Earthing Design Instruction

Earthing design, construction and testing of overhead transmission mains

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Endeavour Energy

EDI 0004 Earthing design, construction and testing of overhead transmission mains

Contents

1.0 PURPOSE

To provide minimum standards for the design, construction and commissioning testing of earthing systems associated with transmission mains with the aim of reducing the safety risk to employees and public to be low as reasonably practical in line with industry best practice.

2.0 SCOPE

This standard applies to all components of overhead transmission line earthing with a nominal voltage of 33kV and above. This standard does not apply to underground transmission mains. This standard provides design criteria, a general design process overview, standard construction practices as well as testing requirements. Hazards presented by earth potential rise, electrostatic, electromagnetic and conductive sources in terms of step, touch and transferred voltages, including those posed by nearby conductive objects, are covered by this standard.

3.0 REFERENCES

- Company Policy (Governance) 2.1 – Risk Management
- Company Policy 9.2.5 - Network Asset Design
- Company Procedure GSY 1007 – Dangers from Induced Voltages and Transferred Earth Potentials
- Earthing Design Instruction EDI 001 – Earthing risk assessment
- Earthing Design Instruction EDI 100 – Distribution earthing design, construct and test
- Earthing Design Instruction EDI 516 – Earthing in transmission/zone substations and switching stations
- Mains Construction Instruction MCI 0005 - Overhead distribution: construction standards manual
- Mains Design Instruction MDI 0044 – Easements and property tenure rights
- Mains Design Instruction MDI0047 – Overhead transmission mains design
- Mains Maintenance Instruction MMI 0012 - Overhead transmission line routine inspection
- Standard Asset Data SAD 0001 - Project drawing standards
- SDI520 – Lightning protection and insulation co-ordination
- Network Management Plan December 2013 review
- Endeavour Energy Electrical Safety Rules
- *Work Health and Safety Act* 2011
- Work Health and Safety Regulation 2011
- *Electricity (Consumer Safety) Act* 2004
- Electricity (Consumer Safety) Regulation 2006
- State Environmental Planning Policy (Infrastructure) 2007 – NSW
- ENA Substation Earthing Guide (EG1- 2006)
- ENA - Power System Earthing Guide (EG-0-2010)
- ENA National Electricity Network Safety Code (Doc 01-2008)
- EP 12 30 00 01 SP Electrolysis from stray DC current – RailCorp engineering standard
- AS 2239:2003 - Galvanic (sacrificial) anodes for cathodic protection
- AS/NZS 3835:2006, Part 1-2 - Earth Potential Rise-Protection of telecommunication network users and personnel and plant.
- AS/NZS 1768:2007 - Lightning Protection.
- AS/NZS:4853:2012 - Electric Hazard on metallic pipelines
- AS 1824:2005 – Insulation Co-ordination – definitions, principles and rules
- AS/NZS 1768:2007 – Lightning protection
- AS/NZS:7000:2010- Overhead line design-Detailed procedures

- HB331:2012 – Handbook for overhead line design
- HB-219:2006 - Handbook for AS/NZS 3835 Application guide-Worked examples
- IEEE 1048 – 1990 Guide for protective grounding of transmission lines

4.0 DEFINITIONS AND ABBREVIATIONS

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 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.

BIL
Basic Insulation Level is the level of insulation designed to withstand surge voltages. It is expressed in terms of the crest value of the standard lightning impulse.

clearing time (primary)
The time taken for the upstream protective devices and circuit breaker(s)/fuses to isolate the source of fault current.

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 protection system fails to operate. Protection system includes the relay, CT's, VT's, D.C. supplies, communications systems and CB's.

conductive poles
A pole made of material that is conductive material, typically steel reinforced concrete or steel on Endeavour Energy's network

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

coupling factor
The magnitude of the current returned on a faulted cable's screens and sheath or on an overhead earth wire expressed as a percentage of the fault current magnitude. The coupling factor can also be referred to as the split factor.

counterpoise conductor
A horizontal earth electrode that can be used to connect earth grids, or in isolation.

earth electrode
Uninsulated conductor installed vertically in electric contact with the earth (through dirt of intermediate material) intended for the conduction and dissipation of earth current.

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 a specified value.

earth fault current
Current that flows through the main circuit to earth or earthed parts at the fault location.

earth grid
Interconnected uninsulated conductors installed in contact with the earth (or intermediate material) intended for the conduction and dissipation of current and or for the provision of a uniform voltage reference. A part of the earthing system.

earth return current
The portion of the total earth fault current which returns to the source by flowing through the earth grid and into the surrounding soil

earth rod
Earth electrode consisting of a metal rod driven into the ground

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.

earthing system
Arrangement of earth conductors, typically including an earth grid, earth electrodes and additional earth conductors such as overhead earth wires (OHEW), cable sheaths, earth continuity conductors (ECC's) and parallel earthing conductors (PEC's)

ECC
Earth continuity cable

electrostatic induction
Phenomenon in which an induced voltage or an induced current is produced by a conductive object running parallel to a current carrying conductor.

Ellipse
Endeavour Energy asset management database

ENA
Energy Networks Association

EPR
Earth potential rise - the maximum voltage on the metallic components of the earth system during an earth fault, reference to remote earth

frequented or normal location
Area where people are expected to regularly gather or remain for extended periods (such as bus stop, farm primary residence, churches, sporting ovals and the like). Any location that does not fall under remote or special location category shall be considered as a normal or frequented location.

GIS
Geographical Information System

GPR
Grid potential rise – American IEEE equivalent to EPR.

hazard
Potential to cause harm

LFI
Low frequency induction; power frequency 50Hz in this standard

low individual risk
Based on limits in common use in NSW and in accordance with ENA earthing guide EG-0, a low earthing risk classification is one where the individual fatality risk level for a person exposed to earthing related hazards does not exceed 1 in 1,000,000 per annum.

low societal risk
The occurrence of a hazard (risk event) which results in simultaneous exposure for multiple people is considered less tolerable to society. A societal earthing risk assessment is required in addition to an individual risk assessment where many people are expected to congregate within a hazard area. A low societal earthing risk classification is one where the F-N curve based in ENA EG-0 $N^{-1.5}$ slope aligned with those in common use within Australia relating to hazardous industries is achieved

MEN
Multiple 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.

OHEW
Overhead earth wire; refers to the earth continuity conductor installed above the aerial line conductors. An OHEW may also contain non-metallic communication wires. The most common OHEW is an optical fibre ground wire (OPGW).

power system assets
Power system assets in this standard refer to all assets associated with the distribution of electricity with intentional current carrying components.

