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Earthing Design Instruction

Distribution earthing design

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EARTHING DESIGN INSTRUCTION

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EDI 100 Distribution earthing design

CONTENTS

1.0 PURPOSE

To set the minimum standard for designing the earthing system of all distribution components in the company's network. This standard establishes minimum requirements so that the design of earthing works on the distribution network are carried out in a safe and consistent manner.

2.0 SCOPE

This instruction covers the minimum requirements that must be followed for the earthing design of all components, equipment and systems in the company's distribution network. The company's distribution network comprises all assets with standard voltage ratings of 230/400V, 11kV, 22kV and 12.7kV SWER systems.

While this instruction covers the design criteria of the earthing systems, the following standards cover the other aspects of distribution earthing.

Standard	Aspect covered
SMI 101 - Minimum Requirements for Maintenance of Distribution Equipment	Ongoing maintenance requirements
EDI 001 - Earthing design risk assessment	Earthing risk assessment criteria, methods and limits
EDI 0005 - Distribution earth testing	Testing procedures and requirements
EDI 0006 - Distribution Earthing Construction	Standard distribution earthing construction practices

It is not the intention of this instruction to define the earthing design process in detail. It is the designer's responsibility to design an earthing system that meets the performance requirements of this instruction. However, as an aid to design, this instruction includes a series of Annexures which also provide useful information to achieve a compliant earthing design.

3.0 REFERENCES

Internal

- Board Policy (Governance) 2.0.3 – Compliance
- Board Policy (Governance) 2.0.5 – Risk Management
- Company Policy (Network) 9.2.2 – Network Protection
- Company Policy (Network) 9.2.5 – Network Asset Design
- Company Policy (Network) 9.2.10 – Network Asset Rating
- Company Policy (Network) 9.7.1 – Network Asset Construction
- Company Policy (Network) – Network Operations
- Company Policy (Network) 9.9.1 – Network Asset Maintenance
- Company Procedure (Governance) GRM 0003 – Risk Management
- Company Procedure (Health & Safety) GSY 0026 – Health, Safety and Environment Risk Assessment
- Earthing Design Instruction EDI 001 – Earthing Design Risk Assessment
- Earthing Design Instruction EDI 100 – EDI100S01 Company earthing design tool '3E'
- Earthing Design Instruction EDI 100 – EDI100S02 Company distribution network fault level information

- Earthing Design Instruction EDI 100 – EDI100S03 Company zone substation bonding configuration list
- Earthing Design Instruction EDI 0005 – Distribution earthing test
- Earthing Design Instruction EDI 0004 – Earthing design, construction and testing of overhead transmission mains
- Earthing Design Instruction EDI 0006 – Earthing Construction Standard
- Earthing Design Instruction EDI 516 – Major Substations Earthing Design, Construct and Commissioning
- Mains Construction Instruction MCI 0005 – Overhead distribution: Construction standards manual
- Mains Construction Instruction MCI 0006 – Underground distribution: Construction standards manual
- Mains Design Instruction MDI 0044 – Easements and Property Tenure
- Standard Asset Data SAD 0001 – Project Drawing Standards
- Substation Design Instruction SDI 523 – Switchyard Surfaces
- Substation Design Instruction SDI 528 – Substation Signs and Equipment Labels
- Substation Mains Instruction SMI 100 – Minimum Requirements for Maintenance of Transmission and Zone Substation Equipment
- Substation Mains Instruction SMI 101 – Minimum Requirements for Maintenance of Distribution Equipment
- Substation Mains Instruction SMI 104 – Major substation earthing system test
- *Company Electrical Safety Rules*
- Network Management Plan December 2013 Review

External

- *Electricity (Consumer Safety) Act* 2004
- *Electricity Supply Act* 1995
- *Work Health and Safety Act* 2011 NSW
- Electricity (Consumer Safety) Regulation 2015
- Electricity Supply (Safety and Network Management) Regulation 2014
- Electricity Supply (General) Regulation 2014
- Electricity Supply (Corrosion Protection) Regulation 2014
- Work Health and Safety Regulation 2011 NSW
- ENA National Electricity Network Safety Code (Doc 01-2008)
- WorkCover Code of Practice-Safe design of structures: July 2014
- ENA Substation Earthing Guide (EG1- 2006)
- ENA - Power System Earthing Guide (EG-0-2010)
- AS 2067:2016 - Substations and High Voltage Installations exceeding 1kV ac
- AS-2239:2003 - Galvanic (sacrificial) anodes for cathodic protection
- AS/NZS 1768:2007 - Lightning Protection
- AS/NZS 3000:2007 - Electrical Installations -SAA Wiring Rules
- AS/NZS 3835:2006, Part 1-2 - Earth Potential Rise-Protection of telecommunication network users and personnel and plant..
- AS/NZS ISO 31000:2009 - Risk Management
- AS/NZS:4853:2012 - Electric Hazard on metallic pipelines
- AS/NZS:7000:2016- Overhead line design-Detailed procedures
- HB-219:2006 - Handbook for AS/NZS 3835 Application guide-Worked examples
- IEEE 80:2013 - Guide for Safety in AC Substation Grounding
- IEC61936:2010 Power Installation exceeding 1kV AC

4.0 DEFINITIONS AND ABBREVIATIONS

ABC
Aerial Bundled Conductor – insulated overhead cable

Accredited Service Provider (ASP)
Accredited Service Provider, or "ASP", means a person who has been accredited through a ministerially-recognised accreditation scheme to undertake contestable work.

ALARP
As Low As Reasonably Practicable. The underlying risk management principle whereby risk is reduced as low as reasonably practicable within a risk analysis framework. It means that which is, or was at a particular time reasonably able to be done in relation to health and safety risk levels taking into account various relevant matters including the likelihood, degree of harm, knowledge, suitability of controls and whether costs of controls were grossly disproportionate to the risk. Refer NSW Work Health and Safety Act 2011 section 18.

Argon
Argon is a safety assessment software platform used in conjunction with ENA EG-0 available on the ENA website with registration.

BIL
Basic Insulation Level - expressed in terms of the crest value of the standard lightning impulse.

CCT
Covered Conductor Thick

CLAH
Current Limiting Arcing Horn and discharge connector

Clearing time (primary)
The time from fault initiation to fault extinction.

Clearing time (backup)
The longest time taken for the upstream protective devices and circuit breaker(s) / fuses to isolate the source of fault current assuming any one item of the primary protection system fails to operate. Protection system includes the relay, CT's, VT's, D.C. supplies, communications systems and CB's.

CMEN
Common Multiple Earth Neutral (CMEN) is a system where the combined high voltage and low voltage earthing system is connected to a zone or transmission substation earthing system. *Important note:* The company uses the CMEN terminology for a zone substation bonded to the distribution earthing and potentially LV MEN system either directly or through HV cable sheaths onto common earthed substations – this does not align with the majority of the industry and care must be used when assigning this term.

Common or combined earthing
A common or combined earthing system is one in which the HV distribution and low voltage electrical equipment is earthed to a common terminal bar. This is achieved by connecting the MEN system to the HV and LV earth at the distribution substation or other distribution asset.

Constructors
Earthing workers who carry out the construction includes the company staff and ASPs

Contact criteria: backyard
An area with a contactable metallic structure (for example, fence, gate) subject to fault induced voltage gradients. This metallic structure is not a HV asset but becomes live due to earth fault current flowing through the soil nearby.

Contact criteria: MEN
Contact with LV MEN interconnected metalwork (for example, household taps) under the influence of either LV MEN voltage rise through deliberate bonding and/or through soil voltage gradients from a HV asset nearby

Contact criteria: urban
Network asset outside normal public thoroughfare with low frequency of direct contact by an individual

Designers
Earthing designers refer to company staff and ASPs undertaking or needing to undertake a design or calculation in accordance for earthing systems covered in the scope of this instruction.

Distribution network
Collection of assets (distribution lines, cables, substations and associated equipment) whose purpose is to distribute power from zone substations to distribution substations, which feed the low voltage network

Drawings
Drawings include design drawings and standard construction drawings

Earth electrode
Conductor which is embedded in the earth and conductively connected to the earth

Earth Fault (EF)
Includes a single phase to ground fault and two-phase to ground fault – a fault caused by a conductor or conductors being connected to earth or by the insulation resistance to earth becoming less than the required value.

Earthing conductor
Conductor intended to provide a conductive path for the flow of earth fault current for the control of voltage rise and reliable operation of protection devices.

Ellipse
The company's asset management database

ENA
Energy Networks Australia

EPR
Earth Potential Rise. Voltage between an earthing system and a reference, or a remote earth.

Equipotential
Surfaces have the same electrical potential or with negligible difference in potential.

GIS
Geographical Information System

HV
High Voltage – a voltage exceeding or equal to 1000V AC (refers to 11kV, 12.7kV and 22kV in this instruction).

IDMT
Inverse Definite Minimum Time – An inverse time relay having an operating time that tends towards a constant minimum value with increasing values of current or voltage.

Low risk
Where the risk associated with the earthing system is considered to be low. Typically were the risk is less than 1 in 1,000,000. Refer to EDI 001 - Earthing design risk assessment

LV
Low Voltage – a voltage exceeding 50V AC but less than 1000V AC.

MEN
Multiply Earthed Neutral. A system of earthing in which the parts of an electrical installation required to be earthed in accordance with AS/ANZ 3000 are connected together to form an equipotential bonded network. This network is connected to both the neutral conductor of the supply system and the general mass of earth.

Network
The company electrical network of poles, wires, substations and other assets by which electrical power is transmitted/distributed to its customers.

NMSHV ABC
Non-Metallic Screened High Voltage Aerial Bundled Cable

Not practical
Economically or physically not viable in the risk cost benefit analysis framework

Probability
A measure of the chance of occurrence expressed as a number between 0 and 1.

$P_{coincidence}$
Probability of coincidence; defined as the probability that a person will be present and in contact with an item under consideration at the same time that the item is affected by a fault.

$P_{fatality}$
Probability of a fatality occurring in a given period of time, usually in a year.

$P_{fibrilation}$
Probability that the heart will enter ventricular fibrillation due to contact with an external voltage.

PVC
Poly Vinyl Chloride- a type of insulation used on cables

Remote earth (reference earth)
Part of the earth considered as conductive, the electric potential of which is conventionally taken as zero, being outside the zone of influence of the relevant earthing arrangement.

Remote location
For the purpose of earthing design, any location where probability of coincidence is considered to be low risk (less than 1 in 1,000,000). Typically, it is a location with few people around such as a rural area.

Safe design
The safe design is the integration of control measures early in the design process to eliminate or, if this is not reasonable practicable, minimise risks to health and safety throughout the life of the earthing system being designed. Refer to WorkCover-safe design of structures code of practice.

SEF
Sensitive Earth Fault – A type of feeder protection designed to detect small earth fault currents due to high impedance fault paths. This form of protection may take up to 10 seconds to operate.

Soil resistivity
Specific resistivity of a material which is used to define the resistance of a material to current flow. It is defines as the electric field strength (Vm^{-1}) divided by the current density (Am^{-2}) which represent the value to 1 amp flowing into one metre cube of material yielding units of ohm meter (Ωm).

Separate earthing
A system where the HV and LV earths are electrically separate

Step voltage
The voltage between two points on the earth's surface spaced that are (one) 1 metre distant from each other, which is considered to be the stride length of a person. [ENA EG-0:2010]

Sub-transmission network
The collection of assets (transmission lines, cables, zone substation and associated equipment) whose purpose is to distribute power in bulk from sub-transmission substations to zone substations which feed the distribution network or a particular customer substation. Sub-transmission voltages in the company's network are typically 132kV, 66kV and 33kV.

Substation
Part of a power system, concentrated in one place, including mainly the terminations of transmission and/or distribution lines, switchgear and housing which may also include transformers. The reference to 'major substation' in this document refers to all zone substations, transmission substations and switching substations with sub transmission voltages.

SWER
Single Wire Earth Return - a single phase electrical system where the return path for the load current is through the ground.

SWMS
Safe Work Method Statement

TDMEN
A "low risk" touch voltage limit applicable to the MEN contact criteria. Refer to EDI 001 – Earthing design risk assessment

Touch voltage
The voltage between an accessible conductive part and a point on the earth's surface one (1) metre horizontally away, when the conductive parts is not being touched. This is often referred to as "prospective touch voltage". For the purpose of this instruction, touch voltage implies "prospective touch voltage" only.

Transfer voltages
Transfer voltages are a more specific form of touch voltage that can occur when a long metallic object such as a metallic fence transfers a voltage from one location to another closer to remote earth potential. Conversely a transfer-in touch voltage can occur when for instance a conductive tap bonded to the LV MEN system transfers-in a low voltage close to the area of a fault point. The local soil voltage caused by that fault point results in a high touch voltage to the conductive tap.

