it is to be used to line-tap to sections of tray or ladder.

- Where the tray sections are separated due to obstructions, separation of earth bonding may need to be considered to reduce the chances of circulating currents, otherwise the two separated sections should be bonded with 70mm^2 cable.

5. Earthing Mesh in power station and switchyard [18][32]

- All earthing and bonding conductors should be copper conductors. Aluminium or steel (including galvanised steel) may only be used where galvanic corrosion may occur with SHL Engineering approval.
- Buried earthing conductors should be bare copper and buried at a minimum depth of 500mm.
- Section 4.2 Construction Design in Snowy Standard SHL-ELE-128 covers the requirements for direct buried, embedded and transitional earth grid (mesh) requirements.
- Testing of the earthing mesh should be performed as per SHL-ELE-156 and developed routes.

6. Pad mounted transformers [25][26][27][28][29]

- A local earth grid is to be installed including earth electrodes, which is to be completed before the concrete plinth is installed.
- The following parts need to be earthed:
    - concrete plinth reinforcing
    - transformer tank and switchgear casing
    - metal padmount housing including doors that are hinged
    - low voltage neutral
    - cable screening or armour (predominantly HV cabling)

7. Pole top transformers [25][26][27]

The following requirements are needed to be earthed:

- transformer tank
- HV surge arrester
- LV neutral and LV surge arrester
- Conductive pole (metal and concrete poles)
- any metallic objects (i.e. cable sleeves and cable covers)
- local earthing electrode system
- grading ring (where fitted)

- The earth cable must be covered with a guard from the base or just below ground level to 3m above the ground.

8. Remote Hydraulic structures [19][20][21][22][13][37]

- All equipment that comes into contact with water or soil should be bonded to the local remote earth grid by at least two connections.
- Minimum size earthing conductor is 120mm^2.
- The remote earth grid must be provided for local bonding. Where the local structure requires a low voltage system, a local MEN link must be provided within the local main switchboard.
- General Steel work is to be bonded to the local earth grid
    - Bases of steel columns around the perimeter of the structure must be connected to the perimeter earth grid by a 120mm^2 earthing conductor.

9. Penstock [19][23][24][20]

- Metallic penstocks or penstock liners should be bonded to the head gates and scroll casing where practical. The bonding must be electrically continuous throughout the length with sliding or gland-type expansion joints bypassed.
- The metallic components of the scroll case to be bonded at least twice.
- Metallic draft tubes and pit liners to be bonded at least twice.
- Minimum size earthing conductor to be 120mm^2

- No maintenance should be undertaken on penstock without a risk assessment of potential touch and step voltages as a result of transferring voltage.

10. Exterior Piping (Natural Gas / Water)

- In order to prevent transferring potentials exterior to the station, piping such as natural gas or water shall be fitted with insulating joints or flanges at the point of entry into the station. This should be part of the earthing design.

11. Fences [20][28]

- Fences and gates should be connected to the earthing system with a minimum size copper earth conductor of 3 x 25mm^2 strap or 120mm^2 cable.
- Switchyard fences should be earthed every 10m maximum.

12. Connections within facility earthing - material, tinning, bolted connections, brazing, [8][30][31][39]

- All exposed earth joints and connections must be made using bolted connections.
  - bolts to be made of brass or stainless steel
  - lugs to be highly tinned copper lugs
  - exposed bolted connections to be covered with an approved sleeve or tape.
  - threaded connections should not be buried.
- Connections from the main earth to the earth electrode to be completed using an approved copper compression earth clamp.
- all underground earth connections should be made using a copper compression “C” clamp. Clamp to be a Burndy copper C-tap style clamp or an approved equivalent. Preference is given for two compression lugs per joint.
- Lugs should be tinned when connecting between dissimilar metals.
- Earthing connections to equipment and for exposed joints shall be bolted, using approved bolted earth connectors and lugs or bolted earth clamps.
- Exposed connections to be covered with approved sleeving or tape.
- Brass or stainless steel bolts, studs, washers and nuts to be used. Mild Steel can be used, but is less preferred due to its reactivity with copper.
- Nuts should be fitted with a locking device, i.e. a second nut to lock the first in place.
- Serrated (tooth) lock washers are not to be used.