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

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 (see low individual risk) that any risk calculation would generally result in a low risk. This is usually the case for rural installations that are not close to a customer's residence, shed or gate.

risk
The change of something happening that will have an impact on objectives. Potential for realisation of unwanted, adverse consequences to human life, health, property or the environment. Note: A risk is often specified in terms of the expected value of the conditional provability of the event occurring times the consequence of the event given that it has occurred.

risk assessment
The overall process of identifying, analysing and evaluating the risk.

risk management
The culture, processes and structures that are directed towards realising potential opportunities whilst managing adverse effects

risk treatment
Process of selection and implementation of measures to modify risk. The term is sometimes used to represent the measures themselves.

SDR
Safe design report which is prepared by the designer and addresses any potential construction and in service safety risks associated with the design.

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

special location
The 'special' location category implies an area within close proximity to or within a premise where there is a high likelihood that shoes will not be worn and/or the risks associated with the earthing system has the potential to be exposed to a number of people simultaneously through contact with affected metalwork. This includes (but is not limited to) schools, pre-schools, day care centres, aquatic centres, recreational swimming areas and beaches.

step voltage (prospective)
The voltage between two points on the earth's surface spaced that are 1 metre distant from each other, which is considered to be the stride length of a person. (Often referred to as "Prospective Step Voltage")

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 transmission voltages.

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

SWMS
Safe Work Method Statement

third party asset
An asset owned by a third party that has the potential to be exposed to hazards in the event of an earth fault. These include, but are not limited to, telecommunication assets, water pipelines, gas pipelines and railway infrastructure.

touch voltage (prospective)
Voltage between simultaneously accessible conductive parts and/or nearby soil at the feet when those conductive parts are not being touched. The term touch voltage refers to prospective touch voltages unless otherwise stated

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 Endeavour Energy's network is typically, but not exclusively, 132kV.

5.0 ACTIONS

5.1 General

This standard is intended to enforce compliance to following:

- AS/NZS 7000:2010 and HB 331, which covers the application of risk based earthing principles to transmission line design.
- AS/NZS 4853:2012 for assessment of hazards to pipelines in the vicinity of the transmission line.
- AS/NZS 3835 and HB 100/101/102/103, for assessment of hazards to telecommunications assets.

This standard is complimentary to, and should be read in conjunction with, the following:

- Mains Design Instruction MDI 0047, which covers aspects of transmission line construction as well as lightning performance requirements which are not covered by this standard.
- Substation Design Instruction SDI 520, which covers lightning protection and insulation co-ordination.
- Mains Maintenance Instruction MMI 0012, which covers the inspection and maintenance regimes for overhead transmission lines.
- Earthing Design Instructions EDI 001, EDI 100, EDI 516 which cover risk based earthing, distribution earthing and major substation earthing respectively.

This instruction covers the requirements and network procedures to be adopted for all localities encountered throughout Endeavour Energy's area. This standard will apply to all transmission mains designs, including new and refurbished lines. The principles outlined in this standard can also be applied to the earthing assessment of existing lines where testing, maintenance or programs identify a need.

The designer of the transmission line earthing system is required to be aware of all aspects of the installation including design, construction and test. This is required to establish that the SDR covers all aspects and that the design will allow for a constructible and testable system.

5.1.1 Transmission mains earthing principles

Transmission mains earthing systems are required so that during steady state or fault conditions there is ALARP safety risk to staff and public associated with electromagnetic induction, electrostatic induction, transferred voltages and soil voltage gradients. The increasing urbanisation throughout Endeavour Energy's network coupled with the increasing numbers of conductive structures used for transmission lines mean that the correct design of the transmission line earthing system is increasingly important for public safety. The earthing system is also required so that in the event of an earth fault or insulation failure that the protection will operate as designed.

The earthing design of transmission mains, and the construction safe design report, shall take into account the following:

- Hazardous touch and step voltages around the poles.
- Transferred voltages to adjacent conductive objects and third party assets through LFI or other transfer mechanism.
- Impact on non-utility conductive infrastructure.
- The risk of lightning strike and back flashover.

- The earthing system shall last for the lifetime of the asset it is protecting; special consideration should be given to corrosion protection and theft protection, the latter is particularly relevant in remote areas.
- The earthing system shall be designed so that an earth fault will result in a protection operation.
- Fault current shall be able to be conducted without damage to the earthing system, including both mechanical and electrical constraints.

5.1.2 Earthing components and configurations

The earthing system of a transmission line can consist of an OHEW, downleads, electrodes at each pole, ECC, counterpoise conductors and the earth grids of each major substation connected by the transmission line. Where a conductive pole is used it shall be considered a part of the earthing system.

Unless otherwise cost-risk justified the OHEW shall be bonded into each substation earth grid, be electrically continuous between substations and be bonded into each pole electrode system. In the event of an underground section of transmission line the OHEW shall be bonded to the cable screens/ECC to establish electrical continuity between substation earth grids. The cable screens/ECC shall also be designed to establish continuity between substations where practical. Where a small section of line is being modified it is not a requirement to establish continuity across the entire feeder.

A continuous OHEW has significant benefits for earthing performance, network reliability, lightning performance and protection sensitivity. Any justification for not making the OHEW continuous shall address these benefits as a part of a cost benefit analysis. Earthing Design Instruction EDI 516 - Earthing in transmission/zone substations and switching stations, has further details on the connection of the OHEW to the substation earth grid.

Where a transmission line has been designed with a discontinuous OHEW the OHEW shall be installed for the first section of the feeder from all connected substations as an alternative to improve the earthing and lightning protection at the substation, unless cost-risk justified. Details on lightning protection requirements can be found in section 5.2.7.

Where the works require the modification of a small section of a feeder with a discontinuous OHEW the hazards at the discontinuities of the OHEW shall be assessed as a part of the design process. The design would not typically require replacement of the OHEW for the entire feeder.

Pole electrodes shall be placed as close as possible to the pole and parallel with the direction of the line. This minimises the risk of transferring voltages to surrounding infrastructure.

5.1.3 Risk management

Endeavour Energy has adopted the risk based assessment criteria developed by Energy Networks Australia (ENA). In general, this standard applies the criteria given in Earthing Design Instruction EDI 001 - Earthing risk assessment, to transmission line earthing systems.

Faults at individual poles are required to be assessed under the principles of AS/NZS 7000:2010, as outlined in Earthing Design Instruction EDI 001 - Earthing risk assessment,.