Transmission system
The collection of assets (transmission lines, cables, zone substation and associated equipment), whose purpose is to transmit power in bulk from a Transgrid supply point to a sub-transmission substation. The transmission voltage in the company's network is typically, but not exclusively, 132kV.

UGOH
Underground Overhead – a connection between overhead and underground mains.

Works
All of the work necessary to complete the contract as described in a standard or project and associated drawings.

XLPE
Cross linked polyethylene – a type of insulation used on cables

5.0 ACTIONS

5.1 General requirements

5.1.1 Safe Design
All earthing designs undertaken for the company will follow the principles of Safe design:

- Standard earthing safety practices are covered in this standard and associated standard drawings
- Any additional site specific safety requirements must be taken into account by the designers and constructors

The key information about identified hazards and action to control risks will be recorded and transferred from the design phase to the next stages of the lifecycle. Refer to section 5.6 design and as constructed documentation and storage.

5.1.2 Intended purpose and general requirement of earthing system
Earthing systems for distribution assets are required to manage the transfer of unbalanced or faulted network energy by low impedance paths back to the source and in this time to limit the risk to people, equipment and network reliability.

The design, selection and installation of the earthing systems for distribution systems must meet the minimum performance and functional requirements stated in this standard and EDI 001 - Earthing design risk assessment. When assets are augmented or improved, the integrity and safety of the existing earthing system must be evaluated in accordance with this instruction.

5.1.3 Power frequency earthing risk management
Power frequency hazard assessments associated with earthing are a requirement of all distribution network designs and must meet the design risk assessment requirements of EDI 001 – Earthing design risk assessment. The earthing design process is detailed further in Section 5.2.

5.1.4 Earthing design overview
The earthing design component of a project is an essential part of the overall design associated with a distribution asset. As part of Safe Design it is essential to undertake the earthing design in the early stages of the project so the risks can be eliminated or economically managed, and the proposed asset location may be chosen in such a way to limit the earthing risk.

Simplified design methods are provided in this instruction. When simplified design methods are followed correctly, it can provide a 'low risk' outcome. Refer to Annexure 1 for simplified design methods. If the simplified design method cannot achieve a 'low risk' outcome, the designer must provide a detailed analysis through the use of software and demonstrate that the earthing system design can achieve a 'low risk' outcome.

If a reasonably practical 'low risk' outcome cannot be achieved, then a design must target a level of risk that is 'As Low As Reasonably Practicable' (ALARP) in accordance with EDI 001 – Earthing design risk assessment. All designs targeting an ALARP risk level require approval in line with the requirements of Company Policy 9.2.5.

A properly designed earthing system must:

- provide appropriate current paths for fault energy in such a manner so as to limit the risk to people, equipment and system operations to acceptable levels. Hence, as a prime requirement, any earthing system will be designed so that the step, touch and transfer voltages that result from an earth fault comply with the requirements set out in EDI 001 - Earthing design risk assessment;
- limit the level of abnormal transient and power frequency voltages impressed on the electrical distribution system during equipment operation;
- HV earthing systems are designed for activation of primary earth fault protection as well as SEF. Refer to 5.2.7.2 for high impedance distribution earthing designs which require activation of SEF only;
- where practical, the LV earthing should always be accompanied by a low impedance MEN system to improve the safety of the LV system, and that the LV circuit design is such that the fault currents will activate the respective protective devices;
- stabilise the voltage under normal operating conditions. That is, to maintain the operating voltage at one level relative to earth so that any equipment connected to the system will experience the same operating voltage or potential difference, subjected to allowable variation due to conductor voltage drops; and
- minimise stray currents.

5.1.5 Robustness

The earthing system and its components will be capable of withstanding and conducting the expected fault current without exceeding material or equipment limitations for thermal and mechanical stresses as required in EDI001 – Earthing design risk assessment.

When designing an earthing system, it is important to reasonably consider the implications of future development around the asset as well as the potential for increased fault levels, clearance times or other earthing impacts. Data sourced from company either through the standards website or through direct contact will include provisions for network changes. However consideration of development around earthing assets and their effects are the responsibility of the designer and a sensitivity analysis must be part of the design to cater for future adequacy.

5.1.6 Modification to existing network

Augmentation or modification of an existing distribution asset will require a review of the integrity and safety requirements of the existing earthing system. Where it can't be demonstrated that the existing earthing system meets the integrity and safety requirements of this instruction, additional works may be required.

Any significant augmentation works to network that can change in Phase to Earth (P-E) fault level exceeding 10% must initiate a review of all impacted earthing systems. Work to achieve earthing compliance of associated earthing systems must be evaluated by a cost risk assessment.

The works that can change the fault levels include:

- change to network configuration: Planning section is required to be consulted for assessing change in fault levels; and
- Network augmentation works: Refer to Annexure 5 for the simplified fault level change determination for conductor augmentation.

When key components of the asset such as transformer, regulator etc. are replaced with uprated devices the earthing system will be assessed and redesigned to comply with the current standard. Full or part of the existing earthing system can be utilised for the new earthing system design provided existing earthing system has a minimum of 30 years remaining life left and meets the requirements of this standard. The target life of an earthing system can be assessed as 60 years (same as distribution underground cables).

During fault and emergency situations, if distribution assets such as transformers require a like-for-like replacement, a review of the integrity and safety requirements of the existing earthing system is not required. Existing earthing systems of higher rated replacements that do not meet the current safety compliance requirements must upgrade the earthing system to meet current standard requirements within six (6) months of the asset replacement or a time frame agreeable to Earthing and Power Quality Manager.

5.2 Distribution earthing design

5.2.1 Earthing design tools

The earthing design and associated risk management depends on site specific conditions including soil electrical resistivity, local short circuit fault levels, presence of auxiliary fault current return paths and separation from nearby metallic infrastructure. To assist in managing the design of the earthing systems for distribution equipment, the company developed earthing design tool '3E' is made available in company standards website. Use of this design tool is not mandatory but can assist in developing a robust and safe earthing design.

Commercially available earthing software with the facility for solving a minimum of two layer soil models can also be used by the earthing designer.

5.2.2 Design process

A simplified design process for distribution earthing design is provided in Table 5-1. A flow chart is provided in EDI 001 – Earthing design risk assessment.

Table 5-1: General power frequency earthing design process summary

Requirement / Process	Reference
Design context and consultation	5.2.3
Data gathering - Protection information - Soil electrical resistivity - Location and future planning provisions - Zone substation bonding configuration	5.2.4 5.2.4.1 5.2.4.2 5.2.4.3 5.2.4.4
Power frequency hazard assessment - Conservative compliance or - Detailed assessment of risk - Separation requirements other metallic infrastructure - Risk mitigation methods	5.2.7 5.2.7.1 5.2.7.2 5.2.8 5.2.9
Earthing design layout	5.2.6
Minimum separation from metallic infrastructure and other utilities assets	5.2.8
Earthing conductors and rating	5.3
Lightning requirements	5.2.12
Review and design acceptance	5.2.11
Documentation and storage	5.6

5.2.3 Design context and consultation

When new or existing distribution earthing systems are being designed or reviewed, the earthing designer will coordinate the earthing system design aspects of the asset with affected stakeholders. This may include the owners of any adjacent telecommunications, water, gas, railway and petroleum products systems as well as local councils and the company planners. Consultation will also occur with affected workers including the construction crew that will build the asset and associated earthing system.

5.2.4 Data gathering

As part of the initial design process, the following input data is required to develop an earthing design:

- fault level data and clearance times (refer 5.2.4.1);
- soil electrical resistivity (refer 5.2.4.2);
- details of existing and future planning associated with the surroundings (refer 5.2.4.3);
- zone substation bonding configuration (refer 5.2.4.4);
- site layout; and
- details of existing earthing systems if applicable.

5.2.4.1 Fault level data and clearing times

Single phase to earth (P-E) fault levels, connected ZS number and name, HV feeder number and connected customer connection points (CCP) for existing distribution substations are made available in an Excel worksheet on company standards website. Refer to Annexure 5 for a method to determine maximum fault current for safety and minimum fault current for protection operation.

For some specific earthing designs, if required, detailed protection information can be sought from the protection enquiries inbox. If the 3E tool is used for the design, the required protection information includes:

EF Pickup (e.g. 240A);
Time lever (e.g. 0.30);
Instantaneous setting (e.g. 13000A); and
IEC curve (e.g. SI).

The earthing system design will be based on the most onerous supply arrangements in terms of fault levels and clearing times and must consider all staging configurations. However, for the continuous operation, where an alternative supply arrangement is for emergency backup supply only and likely to be utilised for no greater than 1% of the year, then it need not be taken into account in the design.

5.2.4.2 Soil electrical resistivity

An accurate soil electrical resistivity model obtained from soil testing is necessary to determine the electrical characteristics surrounding the site and is essential in determining safety, sensitivity and reliability of an earthing system.

Two (2) soil resistivity tests must be carried out for each design to confirm the integrity of the readings, unless existing soil resistivity test results in the area are available. If this is the case then one (1) soil resistivity test must be carried out and existing results be used for verification. For further information on soil resistivity testing refer to EDI 0005 – Distribution earth testing.

5.2.4.3 Surroundings

It is essential that an earthing design considers the surrounding area and future development that could be reasonably expected. Provisions and suitable arrangement will be made in the earthing design for the management of transfer voltage risk which in some circumstances may require consultation with local councils, company network planners and other utilities.

Search of third party conductive assets surrounding the earthing system must be undertaken. This search will need to identify:

- other utility's assets (Dial before you dig); and
- all metallic objects that will surround the earthing system (for example: metallic fencing, metallic sign posts and street light columns).

Identification of the correct location category from the risk exposure types must be undertaken in accordance with EDI001 - Earthing design risk assessment.

5.2.4.4 Zone substation bonding configuration

A list of the company's zone substations with earth bonding configuration information is available from the company standards website.

The zone substation bonding strategy can have a large impact on the design of a distribution earthing system. Continuous and sufficient metallic return to source can considerably reduce the EPR at a site and therefore the risk and costs of earthing. A metallic return to source is encouraged in urban areas where practical. When designing an earthing system on a CMEN substation the designer must confirm that there is a traceable cable screen or LV neutral connection to the zone substation if metallic return is assumed in the design.

5.2.5 Distribution earthing configurations

Where HV and LV earthing systems exist in close proximity to each other, part of the earth potential rise (EPR) of the HV system can be transferred to the LV system. Two (2) practices are presently used:

- interconnection of all HV with LV earthing systems – referred to as Common Earthing; and
- separation of HV from LV earthing systems – referred to as Separate Earthing.

Common Earthing is the preferred practice where practical and is the usual practice in urban areas.

5.2.6 Earthing system layout

The distribution earthing system is made up of a number of components depending on the design. All components must be considered during the design process.

- earth rods – bare vertical electrodes driven into the general mass of the earth;

- grading ring – A buried horizontal ring of conductor around a substation or conductive pole used to make an equipotential area to reduce touch voltages;
- bonding conductors – The insulated conductors used to bond the different components of the earthing system to the equipment;
- cable screens – Where HV cables are present, the HV cable screen will often be a key component in the earthing system for returning fault currents to source; and
- LV neutral – If the earthing system is common earthed, a connection to the LV neutral will form part of the earthing system.

5.2.7 Power frequency hazard assessment

Any new or modified distribution assets will have an earthing power frequency hazard assessment carried out. Methods of hazard assessment, including simplified conservative compliance criteria are detailed in this section as well as in Annexure 1.

If the conservative 'pass' compliance criteria stated in 5.2.7.1 is achieved then the design meets a 'low risk' profile in accordance with EDI 001 – Earthing design risk assessment. If the 'pass' criteria of 5.2.7.1 cannot be achieved then a detailed assessment of risk is required in accordance with 5.2.7.2.

Dispensation must be requested for any risk modelled, calculated or measured that exceeds a level of 'low risk' from EDI 001 – Earthing design risk assessment. For designs exceeding low risk, dispensation requests must be submitted to the company including a risk cost benefit analysis in accordance with EDI 001 – Earthing design risk assessment. Details in the dispensation application will include all hazard reduction strategies considered and control strategies ruled out as they involve grossly excessive cost and the design option chosen must present the lowest risk-cost justified solution based on the site conditions.

5.2.7.1 Conservative compliance criteria

The following simplified earthing design assessment scenarios are provided to determine whether 'pass' conservative compliance design can be achieved. These methods will not be applicable to all cases, but where the required conditions are met these will allow the designer to follow a number of simple steps to complete their earthing design.