13. New concrete slabs within the perimeter of Power Station Fence.[33][34][35][36][37]

- The extent of the existing below ground earth grid is to be determined in the area required.
  - Where the existing below ground earth grid exists under the proposed slab, there is no requirement to extend the below ground earth grid, and the following is required to bond the new slab reinforcing to the earth grid:
    - Provide at least 4 earth risers of 50mm^2 galvanised steel wire originating from the below ground grid, where each connection is to be made using two C crimps (Burndy). The location of the earth risers are preferably to be located at the edges of the proposed slab.
    - The connections of the earth riser to the slab reinforcing, are to be completed using two C crimps (Burndy) per connection.
  - Where the earth grid does not cover the area required, the grid is to be extended using the same size copper earth conductor as the existing. Connections to the existing earth should be made using two C crimps (Burndy) per connection.
- Direct buried earthing requirements refer to SHL-ELE-128 clause 4.2.1.1 *Dissipative Earthing - Direct Buried.*
- For concrete slab requirements for earthing, refer to SHL-ELE-128 clause 4.2.2.2 *Dissipative Earthing - Embedded.*

- Where there is a requirement for local earth bonding from the reinforcing of the slab to a structure or to create a local earth connection, refer to SHL-ELE-128 clause 4.2.1.4 *Transitional Earthing - Embedded.*
- Testing connections is to be completed after each new connection, and meet the requirements of SHL-ELE-128 clause 4.5.2.2 *Continuity Testing.*

14. **Pipes and Metal Conduit inside the station** [39][40]

Where joints between metal conduits and fittings are made by means of fully threaded hubs, no additional earthing requirements are necessary other than to bond the conduit system to the earthing system. Un-threaded joints shall have a bonding conductor connected across them such as to ensure the earth continuity of the conduit system. The minimum size bonding conductor shall be green/yellow insulated 35mm2 copper conductor, with tinned compression lugs.

Where earth continuity is required pipeline insulated flanged joints should be bridged with copper conductors properly sized according to the earthing design. Paint of the pipe to be removed at contact surface for bridge connection .

References

No.	Document Type	Document Number	Document Name	Clause	Clause Title
1	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.4.1	Motors and other auxiliary low voltage equipment earthing
2	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.3.2	Minimum sizes
3	Standard	CEATI HPLIG 0370	Grounding Guide of Best Practice for Hydraulic Stations	7.9	Motor Drives
4	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.5	Instrument and control system earthing
5	Specification		Installation Specification Electrical Controls Scheme Modernisation Project	2.1	
6	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.4.2	Cubicle and junction box earthing
7	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.4.5	Permanent standby generators
8	Standard	SHL-ELE-156 Annexure B	LV Switchboards	3.3.6	Earthing connections
9	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.4.6	Portable standby generators
10	Standard	CEATI HPLIG 0370	Grounding Guide of Best Practice for Hydraulic Stations	7.4	Step-up Transformer
11	Standard	SHL-ELE-156	LV Earthing	3.4.4	Instrument transformers

		Annexure K			
12	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.4.3	Cable support systems and conduit earthing
13	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.7	Lightning Protection
14	Standard	AS/NZS 3000:2018	Wiring Rules	F2	Surge Protective Earthing and Bonding
15	Standard	AS/CA S009.2013	Installation requirements for customer cabling (Wiring Rules)	20.2	Earthing of surge suppression devices
16	Standard	CEATI HPLIG 0370	Grounding Guide of Best Practice for Hydraulic Stations	7.5	HV Switchgear
17	Standard	AS 2067:2016	Substation and high voltage installations exceeding 1 kV a.c.	5.4.2.4	Earthing
18	Standard	SHL-ELE-128	Earthing	4.2.1	Installation
19	Standard	CEATI HPLIG 0370	Grounding Guide of Best Practice for Hydraulic Stations	7.11	Penstock, Scroll Case and Draft Tube Liners
20	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.6	Earth bonding
21	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.2	Local earthing systems
22	Standard	CEATI HPLIG 0370	Grounding Guide of Best Practice for Hydraulic Stations	7.17	General Steel Work
23	Standard	AS/NZS 3000:2018	Wiring Rules	1.4.48	Earthed situation
24	Standard	AS/NZS 3000:2018	Wiring Rules	5.4.1.1	Exposed conductive parts
25	Standard	DOC SM1138	EVO Energy - Distribution Earthing Design Manual		
26	Standard	Manual 00758	Energex - Distribution Earthing Manual		
27	Standard	NS116	Ausgrid - Design Standards for Distribution Equipment Earthing		
28	Standard		Transgrid - Substation Primary Design Standard		TransGrid publishes this information under clause 5.2A.5 of the National Electricity Rules.

29	Standard	RS22692	TasNetworks - Substation Lightning Protection and Earthing Standard		
30	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.3.4	Mechanical protection
31	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.3.5	Earth electrode
32	Standard	SHL-ELE-156 Annexure K	LV Earthing	3.3.1	Conductor
33	Standard	SHL-ELE-128	Earthing	4.2.1.1	Dissipative Earthing - Direct buried
34	Standard	SHL-ELE-128	Earthing	4.2.2.2	Dissipative Earthing - Embedded
35	Standard	SHL-ELE-128	Earthing	4.4.4	Use of civil structures as earthing elements
36	Standard	SHL-ELE-128	Earthing	4.5.2.2	Continuity Testing
37	Standard	AS/NZS 3000:2018	Wiring Rules	5	Section 5 covers mandatory earthing requirements