Assessment is required using the step and touch voltage criteria of EG1 where the OHEW is bonded into the substation earth grid. This is to assess the risks associated with a substation earth fault transferring current out along the line. Faults on individual poles are generally quite rare; as such the EG1 requirements are much more onerous than the AS/NZS: 7000:2010 requirements. It should be noted that this risk is for a limited number of poles, see section 5.2.6 for more information.

Risk assessment using the principles of AS/NZS 3835:2006 and AS/NZS: 4853:2012 are required to determine the step and touch voltage risk criteria to third party assets such as telecommunication infrastructure and water/gas pipelines.

The primary hazard associated with transmission mains earthing is the flow of current through the body. This current can be brought about by three mechanisms: earth fault current flowing into the soil causing voltage gradients, electromagnetic and electrostatic induction. An assessment of each of these hazard sources is required by the design.

Note that hazards exist to any metallic objects around the pole/line and to the pole if it is conductive. All potential hazards shall be assessed in the design.

5.1.4 Earthing design

An earthing design shall be completed for each new transmission line, where work requires the modification of the earthing system on existing lines or where the line has been identified to be of high risk. Note that the modification of the earthing system includes any change to the pole location, fault level, earth resistance, OHEW, pole type (height and construction) or addition of distribution assets which utilise the transmission earth. The Earthing & Power Quality Manager shall be consulted if there is any ambiguity about this requirement.

The earthing design shall be considered at the early stages of the project so that the risks can be safely and economically managed. For staged projects, for example the commissioning of a line and later a substation, earthing risks shall be considered for each stage and managed accordingly.

The earthing design of transmission line shall be undertaken in two stages.

- Level 1 – Conservative compliance criteria
  - This stage will involve a first pass assessment against conservative criteria given in the tables in section 5.2.4. The poles that are compliant with the separation distances in the table are considered to be of low risk, any poles, or sections of line, that are non-compliant will need to be assessed under level 2 design criteria.
- Level 2 – Detailed line assessment
  - In this stage individual poles/sections presenting non-compliant situations shall be considered, using risk based AS/NZS 7000:2010 touch voltage criteria. Where applicable the hazard mitigation options of Annexure E – Hazard mitigation techniques, shall be assessed to determine the extent that they can mitigate the risk. Assessment against AS/NZS 3835:2006 and AS/NZS 4853:2012 is also required in this stage.

5.1.5 Design software requirements

For level 2 compliance design software shall be used that is capable of the following analysis as a minimum.

- Have configurable conductor separations.
- Be able to analyse the effects of underground transition points.

- Be capable of multilayer soil analysis. Note that a conservative first pass. assessment is permitted using a homogenous soil assumption, and simple hand calculations, but the design shall clearly state this assumption and justify that it is conservative.
- Be able to calculate the induced currents between the faulted phase and any parallel metallic paths.
- Any analytics utilised by software developed by the designer shall be sourced from peer reviewed papers and shall be commercially available.

Where third party software is used the name and version shall be stated in the design report. Where the software is found to be insufficient for the design the report will be rejected.

Examples of suitable software include the SES Technologies CDEGS software design package and EMTP software for level 1 homogeneous soil analysis. Other software will still be considered upon assessment of the design report.

5.2 Earthing design

5.2.1 Design process

The earthing design process that is found in Annexure A - Transmission line earthing design process shall be followed for each transmission line design. The following sections give guidance on each of the major design stages.

5.2.2 Design context and consultation

The design context shall be established in the initial stages of the design. This context shall state the purpose for the design and establish any design constraints that must be applied to the design. Typically this information will be stated in the project definition.

Consultation shall be undertaken with all relevant stakeholders to determine any further design constraints or objectives. If clarification is required for the earthing design the Earthing & Power Quality Manager shall be contacted.

5.2.3 Data Gathering

All relevant data shall be gathered in the initial stages of the transmission line design. Table 1 gives the minimum data required to successfully complete a design.

Table 1: Minimum data requirements for earthing design

Data required	Data source	Notes
Soil resistivity	Measured by designer or other suitably trained party using the test method guidance provided in EDI 100 - Distribution earthing design, construction and test. Where practical the Wenner method shall be used.	Soil resistivity shall be measured at the start and end points of the feeder and where the resistivity is expected to change, for example where a line crosses a gully or at significant changes in altitude. As a minimum it also is tested at least every 5km along the feeder route. Where the section of line being designed is less than 5km in length it shall be tested in the middle and at any termination (UGOH or discontinuous OHEW) points. Maximum spacing of test points required is 16m.

Data required	Data source	Notes
Soil PH and sulphide levels	NSW Government Natural Resource Atlas	Only required where soil resistivity is measured to be less than 25Ωm.
Fault levels and clearance times	Protection Manager Endeavour Energy.	A minimum of four weeks lead time is required. As a first pass the substation bus fault level can be used as a worst case.
Conductor types and line configuration, including conductor clearances.	MCI 0005 – Overhead distribution construction standards manual, and MDI 0047 – Overhead transmission mains design.	
Known current and future development and infrastructure around the feeder route	Various	This information will need to be used when determining appropriate safety criteria
Fault frequency	Information assumed from AS/NZS: 7000:2010 guidance or using substantiated network fault data when available for pole faults.	
Initial required pole footing resistances	Pole resistance requirements of MDI 0047 - Overhead transmission mains design	Note that these resistances may change if required by a level 2 design.
Location of third party utility assets	Dial before you dig	Report shall take into account all assets within a 50m radius of the transmission line as a minimum.
Surrounding pole resistances (where a small section of line is being modified)	Manager Earthing & Power Quality	A minimum of four weeks lead time is required

5.2.4 Level 1 design - conservative compliance criteria

Where each section of the transmission line can be shown to meet the separation distances as listed in Table 2, the design shall be considered to be compliant if the following conditions are also met:

- The pole earth resistances are compliant with the pole resistance requirements of MDI 0047 – Overhead transmission mains design,
- The overhead earthwire is continuous between substations, including continuity across any underground section, either by an ECC or connection of the cable screens,
- Have an average span length of less than 100m.
- The designer has considered all other reasonably practical methods to reduce the risk to individuals in line with the requirements of EDI 001 - Distribution earthing design, construction and test; and
- There are no special locations within close proximity of the transmission line.

Note that this table shows separation distances due to a fault at that individual pole as a worst case scenario.