Common earthing in urban areas:

Two (2) Levels of assessment have been developed for simplified earthing designs for common earthed installations. A first 'pass' assessment, using customer numbers or MEN resistance only will be sufficient in most cases. Where all the conditions of this assessment cannot be achieved, a second pass assessment based on additional details of the system can be carried out. Where neither of these assessment methodologies are met; a detailed power frequency earthing design is required determining that the common earthed system meets the safety requirements of EDI 001 – Earthing design risk assessment.

Annexure 1 provides conditions for design methodologies for common earthing in urban areas.

Simplified design conditions are applicable to common earthed distribution or indoor substations and/or any other distribution equipment such as regulators, autotransformers and switching stations connected to common earthed systems.

In general, a common earthed installation will only be viable in an urban or industrial area with a well meshed MEN network or interconnected common earthed substations (through HV screens or LV neutrals).

Where an installation meets the conservative compliance criteria a single 4.8m or 2 x 2.4m electrodes are required as the HV earthing system.

5.2.7.2 Detailed assessment of earthing risk and design report

Where an earthing design does not qualify for one of the simplified/conservative earthing design methods, a detailed power frequency earthing design with risk assessment as outlined in EDI 001 Earthing design risk assessment is required. The designer may undertake the following process for achieving a successful design. The order of these steps is not essential, but each element must be assessed and included in the design report.

a) Determination of safe voltage limits

The safe voltage limits must be calculated using the protection clearing time applicable for the proposed earthing system with the proposed earthing system impedance, and the resistivity of the top soil if the depth of the top soil layer is more than 1m. If the top soil depth is less than 1m, the lowest soil resistivity value amongst the different soil layers that could be reasonably expected on the surface with provisions for the variation in soil resistivity due to moisture will be used for safety voltage limit determination. Low risk safety voltage limits are provided in EDI 001 – Earthing design risk assessment.

b) Location and hazard identification

The designer must design expected step, touch and transfer voltages on and around the asset in its current environment and for the reasonably foreseeable future to comply with the relevant safety limits. The safety voltage limits may vary for different contact scenarios for the same earth fault scenario, for example; Urban, Backyard and MEN. For this assessment modelling of earthing system and associated metallic assets is required.

c) Assessment of hazard voltages to conductive assets

The designer must evaluate the voltages at identified hazard locations near the earthing system.

d) Checking the compliance

The magnitude of the prospective step and touch voltage for each of the identified assets must be compared to the calculated safe voltage limits to confirm that the specified safety requirements in EDI 001 – Earthing design risk assessment are met.

e) Power system configuration and protection system operation

An assessment of the power system that will normally supply the asset must be undertaken. This assessment will need to identify:

- the nominal system voltage;
- the fault level and/or source impedances;
- impedance of MEN system if applicable;
- the protection device that would operate must a fault occur; and
- where future network configurations are reasonably known, these must also be considered.

The designer will propose an earth grid arrangement, including the number and length of the electrodes, the earthing system configuration (see section 5.2.5) and the designed earth grid resistance. This design will often be an iterative process, where the earth grid arrangement is re-designed if it is determined to be non-compliant until all residual risks have been addressed.

Wherever possible, the designed earth system must provide sufficient earth fault current for operation of primary earth fault protection as well as SEF. If the operation of primary earth fault protection is not economically viable, the earthing design completed to activate SEF operation only may be allowed based on a risk assessment. The reasons for selection of single protection application and details of meeting the other conditions of high impedance distribution earthing design will be stated in the assessment. See 5.2.7.3 for requirements of high impedance earthing designs.

f) Sensitivity analysis of resistance of earthing system(s)

The actual earthing system resistance can vary significantly to the designed earth resistance due to variations in the condition of the top soil. In order to guarantee the earthing system will perform as designed, sensitivity analysis of the earthing system resistance must be carried out.

The designer must determine the range of resistance values that the earthing system will comply. Earthing system tolerable values must be included in the earthing drawings. Refer to drawing 358689. These tolerable earth resistance values will be used for commissioning testing.

g) Lightning performance

Where the earthing system is for an overhead asset, the lightning performance of the system must also be considered (see section 5.2.12).

Detailed designs may require current injection testing (CIT) to prove compliance after construction at the discretion of Earthing & Power Quality Manager. During the CIT if any conductive assets are found to be noncompliant, risk mitigation works are required to be carried out prior to energising the asset. This risk mitigation works must be undertaken based on risk/cost justified basis in consultation with the Earthing and Power Quality Manager.

5.2.7.3 Requirements for high impedance earthing designs

In high impedance distribution earthing designs, a smaller earthing system with lower fault current and a slower protection clearing time may present less risk than a large earthing system with higher fault current and faster fault clearing time as the hazardous soil voltages will be contained to a smaller area around the earthing system.

Conditions for high impedance distribution earthing design:

- safety voltage compliance levels in EDI 001 – Earthing design risk assessment can be achieved. (For padmounts and switching stations, only earthing software capable of modelling grading ring and supplementary earth rods must be used. The 3E software tool cannot be used for this task);
- justification for a design to operate SEF protection vs primary earth fault protection. Modelling must use actual protection settings obtained from protection enquiries. Minimum fault current into the system must have a margin of at least two (2) times the SEF pickup and the feeder must have a confirmed SEF setting;
- this must include calculated risk levels for both options in accordance to EDI 001 - Earthing design risk assessment section 5.2.2. The Argon software tool may be used to assist;
- approval from Earthing and Power Quality Manager obtained for padmount high impedance designs. Other high impedance earthed distribution assets may be certified by the normal process; and
- a current injection test may be requested by the Earthing and Power Quality Manager as a condition of approval to verify the design.

5.2.8 Separation requirements to other metallic infrastructure

As a part of a separate earthing design the designer will need to determine the safe separation requirements from the HV earthing system to third party assets including communications assets, metallic pipelines, conductive structures and swimming pools near the HV earthing system unless the conservative compliance criterion is met. Determination of safe separation distance from HV earthing systems to specific third party assets is detailed below.

MEN connected equipment

Hazard voltages from faulted HV earth systems can be introduced to nearby MEN connected assets through soil voltage gradient. The required separation to any MEN connected equipment must be calculated for all separately earthed HV assets. The required separation is the distance until the soil voltage is expected to fall below the applicable TDMEN limit as stated in EDI 001 – Earthing design risk assessment unless it can be shown that the MEN system voltage rise on the MEN network is less than the TDMEN limit as a part of a detailed earthing design.

LV earth grid

If the substation is connected through a continuous LV neutral to one other distribution substation, then the required separation between HV and LV earth grids is either 4m or the maximum exposed electrode length of both the HV and LV earth grids (whichever is greater).

The separation between the HV and LV earth grids of separately earthed substations with no neutral interconnection to other substations is the distance until the soil voltage is expected to fall below the applicable TDMEN limit stated in EDI 001 – Earthing design risk assessment. If third party software is used to model the LV earth grid and its connections to the MEN, the separation between the HV and LV earth grids is the distance at which the MEN voltage falls below the TDMEN limit.

Transmission structures/earths

Separation distance to conductive transmission structures from distribution earthing must be a minimum separation of 15m as outlined in MDI 0047 – Overhead transmission mains design unless proven otherwise.

Telecommunications infrastructure

Telecommunications equipment must be sufficiently separated from a HV earthing system to comply with AS/NZS 3835. Refer to EDI 001 – Earthing design risk assessment for applicable EPR limits and Low Frequency Induction limits.

Pipelines

Hazardous voltages on conductive pipelines must be assessed as set out in AS/NZS 4853. Refer to EDI 001 – Earthing design risk assessment for applicable touch voltage limits and Low Frequency Induction limits.

Swimming pools and spas

The separation requirement around a common earthed asset for private swimming pools is 5m from any part of the earthing system.

Unless the required separation to private swimming pool (TDMEN limit) is determined in a detailed earthing design in accordance with this instruction and EDI 001 – Earthing design risk assessment, the required separation for private swimming pools near separately earthed assets is 30 metres.

Public swimming pools and aquatic centres will be assessed as special locations according to EDI 001 – Earthing design risk assessment.

Other metallic structures (fences or similar)

Where the common earthing configuration is used, the exclusion zones for conductive structures such as fences will be limited to the substation easement.

The separation requirement for metallic fences and other conductive structures around a separately earthed asset is the distance to the point where the soil voltage falls to the allowable touch voltage for the backyard contact scenario as stated in EDI 001 – Earthing design risk assessment. Where the metallic fence is appropriately mitigated through insulated sections (refer to drawing no. 332073 and 061674) fences may be installed within closer proximity to the earthing system. Refer to Annexure 4 for more information.

5.2.9 Risk mitigation

A list of engineering risk controls commonly used distribution earthing hazards are provided in Annexure 7.

5.2.10 Low voltage network earthing

The low voltage distribution earthing system will be built in accordance with AS/NZS 3000. Australia has adopted an MEN system of low-voltage distribution earthing. The MEN system is primarily a continuous electrical connection of consumer installation earthing and any low voltage equipment earthing through the LV neutral, which is further bonded to earth at several points; at the transformer LV neutral point; and with the substation LV earthing.

Hence, for LV earth faults that involve the neutral, the MEN system is inherently of low impedance. It must be noted that earth faults on the LV system are only generally detected if the connection to neutral is effective and continuous to the source substation. This is particularly the case due to the ongoing replacement of the copper water pipe water reticulation system with non-conductive pipes. If the nature of a LV fault is such that the return path is not through the neutral then the operation of LV protection is unlikely and could pose risk to safety. Thus the integrity of customer neutrals is essential to the health and safety of the public.

For a HV earth fault in a common earthed substation the MEN system can provide a low impedance path to earth depending on the number of consumer installations connected and the soil resistivity of the area. This characteristic, together with the low impedance of the neutral, generally will help to produce a large enough fault current to operate protective devices (fuses or circuit breakers) in the event of an earth fault, whilst limiting EPR. Care must be taken when bonding HV earths onto weaker MEN systems, as HV earth potential rise could pose excessive risk to all LVMEN bonded equipment.

Hence, care will be taken to maintain a low impedance MEN system and the integrity of the neutral connection. In some locations in the network, works may be required to strengthen the MEN system through additional spans of neutral conductor or augmented neutral conductor. Key criteria for the MEN network:

- the low voltage neutral must always be connected, and remain continuously connected across low voltage open points; and
- in order to enhance the safety of the MEN network, LV neutrals will be extended to adjacent existing LV mains where practical. This will increase the integrity of the MEN network improving customer safety.

5.2.10.1 LV earthing system for relevant substations

An LV earth grid is required for separately earthed substations. The LV earth grid must consist of a minimum of two (2) 2.4m electrodes and more if required to meet the conditions below.

The calculated resistance of the LV earths including MEN network and interconnected earths shall be sufficiently low by a safety factor of two (2) to establish that the substation HV protection will operate in the event of a HV line to LV line contact or a HV/LV winding insulation breakdown at an associated distribution transformer.

Note: Safety factor of two (2) means the current required to operate the HV protection must be twice the pickup of the associated protection, or twice the fuse rating where applicable.

Indicative MEN impedances to assist with this calculation are provided in Annexure 1.

If the substation is connected through a continuous LV neutral to one other distribution substation, then this is considered sufficient. Where this requirement proves difficult, the use of additional electrodes bonded to the LV neutral at multiple locations is required to meet the safety factor requirement.

The LV side of a distribution substation should be connected to the general MEN network where it is practical to do so. Supplies to single customers should only be used where it is the only option and the earthing risk is appropriately assessed. Such situations will require a much larger LV earth grid to meet the safety factor requirement.

5.2.11 Review and design acceptance

All earthing designs must go through at least one level of review. This means they must be checked and accepted by at least one person other than the designer, who understands the requirements of the earthing system and the requirements of this instruction.

5.2.12 Lightning requirements

In order to effectively discharge lightning into the ground, wherever practical, the earthing systems of HV overhead distribution equipment pole such as substations, regulators etc. must be designed such that they achieve a local resistance to earth of less than 100Ω. In high resistivity areas, or urban locations where earthing safety is improved by a smaller earth grid with a greater resistance, the earthing safety requirement will take precedence.

5.3 Earthing conductors and ratings

Insulated or bare cables form an integral part of the earthing system. Care will be taken to use conductors that will withstand the effects of corrosion due to the chemical composition of the soil in the area. For this reason, copper cables only have been specified in this document for underground application. If the ground appears to be or is known to be highly corrosive, especially to copper, a suitable bedding or covering material must be used with consideration for conductivity and rating. Details of corrosion assessment for earthing systems are provided in EDI 516 – Major Substation Earthing Design, Construct and Test.

All earth cables will be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on backup fault clearing time. Table 5-2 below shows the cable type for each purpose and the relevant 1 second current rating.

Table 5-2: Earth cable types and short circuit current ratings

Conductor purpose	Cable	Fault rating (kA)	
		1 second	2 seconds
Underground bonding & within substation cubicle	70sqmm Cu bare	11.9	8.4
	70sqmm Cu insulated	9.5	6.7
Earth down leads on poles	95sqmm Al XLPE/PVC	8.5	6.0

A I^2t relationship can be used to determine the rating for other fault durations:

For example, the 2 second rating of a 70mm^2 Cu bare cable is $= \sqrt{\frac{I(1s)}{t}} = \sqrt{\frac{11900^2}{2}} = 8415A$.

A bare aerial cable suitable for the fault rating with minimum size equivalent to 50mm^2 copper from the approved product list will be used for under slung earth wire. Construction requirement are to be submitted to Mains Asset Section using the dispensation application process.

5.4 Testing and ongoing maintenance

5.4.1 Testing after construction

After installation, the resistance of the earth system must be tested as outlined in EDI 0005 – Distribution earthing test. The test results must be compared with the designed earth resistance limits.

If the tests prove that the design requirements of this installation are not met, modifications may be required to the earth grid to confirm compliance with this instruction. This may involve adding more or deeper electrodes. Modifications must be made in consultation with the Earthing Designer.

Results of this test must be recorded in the company's Ellipse database and on works as executed drawings to provide a basis for maintenance earth testing thereafter.

5.4.2 Current injection testing and reporting

Current injection testing based on methods set out in EDI 0005 – Distribution earthing test may be required in critical locations as determined by Earthing and Power Quality Manager. A test report containing the following information must be forwarded to the Regional Services Manager/CWO/CWE for comparison with the design values:

- test method used;
- details of the instruments and the method used;
- table of step and touch voltage measurements taken for metallic objects in the vicinity;
- EPR reading and the distance from earth grid to other authority assets like Telstra installations, metallic pipes, and the like;
- graph of EPR measurements with respect to remote earth (potential difference-Volts versus distance from substation earth grid in metres); and
- soil resistivity values in minimum 2 layers (refer to EDI 0005 – Distribution earthing test).

5.5 Specific requirements for specific plant and equipment

5.5.1 Earth connections for a common earth system

For a common earthing system, all the applicable HV earth connections and the LV earth connections are bonded to one (1) earthing system unless the asset provides the first connection to the zone substation in which case the HV cable screens depend on the zone substation bonding arrangement (refer to section 5.5.14).

5.5.2 Indoor substations

All new indoor substations will be common earthed with a direct bond from the substation earthing system to building steel reinforcement in which it is situated. Refer to drawing 348263 in EDI 0006 – Earthing construction standard for the connection details for a common earthed indoor substation.

For all new indoor substations, a detailed construction drawing must be produced as part of the design. This drawing must identify all earthing connections.

It is required to restrict earthing related hazards to within the premises of the indoor substation rather than spreading onto public footpaths. To achieve this local earthing system may be installed underneath of the footprint of the substation, prior to pouring of the concrete for the floor for the basement. Alternatively local earths can be installed within the premises. Padmount substations installed on outdoor concrete floors for car parks etc. will be treated the same way as indoor substations for earthing. Any alternative earthing installation arrangements are to be based on an assessment of the practicality of applying this requirement and the risk associated with transferred voltages on the footpath area.

5.5.3 SWER substation earthing

The earthing of SWER substations (including SWER isolating transformers) must be designed for the continuous passage of electric load current in addition to safe performance in relation to protective earthing.

For SWER isolating substations, the earthing resistance of the HV earth must be designed such that during load current, the EPR at the substation does not exceed 20V.

Construction of SWER substations and isolating substations on conductive poles require an approval from Earthing and Power Quality Manager.

Two (2) separate and distinct earthing systems must be provided. They are:

- HV earthing system (Table 5-3)
- LV earthing system

Table 5-3: SWER TX maximum HV earth resistance

SWER transformer rating	Maximum HV earth resistance (Ω)
16 kVA	15.5
25 kVA	10.0
100 kVA	2.5

The low voltage earthing system of all SWER isolating and distribution transformers must be less than 10Ω.

5.5.4 Distribution substations within transmission and zone substation

The earthing requirements for distribution substations (Auxiliary supply) within a transmission or zone substation are not covered by this instruction as they form part of the major substation design. Refer to EDI 516 – Major Earthing Design, Construct and Test.

5.5.5 Pole mounted HV voltage regulators

The regulator surge arresters and any other conductive components will be bonded to earth. Where fitted, any associated switch handle will be installed as set out in Air break switch earth section in EDI 0006 – Earthing construction standard. Regulators must be carefully risk assessed as they require the use of a conductive pole.

5.5.6 High voltage underground to overhead terminations (HV UG/OH)

Earthing system for HV UG/OH must be designed to comply with EDI 001 – Earthing design risk assessment. Earthing requirements for UG/OH poles connecting feeder cables from ZS/TS are provided in the ZS/TS earthing design.

5.5.7 Air Break Switches

Air Break switches does not require a designed earthing system. Details of the required earthing is found in EDI0006 – Earthing construction standard.

5.5.8 Load break switches

LBS installed on conductive poles, on joint use transmission and distribution poles and installed on wood poles with other assets requiring earthing (for example HV ABC catenary), a properly designed permanent earthing system for LBS is required to be installed.

A designed earthing system is not required for new load break switches (LBSs) installed on wood poles with no other assets requiring earthing. Refer to EDI 0006 – Earthing construction standard.

5.5.9 Auto recloser earthing

Auto reclosers require a full earthing design in accordance with this standard. Where the recloser/switch is fitted with remote terminal units (RTU) is separately earthed and has an LV supply, the LV supply for the RTU will be isolated from the switch case and HV earth with an isolating transformer (this is not required where the system is common earthed where it may be directly connected). The voltage rating other isolation transformer will be sufficient so that EPR during HV fault is not transferred to the LV neutral. The earthing arrangements for feeder automation (DFA) switches are shown on drawing 348255 and 348256 in EDI 0006 – Earthing construction standard.

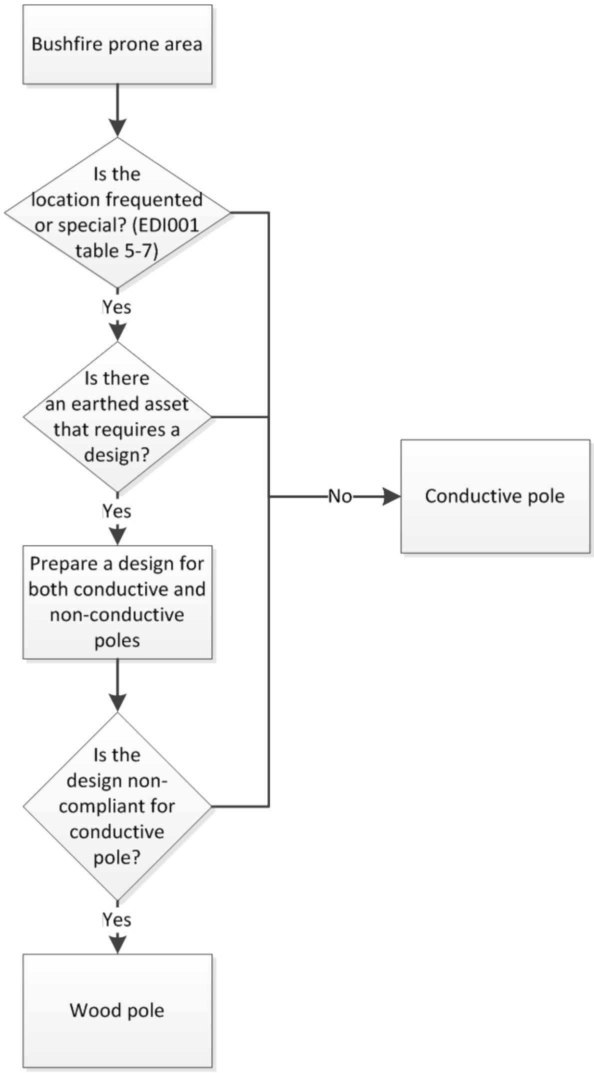
5.5.10 NMSHVABC – catenary earthing

Earthing system for NMSHVABC – catenary must be design to comply with EDI 001 – Earthing design risk assessment.

5.5.11 Use of Conductive poles in bushfire prone areas

Concrete/steel poles are required to be used in bushfire prone areas (including bushfire buffer zone areas) in order to mitigate risks associated with bushfires. As concrete/steel poles are conductive they can increase the risk associated with touch and transfer voltages. Where the asset is to be installed in a bushfire prone area the design must consider the use of a concrete pole. Touch voltage on these poles may be managed with secondary mitigations such as an insulating coating.

If the design shows that a negligible earthing risk cannot be achieved with a concrete/steel pole with secondary mitigation, a timber pole may be used. This exception of using timber pole does not apply to HV poles supporting only HV or HV+LV mains with no other distribution equipment. The assessment requirements for conductive poles are illustrated below.



5.5.12 Distribution equipment and lines on conductive transmission or sub-transmission structures.

For information on distribution assets on transmission poles refer to MDI 0047 – Overhead transmission mains design and EDI 0004 – Earthing design, construction and testing of overhead transmission mains.

5.5.12.1 HV distribution equipment on conductive transmission or sub-transmission structures.

Distribution substations and UGOH terminations for cables supplying distribution substations must not be installed on conductive structures that carry sub-transmission or transmission Voltages without a detailed analysis of the impact of a fault on the transmission network and its effect on the distribution earthing system subject to prior approval from the Earthing & Power Quality Manager.

Other distribution assets such as LBSs may be installed on conductive transmission or sub-transmission poles, subject to an assessment of step, touch and transfer voltages in accordance with this instruction and EDI 001 – Earthing risk assessment.

5.5.12.2 Low voltage equipment on conductive transmission or sub-transmission structures.

LV, streetlight conductor, UGOHs and streetlight fittings must not be installed on a conductive transmission pole or structure unless the insulation requirements are determined in an earthing assessment of the transmission structure unless they are insulated in accordance with the requirements of MDI0047 – Overhead transmission mains design.

5.5.13 Conductive distribution poles

Conductive poles carrying HV distribution mains must be considered as part of the HV earthing system.

5.5.13.1 HV construction only

Conductive poles shall not be used in separate earthing areas unless they are in a bushfire prone area as detailed in section 5.5.11.

5.5.13.2 Additional earthing electrodes

If required, additional earth electrodes may be required and connected to the earthing ferrule to reduce earthing resistance of conductive poles. Concrete poles carrying HV conductors in areas with soil electrical resistivity exceeding 2000Ωm will require additional earthing to confirm that SEF protection will operate at 20A. NMSHVABC or an underslung earth wire can also be considered part of the HV earth system to provide a sufficiently low resistance to operate SEF.

5.5.14 First cable out (connection to zone substations)

No distribution voltages will be reticulated into major substations without prior approval from the Earthing & Power Quality manager. The earthing and bonding at both the major substation end and the first asset being supplied must be assessed. Similarly where reticulation works affect the first asset out of a zone substation (that is, such as a new substation installed on an existing first cable out) – a review of the next asset supplied or second asset from the zone substation may be required to confirm earth continuity as appropriate. This will be described in any approval from the Earthing & Power Quality Manager.

5.6 Design and as constructed information documentation and storage

5.6.1 Safety Information

Key information about identified hazards and action to control risks will be recorded and transferred from the design phase to the next stages of the lifecycle. This safety information will be included in the design drawings particularly where designs deviate from this standard.

5.6.2 Drawing information

For all new and augmented earth installations, the following information must be provided in the project drawings in the format given in Drawing no. 358689 (refer SAD 0001 – Project Drawing Standards). This format must be used to provide for easy capture of the earthing information to GIS.

Company's asset management database (Ellipse) will be updated with this information.

Company Project Managers or CWO/CWEs will confirm that correct information is transferred to Ellipse and GIS earthing layer before closing the project.

5.6.3 Reporting

Where a detailed earthing design risk assessment is required, a report must be generated. As a minimum, this report must detail the following:

- soil resistivity model used, and the location the measurements were taken;
- the relevant safety criteria used, and demonstrated compliance to these;
- assessment of safety of other utility assets (if applicable);
- risk assessment in accordance with EDI 001 – *Earthing design risk assessment*;
- any testing requirements;
- any assumptions made in the design; and
- reports on fault current distribution, EPR and touch voltages generated from the earthing design software.

This report must be filed with the design packet, such that it can be accessed for the life of the asset.