Table 2: Conservative compliance criteria for poles and adjacent conductive objects

Soil resistivity (Ωm) [1]	Clearance time (s)	Fault Level (kA) [2]	Pole touch voltage (V) [3]	Minimum separation distance (m)			
				Telecom pits	MEN	Backyard[4]	Urban [4]
50	0.1	10	2671	3	5	3	0
50	0.1	20	5343	7	11	6	0
50	0.1	30	8015	11	18	10	1
50	0.1	40	10686	15	24	13	1
50	0.2	10	2671	3	6	4	0
50	0.2	20	5343	7	13	9	0
50	0.2	30	8015	11	20	13	1
50	0.2	40	10686	15	27	18	1
50	0.5	10	2671	3	13	8	0
50	0.5	20	5343	7	27	16	1
50	0.5	30	8015	11	41	25	2
50	0.5	40	10686	15	55	33	2
50	1	10	2671	8	33	20	0
50	1	20	5343	17	67	42	1
50	1	30	8015	26	101	63	2
50	1	40	10686	35	135	84	2
100	0.1	10	1838	6	10	5	0
100	0.1	20	3676	14	21	12	1
100	0.1	30	5514	21	32	18	2
100	0.1	40	7351	29	44	25	3
100	0.2	10	1838	6	11	7	0
100	0.2	20	3676	14	24	16	1
100	0.2	30	5514	21	37	24	2
100	0.2	40	7351	29	50	33	3
100	0.5	10	1838	6	25	14	0
100	0.5	20	3676	14	51	30	1
100	0.5	30	5514	21	77	46	3
100	0.5	40	7351	29	103	62	4
500	0.1	10	377	19	14	7	0
500	0.1	20	755	45	36	22	0
500	0.1	30	1132	72	58	37	2
500	0.1	40	1510	99	81	51	6
500	0.2	10	377	19	22	12	0
500	0.2	20	755	45	51	31	0
500	0.2	30	1132	72	80	51	4
500	0.2	40	1510	99	110	71	7
500	0.5	10	377	19	55	30	0
500	0.5	20	755	45	119	68	3
500	0.5	30	1132	72	182	106	8
500	0.5	40	1510	99	245	144	13

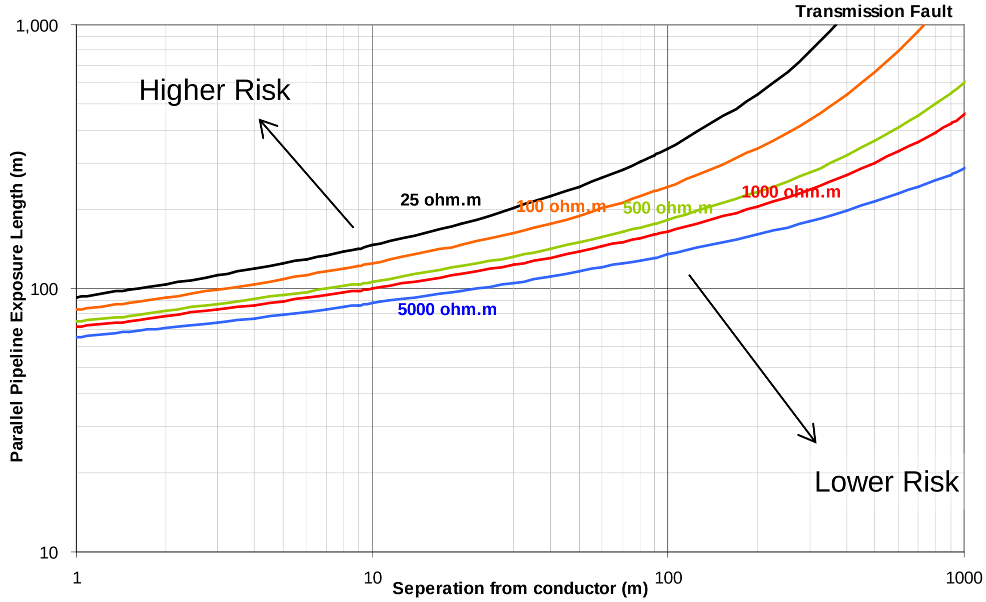
[1] Soil resistivities used in this table are quoted as homogeneous. The highest value of a multilayer soil model shall be used for reference in this table, except where the ratio between the highest soil resistivity layer and the lowest exceeds 3 then case a level 2 design is required.
[2] Unless a specific pole fault level is available the highest substation bus fault level shall be used.
[3] Pole touch voltages shall be assessed against appropriate safety criteria to determine if the pole is non-compliant.
[4] Urban and backyard criteria are defined in EDI001 and AS/NZS7000. Where a location along the transmission line meets these criteria the separation defined in the table shall be used to assess compliance.

A design shall be considered to be compliant where it meets the minimum separation distance for all safety criteria and does not exceed any of the soil resistivity, clearance time or fault level requirements. The values cannot be interpolated as the relationship is not linear.

Where the design meets these criteria it is still required that every reasonable effort is made to reduce the risk to a level that is as low as reasonably practical. This includes increasing the separation distances to as far as is practical.

For conservative compliance limits to parallel pipelines the following graphs can be used. If the configuration falls below the relevant curve the pipeline can be considered to be compliant, further information can be found in EDI 001 – Earthing risk assessment.

Conservative exposure length for above ground pipeline in parallel with transmission power lines