5.7 Standard drawings

Earthing Information Drawing

Drawing no.	Amd. no.	Subject / Title
358689	B	Format of Earthing information on Project Drawings (Page 1 and 2)

6.0 AUTHORITIES AND RESPONSIBILITIES

Manager Asset Standards and Designs has the authority and responsibility for:

- approving this amended instructions; and
- approving any variations to the requirements of this instruction.

Substation Design Manager has the authority and responsibility for:

- endorsing this instruction; and
- recommending changes and revisions to this instruction.

Manager Network Connections has the authority and responsibility for establishing that:

- earthing designs are carried out for all network projects in accordance with the design and the standard;
- contractors construct/install the earth systems in accordance with the design and this standard;
- earthing designs are carried out for all network projects in accordance with the design and the standard;
- test results comply with the design and this Standard; and
- data is uploaded into the Ellipse and GIS databases where such data is forwarded by the ASP.

Regional Service Managers are responsible for establishing that:

- earthing design, construct and installation are carried out for all network projects in accordance with the design and this standard;
- earthing related data is uploaded into the Ellipse and GIS databases;
- test results comply with the design and this standard;
- the work performed is carried out in accordance with local and statutory requirements;
- standard risk management principles and procedures are followed and public safety is not unduly compromised within their reasonable capability; and
- clarification of this standard is sought, where necessary, from Earthing & Power Quality Manager.

Earthing & Power Quality Manager has the authority and responsibility for:

- revising and updating this instruction in accordance with Endeavour Energy's Policy and Procedures; and

- recommending changes and revisions to this instruction.

Protection Manager has the authority and responsibility for:

- providing and reviewing fault level information for regular update on the ASP Standards website; and
- providing fault level and clearance times on request from Regional Services or Network Connections.

Earthing Designers are responsible for:

- carrying out all design and construction works as set out in this design standard;
- seeking clarification of this standard, where necessary;
- confirming that work performed is carried out in accordance with local and statutory requirements;
- confirming that standard risk management principles and procedures are followed and public safety is not unduly compromised within their reasonable capability; and
- coordinating the appropriate consultation with relevant stakeholders including but not limited to owners of any adjacent telecommunications, water, gas, and petroleum products systems as well as local councils and network planners.

7.0 DOCUMENT CONTROL

Documentation content coordinator: Earthing & Power Quality Manager

Documentation process coordinator: Standards Process Coordinator

Annexure 1: Conditions and methodology for common earthed system design

The simplified design method for common earthing can be broken down into three (3) stages, each stage increasing in complexity and data requirements

Level 1 – Conservative compliance criteria, using customer numbers only – detailed below

Level 2 – Predetermined voltage limit criteria, using system configuration to develop target system impedance.

Level 3 – Risk based compliance. A detailed power frequency earthing study modelling the entire earthing system to establish that all relevant safety criteria are satisfied. (This will require sophisticated earthing modelling software, and a sound knowledge of power system earthing design).

The basic requirement is that the impedance of the earthing system, looking into the earthing network from any potential fault point, should be low enough to minimise the EPR and confirm that the step, touch and transfer voltages are maintained at acceptably low levels. In general this will require a large MEN network with sufficient parallel paths for fault currents. By way of example, large congregations of residential subdivisions connected together satisfy this condition.

Where a distribution asset meets a) and b), below it qualifies to be connected as a common earthed asset.

a) is connected to a residential , commercial or industrial distribution network where the low voltage neutrals are connected to the general mass of earth using the MEN system; and,

b) the requirements of the simplified earthing design method detailed below can be met;

Level 1 – Conservative compliance criteria

Compliance with these requirements meets the ‘low risk’ profile of ENA EG-0 in accordance with company policy. Simplified conservative common earthing compliance requires:

- Two (2) solid earth connections from the HV equipment under design into the wider MEN system either through adequately rated HV screens of LV neutrals.
- Is connected to a MEN system with the upper layer of soil resistivity less than or equal to 100Ωm and meets the earth system impedance (MEN Ω) in the table below based on the associated fault level. Multiple soil resistivity tests in the area may be required to confirm that the soil model represents the entire area.
- Has local HV earthing associated with the distribution assets of 7Ω (for example that typically provided by five 4.8m long bare vertical electrodes at soil resistivity of 100Ωm)
- If bonded to the source zone substation deliberately through HV screens and/or LV neutral assumed to have between 50% and 75% of current returning through metallic paths and not through the general mass of the earth.

The specified protection:

- Table A4-1: HV installations protected by an upstream fuse with rating of less than 40A; commonly used for pole substations rated 400kVA or less or along overhead spur lines.
- Table A4-2: HV installations protected by an upstream circuit breaker and associated relay with a IEC standard inverse characteristic, time multiplier of 0.2 and pick-up of 240A (typical Endeavour Energy distribution curve characteristic). This protection assumption is commonly used for all padmount substation assets.

- Table A4-3: HV installations protected by an upstream circuit breaker and associated relay with a IEC standard inverse characteristic, time multiplier of 0.13, pick-up of 200A and high-set of 3.6kA – new Endeavour Energy distribution curve characteristic. This protection assumption is used for new or modified CB's which can be obtained from Endeavour Energy.

Location categories as specified:

- AQ12: High public and societal contact likelihood assuming wet bare hands and feet exposed 12 months per annum.
- TDMEN Normal: Normal public contact likelihood with affected MEN bonded metallic infrastructure with typical mix of footwear.

Table A4-1: Level 1 common earthing assessment - 40A Fuse protected

Touch voltage curve		**AQ12** Locations				**TDMEN** Normal Locations			
Metallic connection to source		Yes		No		Yes		No	
I_{lg} (kA)	t_c (s)	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω
0.10	15	50	1.60	250	0.40	30	2.80	130	0.70
0.15	2.4	60	1.50	310	0.34	30	2.29	170	0.57
0.20	1.1	60	1.35	310	0.34	40	2.21	170	0.55
0.25	0.66	60	1.35	310	0.34	40	2.21	170	0.55
0.50	0.15	60	1.35	310	0.34	40	2.21	170	0.55
1	0.04	60	1.35	310	0.34	40	2.21	170	0.55
2	0.02	100	0.91	500	0.23	60	1.33	320	0.33
4	0.02	220	0.45	1160	0.11	140	0.67	730	0.17
8*	0.02	500	0.23	2680	0.06	320	0.33	1690	0.08
16*	0.02	1160	0.11	*N/A*	*N/A*	730	0.17	3920	0.04

*Boric acid fuse are required where the fault level exceeds 8kA

Table A4-2: Level 1 common earthing assessment - CB Protected: Traditional Endeavour Settings

Touch voltage curve		**AQ12** Locations				**TDMEN** Normal Locations			
Metallic connection to source		Yes		No		Yes		No	
I_{lg} (kA)	t_c (s)	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω
0.30	6.42	360	0.30	840	0.15	190	0.51	440	0.26
0.50	2.01	540	0.21	1250	0.11	290	0.36	670	0.18
0.75	1.33	750	0.16	1720	0.08	410	0.27	950	0.13
1	1.08	870	0.14	2010	0.07	480	0.24	1110	0.12
2	0.75	1290	0.10	2980	0.05	710	0.17	1630	0.09
3	0.65	1630	0.09	3790	0.04	850	0.15	1970	0.07
4	0.59	1660	0.08	3840	0.04	860	0.15	1990	0.07
5	0.55	2170	0.07	*N/A*	*N/A*	1130	0.12	2610	0.06
6	0.53	2710	0.06	*N/A*	*N/A*	1400	0.10	3250	0.05
8	0.49	2670	0.06	*N/A*	*N/A*	1470	0.09	3400	0.05
10	0.47	3500	0.05	*N/A*	*N/A*	1920	0.07	*N/A*	*N/A*
12	0.45	*N/A*	*N/A*	*N/A*	*N/A*	2400	0.06	*N/A*	*N/A*

Table A4-3: Level 1 common earthing assessment - CB Protected: New Endeavour Settings

Touch voltage curve		**AQ12** Locations				**TDMEN** Normal Locations			
Metallic connection to source		Yes		No		Yes		No	
I_{lg} (kA)	t_c (s)	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω	Electrodes	MEN Ω
0.30	2.36	310	0.34	710	0.17	170	0.57	380	0.29
0.50	1.09	380	0.29	870	0.14	210	0.47	480	0.24
0.75	0.79	390	0.28	910	0.14	220	0.46	500	0.23
1	0.66	430	0.26	1000	0.13	230	0.44	520	0.22
2	0.49	500	0.23	1150	0.11	280	0.37	630	0.19
3	0.43	640	0.18	1490	0.09	370	0.29	860	0.14
4	0.20	640	0.18	1490	0.09	370	0.29	860	0.14
5	0.20	840	0.15	1950	0.07	490	0.23	1130	0.12
6	0.20	1050	0.12	2430	0.06	610	0.19	1410	0.10
8	0.20	1490	0.09	3440	0.05	860	0.14	2000	0.07
10	0.20	1950	0.07	*N/A*	*N/A*	1130	0.12	2620	0.06
12	0.20	2430	0.06	*N/A*	*N/A*	1410	0.10	3270	0.05

Notes:

- *Metallic connection to source: means continuous metallic return to source substation and source substation is deliberately bonded into the distribution earthing system (CMEN) through HV cable sheaths and/or LV neutrals.*
- *I_{lg} (kA): total prospective fault current (kA) at the distribution assets (refer annexure 9)* t_c (s): *Fault clearing time in seconds,*
- *Table* A4-1 - *40A fuse protection,* Table A4-2 - *HV CB and relay protected with IEC SI 0.2TL and 240A Pickup,* Table A4-3 Table - *HV CB and relay protected with IEC SI 0.13TL, 200A pickup and high-set of 3.6kA.*
- *Customer Installations: is the equivalent number of interconnected low voltage 1m electrodes in parallel with the HV earth associated with the MEN system connected in close proximity to the substation or distribution asset.*
- *MEN Ω: is the equivalent earth input impedance in ohms which is likely to be seen at this point in the network with the number of LV electrodes above.*

Level 2 – Predetermined voltage limit criteria

When level 1 cannot be achieved, common earthing can still be utilised using a level 2 assessment. This level of assessment can also be used where the soil resistivity exceeds 100 Ωm. The underlying requirement behind a level 2 assessment is the calculation of required earthing impedance based on more site specific conditions. Compliance with these requirements meets the ‘low risk’ profile of ENA EG-0 in accordance with company policy. Level 2 assessment can be undertaken using the 3E tool.

Note: Common earthing can still be achieved by measurement or calculation provided a detailed earthing study is undertaken.

Simplified voltage based criteria for common earthing compliance requires:

A. Two (2) solid earth connections from the HV equipment under design into the wider MEN system either through adequately rated HV screens and/or LV neutrals.

B. Has local HV earthing associated with the distribution assets of 7Ω (for example that typically provided by five 4.8m long bare vertical electrodes at soil resistivity of 100Ωm)

C. If bonded to the source zone substation deliberately through HV screens and/or LV neutral assumed to have a factor, K, of current returning to the source through metallic paths. This factor is determined by the inverse of the earth fault current which flows from the main circuit to the general mass of the earth divided by the total fault current including the portion of fault current which flows back to the transformer neutral point via the metallic parts without ever discharging into the soil. $\boldsymbol{K} = \left(\frac{\boldsymbol{I_g}}{\boldsymbol{I_f}}\right)^{-1}$

D. Have a factor, F, applied which is the inverse of the prospective touch voltage U_T as a proportion of the maximum EPR. $\boldsymbol{F} = \left(\frac{\boldsymbol{U_T}}{\boldsymbol{EPR}}\right)^{-1}$ where the U_T limit is defined by U_{TDMEN}. This value takes into account that the touch voltages will typically only be a portion of the total EPR.

E. The specified protection clearance time can be calculated or be based on:
- **i.** Table A4-4: HV installations protected by an upstream fuse with rating of less than 40A; commonly used for pole substations rated 400kVA or less or along overhead spur lines.
- **ii.** Table A4-5: HV installations protected by an upstream circuit breaker and associated relay with a IEC standard inverse characteristic, time multiplier of 0.2 and pick-up of 240A (typical Endeavour Energy distribution curve characteristic). This protection assumption is commonly used for all padmount substation assets.
- **iii.** Table A4-6: HV installations protected by an upstream circuit breaker and associated relay with a IEC standard inverse characteristic, time multiplier of 0.13 and pick-up of 200A and an instantaneous high set at 3.6kA (new Endeavour Energy distribution curve characteristic). This protection assumption is only to be used for padmount substation where these protection settings are known to be used.

F. Location categories as specified:
- **i.** Wet TDMEN: High public contact likelihood assuming wet bare hands and feet.
- **ii.** Normal TDMEN: Normal public contact likelihood with affected MEN bonded metallic infrastructure with typical mix of footwear.

The methodology is as follows:

In order to allow the interconnection of low-voltage and high-voltage earthing systems, the following EPR limit must be obtained:

(A4E1) $\boldsymbol{EPR_{MAX} = F.U_{TDMEN}}$

Where,

F is the touch voltage factor which is the inverse of the prospective touch voltage U_T as a proportion of the maximum EPR. $\boldsymbol{F} = \left(\frac{\boldsymbol{U_T}}{\boldsymbol{EPR}}\right)^{-1}$ where the U_T limit is defined by U_{TDMEN}.

- In homogenous soil with typical evenly distributed lot sizes not exceeding 1200m2; the F-factor curve shown in Figure A4-1 can be conservatively applied depending on the number of LV MEN connections available in close proximity. This has been created to represent the worst case mesh voltages within an MEN system but also consider possible weaknesses at MEN system extremities.
- Where the MEN only consist of a single customer earth, F should be 1.

U_{TDMEN} is the maximum allowable touch voltage to be considered ‘low risk’ in accordance with company policy. It is provided in EDI 001 – Earthing Risk Assessment or can be gathered from the tables below depending on the associated clearance time.

Figure A4-1: F-factor allowance

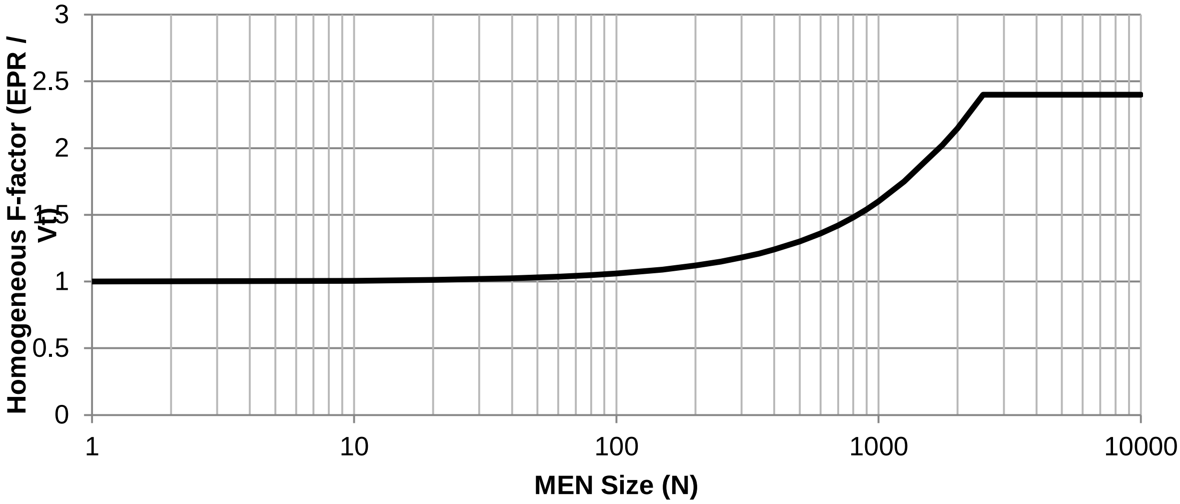


Table A4-4: Level 2 Common earthing assessment - 40A Fuse protected

Fault Level – I_f (kA)	Clearing Time – t_c (s)	Maximum allowable prospective touch voltage – low risk				
		EG0	EG0 [U_{TDMEN} (V)] – soil resistivity			
		AQ12	50 Ωm	100 Ωm	200 Ωm	500 Ωm
0.15	10.00	40	68	70	76	95
0.20	2.50	49	80	86	92	113
0.25	1.20	64	101	106	116	142
0.30	0.70	104	163	171	192	247
0.35	0.50	169	271	291	326	420
0.40	0.30	300	440	471	541	747
0.45	0.30	300	440	471	541	747
0.50	0.20	369	541	579	650	897
0.75	0.06	454	621	665	800	1210
≥1.00	0.06	454	621	665	800	1210

Table A4-5: Level 2 Common earthing assessment - HV CB Protected: Standard Endeavour Settings

Fault Level – I_f (kA)	Clearing Time – t_c (s)	Maximum allowable prospective touch voltage – low risk				
		EG0	EG0 [U_{TDMEN} (V)] – soil resistivity			
		AQ12	50 Ωm	100 Ωm	200 Ωm	500 Ωm
0.25	10.10	40	68	70	76	95
0.50	2.01	53	85	89	96	118
0.75	1.33	61	95	100	110	135
1.00	1.08	68	107	112	122	152
1.50	0.86	83	129	135	148	188
2.00	0.75	96	151	157	175	225
2.50	0.69	107	168	176	197	255
3.00	0.65	116	186	198	219	286
4.00	0.59	132	213	228	251	330
5.00	0.55	149	237	254	282	367
6.00	0.53	157	255	273	305	394
8.00	0.49	175	280	300	336	435
10.00	0.47	187	301	320	359	471
12.00	0.45	199	316	334	375	497

Table A4-6: Level 2 Common earthing assessment - HV CB Protected: New Endeavour settings

Fault Level – I_f (kA)	Clearing Time – t_c (s)	Maximum allowable prospective touch voltage – low risk				
		EG0	EG0 [U_{TDMEN} (V)] – soil resistivity			
		AQ12	50 Ωm	100 Ωm	200 Ωm	500 Ωm
0.25	4.21	35	75	77	84	103
0.50	1.09	50	106	111	122	150
0.75	0.79	62	142	148	163	210
1.00	0.66	74	180	191	212	276
1.50	0.55	95	238	255	284	369
2.00	0.49	111	280	299	335	434
2.50	0.45	127	314	332	373	493
3.00	0.43	135	331	349	392	522
4.00	0.2	256	541	579	650	897
5.00	0.2	256	541	579	650	897
6.00	0.2	256	541	579	650	897
8.00	0.2	256	541	579	650	897
10.00	0.2	256	541	579	650	897
12.00	0.2	256	541	579	650	897

Notes:

- I_{lg} *(kA): total prospective fault current (kA) at the distribution assets (refer Annexure 5)*
  t_c (s): *Fault clearing time in seconds,*
- Table A4-4 - *40A fuse protection,* Table A4-5 - *HV CB and relay protected with IEC SI 0.2TL and 240A Pickup,* Table A4-6 - *HV CB and relay protected with IEC SI 0.13TL, 200A pickup and high-set of 3.6kA.*
- U_{TDMEN} *is the maximum allowable prospective touch voltage to be considered 'low' risk.*

In order to determine the minimum impedance to earth at 50Hz (Z_E) required to obtain the 'low risk' limit in accordance with Endeavour Energy company policy; the following equation shall be satisfied:

(A4E2) $$\boldsymbol{Z_E \leq K.\frac{EPR_{max}}{I_f}}$$

Where,

K is a factor determined by the inverse of the earth fault current which flows from the main circuit to the general mass of the earth divided by the total fault current including the portion of fault current which flows back to the transformer neutral point via the metallic parts without ever discharging into the soil. $\boldsymbol{K = \left(\frac{I_g}{I_f}\right)^{-1}}$

- Where a zone-substation has deliberate and parallel metallic paths bonded into the distribution system (either through HV sheaths and/or LVMEN) and the distribution asset being designed has path(s) back to the source, the value of K can be assumed to be 2. Higher values of K may be applied within 1km of the zone-substation or if a dedicated HV cable screen is available as shown by measurement or calculation. See EDI 001 - Earthing Risk Assessment for more information.
- Where the zone-substation is not bonded into the distribution earthing system or the asset being designed does not have a metallic return to the source for instance an overhead fed pole substation feeding an isolated MEN system, the value of K must be set to 1.

This minimum impedance requirement is the parallel impedance of the local earth grid, earthing impedance of nearby earth grids bonded by HV screens and earthing impedance of the bonded LV multiple earthed neutral network in the area (MEN).

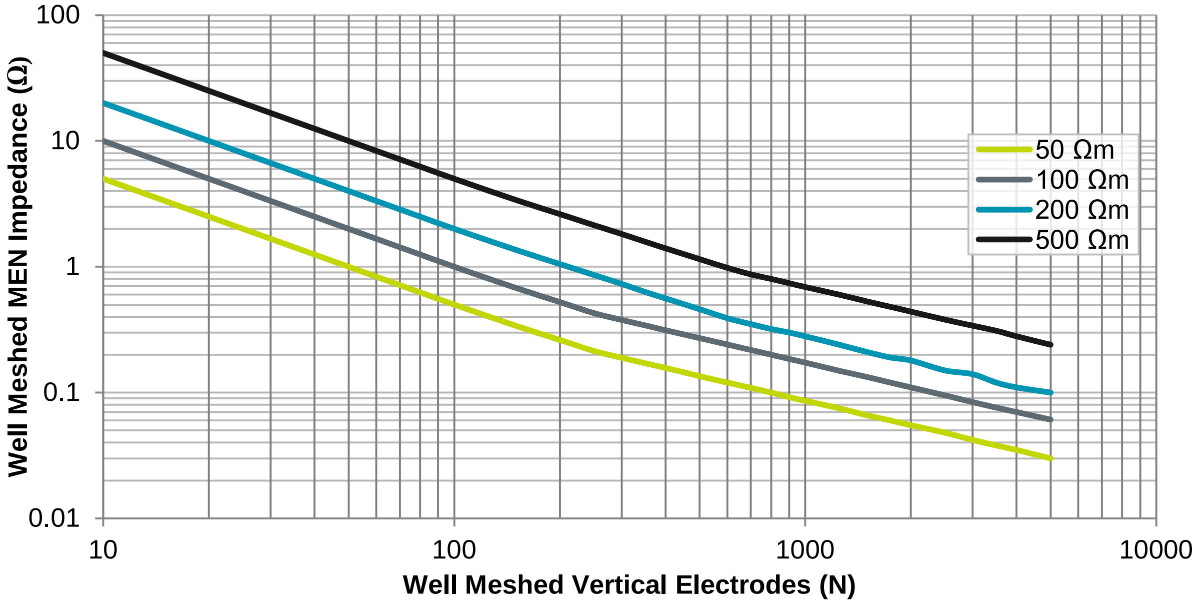
(A4E3) $$\boldsymbol{Z_E} = \left(\frac{\mathbf{1}}{Z_{HVlocal}} + \frac{\mathbf{1}}{Z_{HVbonded}} + \frac{\mathbf{1}}{Z_{MEN}} + \cdots\right)^{-\mathbf{1}}$$

A Z_{MEN} impedance table is provided in below to assist with this calculation.

The following table may be used to determine the indicative well-meshed MEN impedance value in homogenous soil models, or where the upper layer of a two layered soil model is greater than 2m in depth:

Table A4-7: Well meshed indicative MEN network impedance

MEN input numbers (n)	Well meshed indicative MEN network impedance: Z_{MEN} (Ω)			
	50 Ωm	100 Ωm	200 Ωm	500 Ωm
10	5.000	10.000	20.00	50.00
20	2.500	5.000	10.00	25.00
40	1.250	2.500	5.00	12.50
60	0.833	1.667	3.33	8.33
80	0.625	1.250	2.50	6.25
100	0.500	1.000	2.00	5.00
150	0.339	0.678	1.36	3.39
200	0.262	0.524	1.05	2.62
250	0.214	0.428	0.86	2.14
300	0.189	0.378	0.73	1.82
350	0.171	0.342	0.63	1.58
400	0.157	0.313	0.56	1.40
500	0.135	0.271	0.46	1.15
600	0.120	0.241	0.39	0.98
700	0.109	0.218	0.35	0.87
800	0.100	0.200	0.32	0.80
900	0.092	0.185	0.30	0.74
1000	0.086	0.173	0.28	0.69
1250	0.075	0.149	0.24	0.60
1500	0.066	0.133	0.21	0.53
1750	0.060	0.120	0.19	0.48
2000	0.055	0.110	0.18	0.44
2500	0.048	0.095	0.15	0.38
3000	0.042	0.084	0.14	0.34
3500	0.038	0.076	0.12	0.31
4000	0.035	0.070	0.11	0.28
5000	0.030	0.061	0.10	0.24



Care shall be taken when using these values particularly when a LV neutral needs to be run a sufficient length to reach the well meshed MEN network. In such situations the self-impedance of LV neutral metallic cable sheath or overhead neutral shall be added in series to the Z_{MEN} impedance.

The methodology above is based on IEC 61936:2010, AS/NZS 7000:2010 and ENA EG-0.