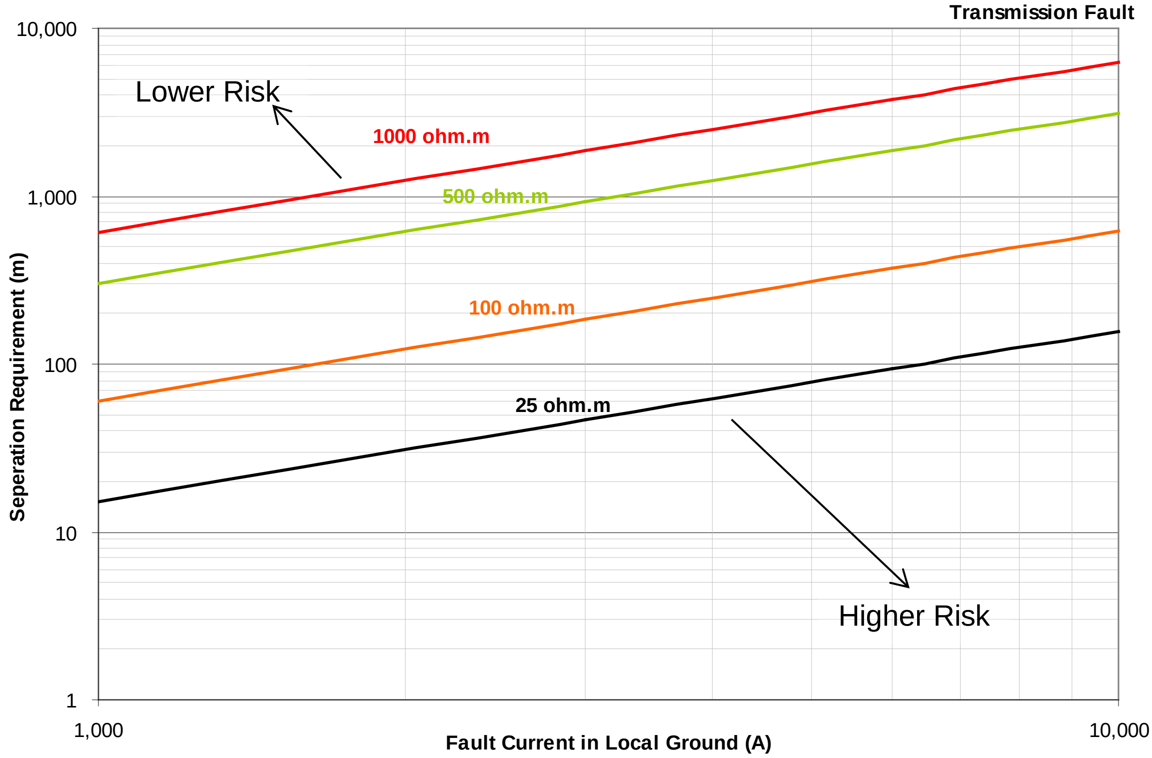


Separation shall be the direct distance between pipeline and closest phase conductor.

1. *Assumptions used in calculating exposure length (based on AS/NZS 4853):*
   - *Shielding factor of 0.8*
   - *Fault current of 8kA. Chart should be scaled to appropriate fault current values. Relationship with current and distance can be considered to be linear*
   - *Source substation grid resistance of 0.1 ohm*
   - *Tower resistance of 5 ohm. A resistance equal to or greater than this is required, otherwise a level 2 assessment shall be used.*
   - *Fault current flows down several tower resistances*
   - *Soil resistivity = deep layer values*

2. *Conservative allowable prospective touch voltage of 220V for transmission power lines*

Conservative separation distance for pipelines subject to EPR from transmission power lines

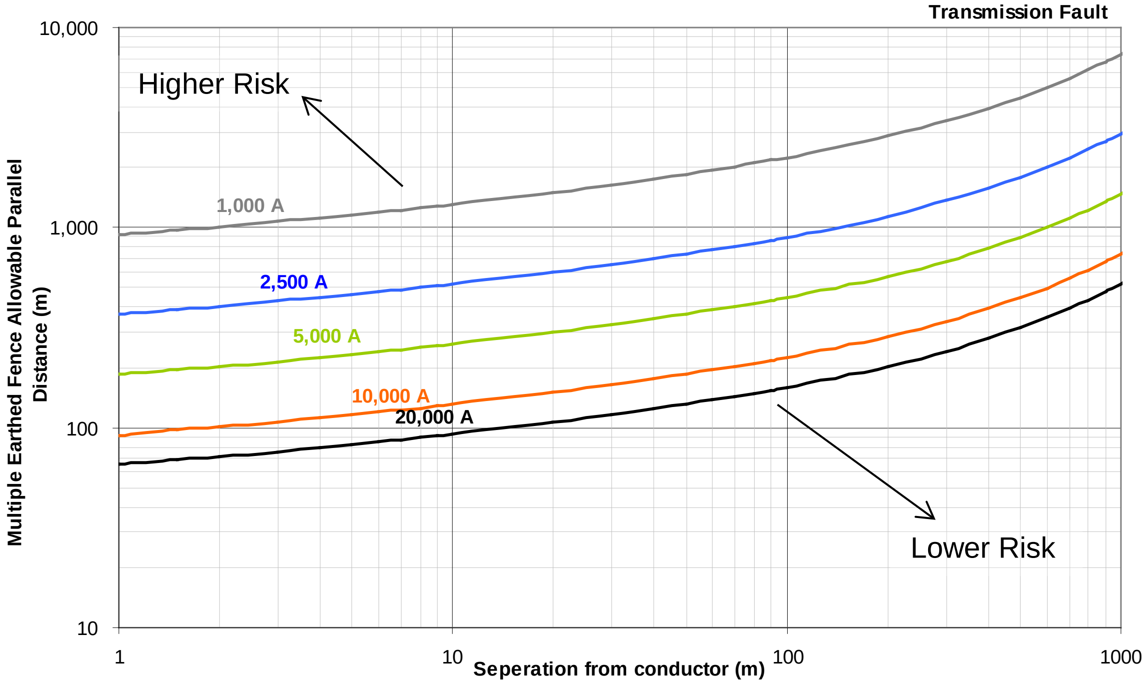


Note that this will typically be for hydrants and other above ground access points

1. *Separation required is from the earthing system to the pipeline appurtenances, access points or earth points.*
2. *Fault current in local ground can be calculated using a shielding factor of 30% or by using the principles of* Annexure B – Technical calculation of pole EPR with homogenous soil assumptions;
3. *Assumptions used in calculating exposure length (based on AS/NZS 4853):*
- *Source substation grid resistance of 0.1 ohm*
- *Tower resistance of 5 ohm. A resistance equal to or greater than this is required, otherwise a level 2 assessment shall be used.*
4. *Conservative allowable prospective touch voltage of 220V for transmission power lines*

Where there is a fence or other continuous metallic object running in parallel with a transmission line there is a risk of induced voltages. Where this is the case the fence shall be assessed against the requirements of EDI – 001 – Earthing risk assessment, Annexure J, an extract is shown below for reference.

Allowable parallel earthed conductive fence length (66kV and 132kV)



1. *LFI separation is the average distance between the fence that runs alongside the power line and the power line itself*
2. *The table is the maximum parallel lengths of a multiple earthed fence for varying parallel fault levels*
3. *A varying voltage limit based 50ohm.m soil resistivity touch voltage with typical footwear based on 416 x 4 second contacts at a fault frequency of 1 per annum for transmission clearance times of 320ms for 20kA scenario and 500ms for all others. The voltage limit has been doubled to cater for 'multiple' earthed scenario*
4. *A soil resistivity of 500ohm.m has conservatively been assumed for calculation of mutual coupling with earth return.*

5.2.5 Level 2 design - individual site assessment

Where sections, poles or the entire transmission line do not meet the conservative compliance criteria a more sophisticated design is required. The following gives guidance on the requirements for the design, further guidance on the initial modelling required can be found in Annexure B - Technical calculation of pole EPR with homogenous soil assumptions.