Level 3 – Risk based compliance

If Level 1 or 2 cannot be achieved, common earthing can still be allowed based on a detailed assessment of risk as set out in EDI 001 - Earthing Risk Assessment (refer EDI 001 – Earthing Risk Assessment and 5.2.7).

Any risk modelled, calculated or measured that exceeds the risk appetite of EDI 001 – Earthing Risk Assessment must be submitted to the Earthing & Power Quality Manager six (6) weeks' prior to any required certification of the design. This shall be done using the dispensation process including risk management procedures provided in Division Procedure GNV 1062 – Granting Dispensation from Network Standards and Company Procedure GRM 0003 – Risk Management. Any risk exceeding the "low risk" limit is subject to approval by the General Manager Asset Management.

Annexure 2: Calculation of the resistance of an electrode system

Single electrode

Electrode resistance can be calculated from the length and radius of the electrode and the average soil resistivity (ρ), as follows:

(a) Measure the length of an electrode (**L**), in metres, and its radius (**r**), in metres.

(b) Calculate the resistance of the electrode from:

$$R = \frac{\rho}{2\pi L}\left[\ln\left(\frac{4L}{r}\right) - 1\right]$$

Where R = resistance of electrode in ohms (Ω)

ρ = average soil resistivity, in ohm metres (Ω-m)

L = length of electrode, in metres (m)

r = radius of electrode, in metres (m)

Multiple electrodes

Combined resistance of multiple electrodes in parallel, yield a higher resistance to ground than normally expected resistance value of a parallel combination of resistances due to proximity effect.

To calculate resistance of an earthing system with several earth rods installed with separation equal to rod length, use the multiplying factor (F) stated in the table 4.6 of IEEE 142-2007. This calculation is applicable to rods in a straight line, hollow triangle, circle or a square.

Table A5-1: Multiplying factor for multiple rods in parallel from IEE STD 142-2007

Number of rods	F	Number of rods	F
2	1.16	12	1.80
3	1.29	16	1.92
4	1.36	20	2.00
8	1.68	24	2.16

Example: To calculate the effective resistance of four electrode system in parallel.

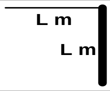
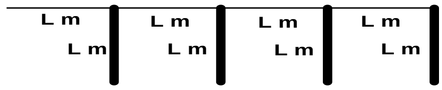
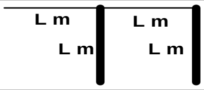
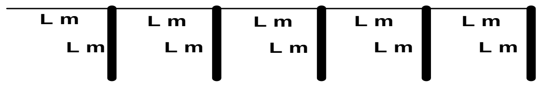
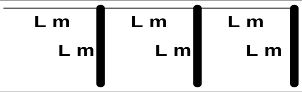
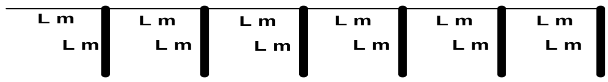
Resistance R for one rod calculated using above formula is 20 Ω.

The resistance value of a four rod system is $\frac{20}{4} \times (1.36) = 6.8\,\Omega$

Table A5-2 is for easy reference to derive the combined resistance of a parallel rod earth system where soil resistivity is ρ (Ω-m) and the electrodes are bonded with insulated cables.

To compute resistance (R) of an electrode system.

Table A5-2: Electrode system resistance

Number of rods	Rod length L (m)	Electrode system resistant (R) Ω	Number of rods	Rod length L (m)	Electrode system resistant (R) Ω
					
1	2.4	0.4081xρ	4	2.4	0.1388xρ
1	4.8	0.2271xρ	4	4.8	0.0772xρ
1	7.2	0.1603xρ	4	7.2	0.0545xρ
1	9.6	0.1250xρ	4	9.6	0.0425xρ
1	12	0.1030xρ	4	12	0.0350xρ
1	14.4	0.0878xρ	4	14.4	0.0299xρ
1	16.8	0.0767xρ	4	16.8	0.0261xρ
1	19.2	0.0683xρ	4	19.2	0.0232xρ
					
2	2.4	0.2367Xρ	5	2.4	0.1175xρ
add 2	4.8	0.1317xρ	5	4.8	0.0654xρ
2	7.2	0.0930xρ	5	7.2	0.0462xρ
2	9.6	0.0725xρ	5	9.6	0.0360xρ
2	12	0.0597xρ	5	12	0.0297xρ
2	14.4	0.0509xρ	5	14.4	0.0253xρ
2	16.8	0.0445xρ	5	16.8	0.0221xρ
2	19.2	0.0396xρ	5	19.2	0.0197xρ
					
3	2.4	0.1755xρ	6	2.4	0.1034xρ
3	4.8	0.0976xρ	6	4.8	0.0575xρ
3	7.2	0.0689xρ	6	7.2	0.0406xρ
3	9.6	0.0538xρ	6	9.6	0.0317xρ
3	12	0.0443xρ	6	12	0.0261xρ
3	14.4	0.0378xρ	6	14.4	0.0222xρ
3	16.8	0.0330xρ	6	16.8	0.0194xρ
3	19.2	0.0294xρ	6	19.2	0.0173xρ

For a buried horizontal wire

$$R = \frac{\rho}{2\pi L}\left[ln\left(\frac{2L}{2dr}\right) - 1\right]$$

where,

L is the length of the length of the buried horizontal wire in meters

r is the radius of the wire in meters

d is the depth of burial in meters

A list of calculated earth resistance for two burial types in different homogenous soil models is provided in the table below for a standard 15mm diameter bare earthing electrode:

Table A5-3: Vertical and Horizontal electrode resistance

Rod Type	Rod Length (m)	Burial Depth (m)	25Ωm	50 Ωm	100 Ωm	200 Ωm	500 Ωm	1000Ω m
Vertical	1.2	N/A	18.1	36.2	72.4	144.5	362.2	724.3
	2.4	N/A	10.2	20.4	40.8	81.6	204.1	408.1
	4.8	N/A	5.7	11.3	22.7	45.4	102.0	227.0
	7.2	N/A	4.0	8.0	16.0	32.0	80.2	160.3
	9.6	N/A	3.1	6.2	12.5	25.0	62.5	125.0
Horizontal	1.2	0.5	15.8	31.6	63.2	126.5	316.2	632.4
	2.4	0.5	9.0	18.1	36.2	72.4	181.1	362.2
	4.8	0.5	5.1	10.2	20.4	40.8	102.0	204.1
	7.2	0.5	3.6	7.3	14.5	29.0	72.5	145.0
	9.6	0.5	2.8	5.7	11.3	22.7	56.7	113.5

Table A5-4: Grading ring and supplementary earth resistance for separately earthed pad mounts.

(Ref drawing 348262 sheet 1 and 348264)

Installation Type	Grading Ring Burial Depth (m)	Resistance @ soil resistivity					
		25Ωm	50 Ωm	100 Ωm	200 Ωm	500 Ωm	1000Ωm
Grading ring and 2x2.4m or 1x4.8m earth rod/s	0.3	4.8	7.6	13.3	24.7	58.7	115.5

Annexure 3: Metallic pipeline hazard assessment and mitigation options

Introduction

A touch voltage assessment must first be undertaken. Assuming the pipeline is well grounded, so will remain at remote potential during an earth fault, the touch voltage to a part of the pipeline that can be contacted is maximum voltage on the soil at any point one metre from the metallic component that can be touched. Once this touch voltage has been determined, it must be compared to the relevant voltage criteria to determine if it is acceptable.

Metallic water pipes

There a variety of contact scenarios for contactable water pipeline appurtenances. The most onerous of these are the MEN connected contact scenario for residential pipelines, and the operator contact scenario. Both of these can be assessed using figure 5.5 in EDI 001 – Earthing Risk Assessment or using the MEN contact scenario using the computer program Argon.

Where a distribution earthing system requires a detailed design as stated in this instruction (where it does not qualify for a simplified design), in the assessment of the electrical hazards on metallic pipelines, the designer must establish that the touch voltage to any contactable appurtenance on the metallic pipeline provides a low *risk level*, in line with company policy, for MEN contact scenario using Argon, or is below the TDMEN curve provided in AS 7000:2010. Unless it is known to the contrary, it is assumed that the voltage on the pipeline will remain at remote earth potential (zero Volts), so the touch voltage will be the soil voltage (EPR) at the appurtenance location.

Mitigation

The option of avoidance will always be considered first. Company's preferred option, where a risk is identified, is to completely remove the risk by not installing the asset, relocating the asset or opting for an alternative that does not require a high voltage earth.

Where there is no option but to install the high voltage earth and the touch voltage results in a higher than low risk scenario, the following mitigation options may be used (in order of preference).

- Reduce the EPR at the pipeline through modifications to the earthing design
- Asphalt layer installed around pipeline appurtenance. This will allow the touch voltage to be assessed as MEN contact scenario with an asphalt layer using Argon. The asphalt layer must be installed a minimum of one (1) metre from any point at which the pipeline appurtenance can be contacted. The asphalt must be hot mix asphalt, installed a minimum of 50mm thick, with no cracks.
- Plastic inserts installed up to 2m either side of pipeline appurtenance. This will remove the touch voltage hazard to the pipeline appurtenance as the voltage on the contactable component will rise with the local soil voltage. This option will usually only be possible for pipes up to 300mm in diameter.

For both mitigation options the designer must contact a "Water Servicing Coordinator" to submit the design to Sydney Water for approval. A list of water servicing coordinators can be found at: http://www.sydneywater.com.au/Buildingdeveloping/SupplierInformation/wsc/waterserv_ext.htm

Gas pipelines

Where hazardous voltages are expected on gas pipelines, a detailed earthing assessment must be performed according to AS 4853.

Annexure 4: Metallic fences – simplified insulation design method

Where metallic fences are continuous for long distances, or the continuous length of a metallic fence is unknown, it is assumed that the fence continues to “remote earth” so will cause a transfer voltage equal to the soil voltage at the fence (it will transfer zero V, or remote earth, to the point closest to the earthing system). If this transferred voltage is lower than the relevant allowable touch voltage, then no mitigation is required. However, this is a worst case scenario, and the actual touch voltage will generally not be as high as calculated. Analytic modelling using computer packages may be used to determine whether the voltage on a metallic fence is satisfactory where the worst case scenario does not prove compliant.

If the continuous metallic length of the fence is known, the worst case touch voltage to the fence is equal to the difference between the soil voltage at the furthest point on the fence from the earthing system, and the soil voltage at the closes point on the fence to the earthing system. For example, as shown in Figure A8-1,

$V_{touch} = EPR(Shortest\ distance\ to\ fence) - EPR(Longest\ distance\ to\ fence)$.

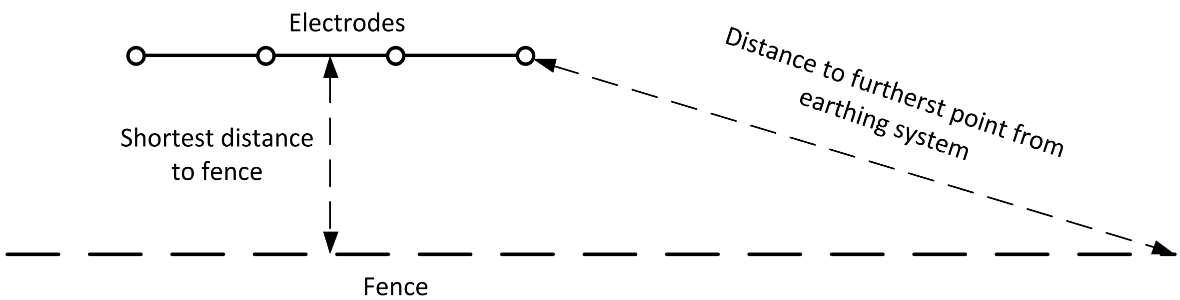


Figure A8-1 - Touch voltage to fence - known fence length

If the calculated touch voltage to the fence is determined to be non-compliant, and the earthing system can’t be designed such that it is complaint, then the fence may be insulated to reduce the touch voltage on the fence. Insulation panels must be installed at the point where the soil voltage falls below the allowable touch voltage.
If the worst case touch voltage is greater than two times the allowable touch voltage, then multiple insulation panels are required to be installed. The location of each insulation panel must be such that the difference in soil voltage between two adjacent insulation panels is less than the allowable touch voltage.

Where an insulated section is applied a warning label is required in line with drawing 061674.

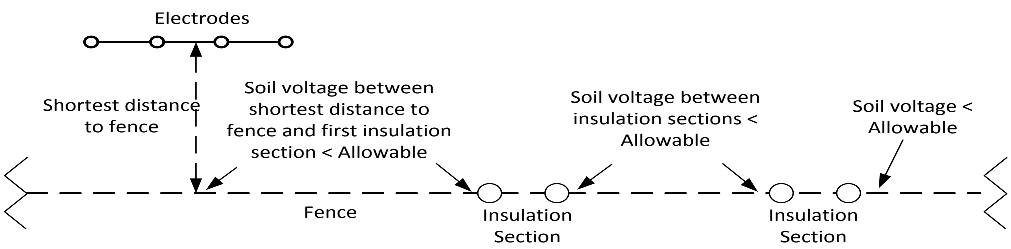


Figure A8-2 - Location of multiple insulation panels

Annexure 5: Distribution system information for earthing design

Simplified maximum-minimum fault current determination

Single phase to ground fault levels for existing distribution substations are available on Company's standards website. These fault levels are bolted fault levels and do not account for earthing system impedances, arc or fault impedances. Where these figures are used in a distribution earthing design, the maximum and minimum fault level must also be calculated to allow for the earthing system impedance. The method to do this is detailed below.

The fault level for the substation being modified, or next available substation upstream (towards the source) must be obtained from the database. If the nearest upstream node is the zone substation bus, then the Earthing & Power Quality Manager must be contacted for advice.

The fault levels in this database are provided as a current magnitude with no phase angle, so the determination of the resistive and reactive components (R_s and X_s) values is required for this assessment.

- **Assumption for determining minimum fault current for protection activation:** Assume that the source impedance is purely resistive (that is, $X_s = 0$) to calculate the minimum fault current ($I_{Grid} = 0.9V_s /(Z_{sys} + R_s)$).
- **Assumption for determining maximum fault current for safety determination**: Assume that the source impedance is purely reactive (that is,. $R_s = 0$) to calculate the maximum fault current at the earth grid ($I_{Grid} = 1.1V_s /(Z_{sys} + jX_s)$).

Note: Voltage factor c = 0.9 is used for minimum fault current, and voltage factor c = 1.1 is used for maximum fault current, as set out in AS3851:1991.

Where;
$\boldsymbol{R_s}$ – Source resistance (Ω)
$\boldsymbol{X_s}$ – Source reactance (Ω)
$\boldsymbol{I_{Grid}}$ – Fault current through earth grid (kA)
$\boldsymbol{V_s}$ – Source voltage (kV) Phase to earth
$\boldsymbol{I_{FL}}$ – Fault level (kA) – Refer to Company's standards website
$\boldsymbol{Z_{sys}}$ **–** The earthing system impedance
$\boldsymbol{X_l}$ – Existing Line reactance (Ω) - refer to conductor data
$\boldsymbol{X_L}$ – Proposed Line reactance (Ω) - refer to conductor data

Simplified fault level change determination for conductor augmentation

For this determination assume that the source impedance as well as line impedance is purely reactive.

Calculate the X_s – Source reactance (Ω) from fault level at the sending end using the following formula.

$$\boldsymbol{X_S = \frac{1.1 * V_S}{I_{FL}}}$$

Percentage change in fault level at receiving end after augmenting the conductor =

$$\boldsymbol{100 * \left(\frac{X_S + X_l}{X_S + X_L} - 1\right)}$$

Zone substation bonding configuration information
Zone substations bonding configuration information including the status of a CMEN connection can be found on Company's standards website. The report provides information on whether the substation earth grid is currently bonded to the surrounding HV earthing systems and potentially to the MEN system, or if there is planned work to create these bonds. This information can be used to design/verify earthing systems for distribution substations.

The report is updated regularly by Compnay and as such it is recommended that the user obtains an updated version from the standards website for each new design rather than referring to a printed copy.

Feeder protection clearance time

If the upstream protection settings are not known, the following generalised protection clearing times may be used. These clearing times are based on the worst case scenario. Linear interpolation between values may be used.

Table A9-1: EF protection clearing time

Fault current (A)			Primary clearance time (s)
7000		∞	0.6
5000	to	6999	0.7
4000	to	4999	0.8
3000	to	3999	0.9
2000	to	2999	1.0
1500	to	1999	1.5
1000	to	1499	2.0
500	to	999	3.0
20		499	10.0

Annexure 6: Earthing in high soil resistivity areas

In high soil resistivity areas, alternative earthing techniques may be required to provide a safe earthing system. These include;

Overhead HV aerial earth

A larger number of deep drilled earth electrodes may be required to achieve the design earth resistance in high soil resistivity situations. The use of an overhead HV earth wire may be constructed to connect a series of remote electrodes at different poles to form a substation HV earth system. Typically two (2) electrodes would be installed at the substation and one (1) deep drilled electrode installed near each pole along the line from the substation pole.

Similarly, deep drilled electrodes may be connected to the LV aerial neutral to form a LV/MEN earth system.

Overhead earth wire must be insulated to 0.6/1kV to allow work to be carried out on the (de-energised) HV mains or LV mains without risk of shock from the earth wire due to transferred earth potentials or induced voltages.

The size of the overhead earth wire must be minimum 50mm² (AAAC-1120 alloy, 0.6/1kV, XLPE insulated or equivalent) .The fault rating of this aerial wire is 4.4 kA for one (1) second.

The use of this system is subject to the approval of the Earthing and Power Quality Manager.

Underground earth cables

In high soil resistivity areas, new padmount substation earthing systems can be connected to existing padmount substation earthing systems to achieve a satisfactory outcome, subject to the approval from the Earthing and Power Quality Manager.

To connect the earth systems of two substations, 2x70mm² copper, PVC or equivalent cable must be used.

Annexure 7: Engineering earthing risk mitigation techniques

The following hazard mitigation and risk reduction techniques are provided as alternative options to be used where methods presented in the main body of this instruction are not sufficient. They will require consultation with Company, and may not always be practical or even possible. Any alternative risk mitigation technique proposed must be fully justified, identifying the reduction in risk, and all other options considered.

Earth electrodes

The earthing impedance can be reduced by enlarging the earthing system (more earth rods). In this case, even though the EPR of the earthing system will be reduced, the resultant EPR contours may be pushed out further. In some circumstances, the increase in the size of the EPR contours may be significant for a small reduction in the EPR magnitude of the system. Care will be taken when designing a system in this manner since the hazards associated with transfer-in touch voltages due to soil gradients on nearby metallic infrastructure may increase overall risks considerably.

The use of earthing rods and buried conductors must generally be limited to the area available at site. This is not only due to proximity effect and transferred EPR, but generally on the concept that various other strategies are available to reduce hazards locally and more economically.

Annexure 2 has details on the response of various buried electrode configurations.

Common earthing

Where there is a significant density of earth electrodes on the LV system and local soil resistivity, fault level and sheath bonding strategy provides a safe outcome, such as in dense urban areas, the preferred method of earthing is to bond HV and LV earthing systems. This ‘common earthing’ method provides an arrangement where the HV earthing system is intentionally bonded to the LV MEN earthing system to provide a significantly low impedance path for fault current to flow back to the source during an HV earth fault. In these circumstances any person contacting any conductive equipment connected to that MEN system (e.g. a garden tap) can be exposed to voltages across their body and therefore the criteria and assessment process to determine this arrangement is strict. However, common earthing provides the safest long-term risk management strategy in significant urban areas.

Separate earthing

In particular circumstances the separation of HV and LV earthing systems is appropriate. This is typically where the LV system has limited paths and high impedance and any HV side fault will result in significant risk transferred to the LV system. Where separation is required it is important to establish the integrity of the physical separation (including separation distances in varying soil), this will depend on:

- Size of the earthing system.
- EPR expectations and soil model.
- Distance to various earth paths.

Separate earthing systems require a more detailed assessment of risk as they generally result in high EPR and longer protection clearing times. As normal practice, this arrangement normally needs to be accompanied by various other earthing hazard mitigation measures. When assessing hazards, the size of the earthing system needs to be carefully considered, for instance a high earth impedance results in a high EPR but generally lower transfer voltage hazards, conversely a larger low impedance earthing system may have a lower EPR but be more problematic with soil voltage transfer. This is summarised in the table below.

Table A11-1: Indicative risks of larger v's small earthing systems

Large or long electrode system	Small electrode system (single rod)
o Lower EPR magnitude o Lower touch voltages at the asset o Lower step voltages near the asset o Larger EPR hazard zone o Problematic with large soil voltage transfer hazards to nearby metallic infrastructure o Fault clearing by two or three protection systems - D/O fuse(for pole substations only), feeder/recloser and SEF)	o Higher EPR magnitude o Higher touch voltages at the asset o Higher step voltages near the asset o Small EPR hazard zone o Fewer problems with soil voltage transfer hazards to nearby metallic infrastructure o Fault clearing by one or two protection systems - D/O fuse (pole substations only) and SEF

While separation of HV and LV earthing can be effective at reducing transfer voltages to a weak LV earthing system, the risk of HV line to LV line contact can result in a high impedance fault scenario and therefore significant step and touch voltages onto the LV network. In such cases it is important to determine that the configuration of LV / HV circuits limits possible fault scenarios by removing conjoint HV / LV spans and providing sufficiently low LV earth grid impedance (separate poles, underground LV, and the like).

Cable screens

Bonding together of HV cable screens allows earth fault current to disperse throughout the earthing systems which may result in slightly increased hazard frequency but of much lower magnitude and duration. HV cable screens will be bonded to all HV earths where applicable with the exception of the first asset being supplied from a zone substation which is considered on a case by case basis (refer clause 5.2.4.4).

Earth wires and conductive catenaries

Similar to cable screens, overhead earth wires or the conductive catenary of NMSABC can be used to disperse earth fault current and/or provide a metallic return to source.

Metallic return to source

Earth fault current will generally favour metallic paths back to the zero sequence source (the star point of the Dyn TX at the zone substation). Where continuous and redundant metallic return to source is provided from a distribution asset, a limited portion of earth fault current will return via the soil and therefore EPR will be significantly reduced (refer clause 5.2.4.4).

Company is currently reviewing its zone substations and distributed bonded zone substations (CMEN) will typically be applicable in urban scenarios. The earthing designer must check the configuration of the earthing at the zone substation that supplies the distribution asset to confirm that the correct earthing configuration is applied to the distribution asset.

Grading rings

Grading rings reduce touch voltages by spreading EPR further from an earthing system. The potential gradient control conductor must be positioned in a concentric configuration at a distance of one (1) metre from a structure and buried at a depth of 300mm. However, this measure will push EPR contours further out from the structure and the resulting effects on third party equipment must be assessed.

Crushed rock layer

A layer of high resistivity material like crushed rock on top of normal ground will increase the tolerable levels of touch and step voltage during an earth fault. This layer must be installed as stated in SDI 523 – Switchyard Surfaces. Due to the difficulties in maintaining loose crushed rock in uncontrolled areas, approval must be obtained from the Earthing & Power Quality Manager to use this material, specifically identifying why alternative risk mitigation techniques could not be used.

Asphalt layer

Asphalt is the preferred material to be used to increase the tolerable levels of touch and step voltage during an earth fault. Where an asphalt layer is specified in the design, the designer must clearly specify that this layer is;

- A minimum thickness of 50 mm when compacted
- Free from cracks.
- Compacted road base
- Hot mix

Approval is required from the Earthing & Power Quality Manager for the use of an asphalt layer as mitigation. An increased size easement with 1m around standard easement is required for earthing designs with asphalt layer.

Installation of electrodes deeper in to the ground

EPR on the surface of the ground can be reduced by installing earth electrodes deeper in the ground and connecting these electrodes with insulated cables and insulating all exposed joints (refer Drawing no. 348246).

Insulating earth electrodes below ground level may also be used to reduce the surface voltage to comply with voltage requirements on other utilities equipment. Where conductive structures are used on the surface (for example concrete or steel poles, or concrete substation footings) the effectiveness of this option will generally be reduced as current will leak from this conductive structure, resulting in higher EPR on the surface. Where the soil structure is identified as “high on low”, it will be beneficial to utilise a two layer soil model in the design.

Insulated coatings and covers

There are currently no approved insulated coatings or covers for concrete or steel poles or structures, however, must a product become approved, this mitigation technique may be considered. The additional maintenance costs associated with the use of an engineering control such as this over substitution control such as the use of non-conductive structures must be also considered.

Protection clearing time reduction

A key component in the risks associated with an earthing system is the duration of an earth fault. In many cases, significant risk reduction over an entire distribution system could come from a review of protection settings. Company is continually reviewing protection clearance times with a view of reducing them to a level that is as fast as possible.
This will not always be possible, as protection systems must grade with downstream systems for network reliability, and this can often limit any improvements to zone substation settings. Therefore, proposals for protection system reviews will generally only be considered once all other options have been exhausted.