1. It is acceptable for the first pass assessment to use homogeneous soil assumptions but the design shall confirm this to be conservative. If the line fails this assessment then analytical modelling software shall be used as stated in section 5.1.5.
2. When undertaking modelling it shall be assumed that the phase furthest from the OHEW is the faulted phase as this represents the highest risk for a local pole fault scenario. When calculating OHEW thermal ratings the closest phase shall be modelled.
3. The poles identified to have failed the touch voltage conservative compliance criteria of section 5.2.4 shall be assessed against the safety criteria as detailed in EDI 001 – Earthing risk assessment. Note that the requirement is to assess hazards at the pole as well as transferred soil voltages to nearby metallic objects.

4. The sections of line that fail the conservative pipeline criteria shall be assessed against AS/NZS 4853:2012. The inductive and conductive voltages on the pipeline shall both be calculated to establish compliance. LFI for pipelines under steady state conditions shall also be assessed in line with EDI 001 – Earthing risk assessment requirements.
5. The poles that fail the telecommunications compliance shall be assessed against the requirements of AS/NZS 3835:2006.
6. Any poles/sections of line which have been shown to be non-compliant with multilayer modelling software and the criteria listed above shall apply the mitigation methods discussed in Annexure E – Hazard mitigation techniques until it can be proven that the design meets the appropriate safety levels and the risk is as low as reasonably practical.
7. The sections of line in close proximity to special locations shall be assessed against the criteria detailed in EDI 001 – Earthing risk assessment.

5.2.6 Transferred EPR

Where the OHEW is bonded to the zone or transmission substation earth grid poles in a close proximity of the zone or transmission substation are at risk of being exposed to substation earth potential rises being transferred to the pole earth grids.

As the substation is exposed to more frequent faults than the transmission line, these poles shall be assessed for both transmission line fault scenarios and substation fault scenarios in line with the requirements of EDI 516 – Earthing in transmission/zone substations and switching stations. This analysis shall also be considered in consultation with the substation earth grid designer.

Special consideration shall be given to poles where the OHEW is discontinuous and at overhead to underground transition points under this scenario.

5.2.7 Lightning protection

Overhead earth wires provide shielding to the phase conductors from lightning strikes. The local earth impedance of each pole shall be considered to prevent back flashover occurring. Guidance on shielding angle, BIL and pole earthing is given in MDI 0047 – Overhead transmission mains design and AS/NZS 1768:2007. These standards shall be followed where the design does not compromise the safe design as outlined in this standard, the safe design shall be the top priority.

As a first pass for level 1 compliance the pole earthing resistances shown in MDI 0047 – Overhead transmission mains design shall be used for the design as these give the minimum required lightning protection. Where a level 2 design requires a resistance greater than these values a lightning assessment is required to justify the safety improvements against potential reliability impacts. All locations where the pole earth exceeds the MDI 0047 – Overhead transmission mains design resistance values require approval from the Earthing & Power Quality Manager.

5.2.8 Easement encroachments

The guidelines in MDI 0044 – Easement and property tenure rights, shall apply to any object or construction within the transmission line easement. The designer shall identify any metallic objects, and third party assets, within the easement and confirm they are tested against the design criteria of section 5.2.5. The constructor of the line shall determine if the constructed line complies with the design and any encroachments.

5.3 Construction requirements

The designer shall be aware of the construction requirements of the line so that the design gives a constructible design. The construction shall comply with this instruction as well as any additional information provided with the design.

5.3.1 Construction and maintenance safety

The following gives general advice about any potential hazards that workers may be exposed to during construction. As detailed in EDI 001 – Earthing risk assessment, the designer is responsible for seeing that the design considers the construction and maintenance activities that will be undertaken and include all relevant safety details in the safe design report. Relevant SWMS, Company Procedure GSY1007 – Dangers from Induced Voltages and Transferred Earth Potentials, and the Endeavour Energy Electrical Safety Rules shall be used as a minimum when undertaking risk assessments and determining appropriate mitigations. Any construction/maintenance worker shall also be required to assess risks onsite before commencing any work.

Care shall be taken whenever making or breaking any earthing connection including, but not limited to, OHEW connections, connections to cable screens/ECC and connection to earthing electrodes. This work presents a risk of transferred voltages in the event of a remote earth fault. In general the designer and workers shall consider the use of insulating PPE, temporary bonding conductors and the establishment of an equipotential work area. These options shall be considered in consultation with the Endeavour Energy Electrical Safety Rules, Company Procedure GSY1007 - Dangers from Induced Voltages and Transferred Earth Potentials and the relevant SWMS.

Remote lightning strikes present a real risk when working on transmission lines. No work shall be undertaken on the earthing system of the transmission line when it is known that lightning is possible within any section of the transmission line. AS/NZS 1768:2007 provides further guidance on calculating lightning strike distance.

When working on metallic objects adjacent to live mains, including work on adjacent pipelines, there is a risk of exposure to induced currents and subsequent hazardous voltages. There is also a risk of capacitively coupled voltages. Where a risk assessment requires the voltage on the metallic object shall be tested prior to work and work shall be undertaken using the risk mitigations outlined in the Endeavour Energy Electrical Safety Rules, Company Procedure GSY1007 - Dangers from Induced Voltages and Transferred Earth Potentials and the relevant SWMS.

All identified risks during the design shall be included in the SDR that is submitted with the design package.

5.3.2 Thermal Limits of Earthing Components

The designer shall establish that all parts of the earthing system shall be rated for fault current at that point in the network for backup protection clearing time. As a minimum the following conductor sizes shall be used for downleads, unless the designer can show otherwise. Guidance on calculating alternative conductor sizes can be found in EDI 001 Earthing risk assessment. Note that this sizing assumes connection to an OHEW.

- 95mm^2 covered aluminium conductor
- 70mm^2 covered copper conductor
- 70mm^2 bare copper clad steel
- 240mm^2 ECC

For the electrode system below the ground 70mm^2 bare or covered copper, or copper clad steel, shall be used.

5.3.3 Mechanical integrity of earthing components

The passing of fault current through an earthing system puts a large amount of mechanical stress on the conductors and the connections.

Typical connection types between earthing conductors are bolted connections, crimp connections and exothermic weld connections. Unless otherwise justified the following connections shall be used:

- A water sealed crimp or bimetallic crimp for the connection of the downlead to the earthing conductors. This connection shall be made above ground level to prevent contamination of the joint.
- Two appropriate crimp connectors for connecting earthing conductors underground.
- Bolted connection for bonding earth conductors to conductive poles.

The downlead shall be securely attached to the pole with the use of saddles. For wooden poles where the downlead is within three metres of the ground a non-conductive earth batten shall be used instead of saddles.

5.3.4 Chemical integrity of earthing components

The underground components of the pole earthing system shall generally be copper or copper clad steel material, unless another material can be justified by the designer.

Areas shall be identified along the transmission line route that have a high/low PH value or where the soil has a high sulphur content as these conditions can contribute to accelerated copper deterioration. High risk areas requiring mitigation can be identified by measuring the soil resistivity and if it is found to be less than 25Ωm the NSW Government Natural Resource Atlas (found at http://www.nratlas.nsw.gov.au) shall be consulted for the PH and sulphide levels in the area.

As an indication for further investigation, soil resistivity less than 25Ωm, pH values less than 4.0 (acid) or greater than 8.5 (alkaline) and positive traces of sulphides are indicators of heightened concern for corrosion. Annexure D of EDI 516 – Earthing transmission/zone substations and switching stations, provides risk factors for heightened corrosion risk. Any area with testing results including or exceeding 100% from EDI 516 - Earthing transmission/zone substations and switching stations, Annexure D require a corrosion assessment and remediation report which will need to be approved by the Earthing & Power Quality Manager.

Further details of requirements for the prevention of corrosion can be found in AS 2239:2003 - Galvanic (sacrificial) anodes for cathodic protection and EDI 516 - Earthing transmission/zone substations and switching stations.

5.3.5 DC corrosion of earthing components

Installation of copper electrodes adjacent to DC systems can contribute to accelerated corrosion in locations such as railway lines, pipelines and at bridges. Where a risk assessment shows that there is a potential impact the design shall confirm that the risk is low or that appropriate mitigations have been made.

5.3.6 Security of earthing components

The remote nature of many transmission lines exposes them to copper theft. The theft of any pole earthing system will impede the performance of the line and will expose employees and public to potential hazards.

Downleads shall be installed for pole earths as aluminium, connecting to the copper earthing system above ground level in line with Drawing no. 048340. When replacing stolen downleads or where it is known that copper theft is prevalent in an area the downlead shall incorporate a section of copper clad steel. The theft deterrent drawings in section 5.8 shall be applied in these cases. Areas known to be susceptible include, but are not limited to, the Blue Mountains, South Coast, Hawkesbury and Penrith areas.

For all wooden poles a non-conductive earth batten is also required, regardless of area.

5.3.7 Commissioning

Where a design has been made using level 2 design criteria a commissioning test is required to confirm the earthing performance of the line before the line is energised.

Following the approval of the design the details of the earthing construction shall be uploaded into the Endeavour Energy GIS system following the guidelines outlined in SAD 0001 – Project drawing standards.

5.4 Test requirements

All works under this standard are required to have the resistance of the poles checked prior to commissioning to establish that the installation has occurred as designed. MMI 0012 - Overhead transmission line routine inspection details maintenance requirements for lines and shall be referred to for maintenance triggered testing requirements. Refer to Annexure F – Transmission pole earth resistance measurement sheet, for an example standard test sheet.

Testing is also required to prove compliance on all newly commissioned lines where a level 2 design has been completed. Testing will also be required if a potential problem has been identified on an existing line or where required for substation earthing purposes.

All current injection test results shall be sent to Earthing & Power Quality Manager for confirmation. All resistance measurements shall be verified against design parameters.

5.4.1 General testing methodology

A soil resistivity test shall be undertaken as a part of all testing. Generally this test will be undertaken as a part of the design process for new lines, if it is not the requirements of section 5.2.3 will apply. For the testing of a single pole a single soil resistivity measurement is required.

For all testing touch voltage measurements and fall of potential testing is required for the poles that are predicted to exhibit non-compliant touch voltages.

Where multiple poles are to be current injection tested, or if the earthing performance of the line is to be confirmed, the feeder shall be de-energised and the injection set shall be set up at one of the substations. The phase conductor should then be connected one at a time to the OHEW at the poles that have been identified to be assessed.

Where a full line current injection test is impractical, but compliance testing is still required, each pole shall be tested using an overland lead injection. Further details on this test can be found in Annexure C – Overland injection testing of pole earthing performance. In this situation the tester shall measure the current distribution between the pole earthing system and the OHEW to allow for an accurate calculation of the pole earth resistance. Note that the results of this test will be conservative because the inductive response is not taken into account. Allowance for this will be made by Earthing & Power Quality Manager when assessing the report.

5.4.2 Testing equipment requirements

The injection set shall be capable of producing a sufficient current so that reasonable voltage measurements can be made at the relevant poles. This is a particular concern where line is of a long length or where the tested circuit is a part of a dual circuit line. In this situation testing employees should consider the need for a synchronous generator or similar to undertake the testing. The injection set shall be capable of injecting in the range of 48-56Hz, typically 53Hz is used. The use of 50Hz shall be avoided unless there is a specific need.

The voltage/current measuring equipment shall have a minimum measurement resolution of 1mV and be capable of being tuned to the injection frequency.

5.4.3 Pole earth resistance

Where a pole earthing resistance is required to be calculated in order to confirm compliance against MDI 0047 – Overhead transmission mains design requirements, or to assess the condition of the pole earthing system, a three point resistance measurement is required. The test shall also separate the amount of current flowing into the OHEW and the pole earthing system to confirm that the resistance measurement is accurate. Further information on this testing method can be found in EDI 100 – Distribution earthing design.

Pole earthing resistances shall be measured for each pole prior connection to the OHEW and prior to commissioning. The values shall be stored in the Ellipse system for future maintenance.

Where a pole with another assets earthing system is installed (for example a distribution asset installed on a transmission pole) is to be tested the pole earth resistance shall be measured separately. Any other asset on the pole shall be tested to its applicable standard, for example a pole substation on a transmission pole shall be tested in accordance with EDI 100 – Distribution earthing design.

5.5 Requirements for specific equipment

5.5.1 General

Where the requirement for a specific asset installed on a transmission line is not covered by this standard an assessment against the requirements of AS/NZS: 7000:2010 is required to be submitted to the Earthing & Power Quality Manager for approval.

5.5.2 Conductive poles

All metal work installed on conductive poles shall be connected to the pole earthing system. This can be achieved either by direct connection to the down lead or by connection to the pole earthing system, such as the steel reinforcement for a concrete pole.

5.5.3 Distribution equipment on transmission structures

In accordance with the requirements of EDI 100 – Distribution earthing design and MDI 0047 – Overhead transmission mains design, the installation of a distribution assets requiring an earth on transmission poles shall be avoided on conductive poles. Where an earthed distribution asset is installed on a non-conductive pole the transmission and distribution earths shall be separated by a minimum of 15 metres.

Where dispensation is sought to install a distribution asset is installed on a transmission pole it shall be confirmed by the designer that the distribution earthing system is kept electrically isolated from the transmission earthing system with the use of appropriately rated insulators as determined by a level 2 design in line with the requirements of EDI 100 – Distribution earthing design.

Low voltage assets (including street lightning circuits) installed on a conductive transmission pole shall have a wet power frequency withstand of at least 20kV. Where a level 2 design is used the required voltage withstand shall be determined by the designer.

5.5.4 Stay wires

For all installations the stay wires shall be insulated from the ground in line with the requirements of MDI 0047 – Overhead transmission mains design. The placement of earthing electrodes for poles with stay wires shall see that the electrodes are as far as reasonably practical from the stay wire, keeping in line with the requirements of 5.1.2. The earth electrodes shall be installed on the opposite side of the pole to the stay wire.

5.5.5 Transmission UGOH poles

In general, the UGOH poles present the highest risk levels along the transmission line. As such the design shall clearly state the requirements for any UGOH poles along the line, taking into account the changing coupling factor between the overhead and underground systems. Under a level 2 design consideration shall be given to the fact that UGOHs can be exposed to higher EPRs more frequently than other poles due to the change in coupling factor during through faults.

The pole earthing system at the UGOH pole shall be connected to the OHEW where it is present and one side of the phase surge arrestors. Where a single point bonded arrangement is used the cable screens shall be terminated to sheath voltage limiters, which shall also be earthed to the pole earthing system. The cable earthing shall be connected to the pole earthing system to maintain continuity between the OHEW and the cable screens. The design shall take into account the impedance to earth when calculating the cable sheath voltages.

5.5.6 Transmission air break switches

Transmission air break switch handles shall be insulated to the appropriate voltage from the phase conductors. The earthing design for transmission air break switches shall be submitted and approved by the Earthing & Power Quality Manager.

5.5.7 Multiple pole earthing

Where multiple conductive poles are used for a structure on a transmission line, for example a H-pole design, each of the poles earthing systems shall be bonded together underground and connected to the OHEW where appropriate.

5.5.8 Transmission autoreclosers

Where an autorecloser is installed on a non-conductive pole there is no additional earthing design required on top of the normal pole fault assessment. Where the asset is installed on a conductive pole the control equipment shall be insulated from the pole to the full EPR level, this includes any LV supply installed on the pole.

5.5.9 Communication assets on steel towers

Where communication assets, such as antennas, are placed on steel towers under agreement with Endeavour Energy the communications company will be required to confirm that the tower earthing complies with the criteria of this standard. The communications equipment shall be supplied through an isolating transformer and solidly bonded to the tower earthing system. Testing in accordance with Annexure C – Overland injection testing of pole earthing performance is required to confirm compliance.

5.6 Design documentation

The Project Manager shall confirm that all electronic copies of the design reports, commissioning reports and drawings (in both pdf and CAD format) are provided to the Earthing & Power Quality Manager as part of the initial approval process. Drawings shall be prepared in line with the SAD 0001 – Project drawing standards. The designed pole electrode system and resistance shall be confirmed to be entered into Ellipse under the nameplate value for each pole by the project manager.

The following design documentation shall be electronically provided for a standard earthing design associated with Endeavour Energy's network:

a) Earthing design report including the following details:
   a. design assumptions,
   b. design inputs of section 5.2.3,
   c. applicable safety criteria,
   d. full details of the calculations used and the name and version of software used,
   e. details of the required electrode arrangements and the expected resistance,
   f. highest expected pole EPR for each section and the corresponding voltage profile,
   g. designed conductors and confirmation of appropriate fault current ratings,
   h. lightning assessment, if required under section 5.2.7,
   i. details of the assessment of touch voltages and compliance levels for any special locations,
   j. minimum separation distances to third party assets, MEN infrastructure and adjacent metallic objects in accordance with the relevant Australian standards, and

b) Detail of the earthing electrode arrangements is required on the design drawings. Any special requirements and mitigations required by the design must be explicitly noted on the design drawing.

c) Earthing construction SDR and program report identifying inspection, verification, modification, connection and testing requirements throughout the construction period.

d) Where a level 2 design has been undertaken a report confirming compliance with the design is sent to the Earthing & Power Quality Manager for approval.

5.7 Approved Products

A list of commonly used transmission mains approved products is provided in Annexure D – Approved products. These products shall be read in conjunction with latest parts and accessories list provided on the Endeavour Energy standards website.

5.8 Drawings

A list of standard arrangements and their associated drawings are provided in Table 3. Standard construction arrangements can be deviated with prior consent from the Earthing & Power Quality Manager. The reason for the deviation shall be stated clearly and objectively for consideration and assessment.

A list of typical arrangements is also provided. The conceptual drawings are standard drawings, which are not applicable to every situation.

Table 3: Standard drawings

Drawing no.	Amd no.	Subject
051125	J	Overhead transmission earthing connections for concrete poles
056814	J	Overhead transmission concrete pole earth electrode installation detail
404024	A	Earth batten/cable guard installation on transmission poles
048340	L	Overhead transmission wood pole earthing installation detail
241784	B	132kV transmission tower earthing detail at footings

Table 4: Conceptual drawings

Drawing no.	Amd no.	Subject
241955	B	132kV transmission tower additional earthing of tower
404121	A	Timber pole theft deterrent earthing assembly earth connection detail
404122	A	Grading ring for concrete transmission poles
404134	A	Concrete apron for concrete transmission poles

6.0 AUTHORITIES AND RESPONSIBILITIES

Chief Engineer has the final authority and responsibility for:

- approving this standard and the earthing risk management and design methodology associated with Endeavour Energy's network;
- advising the risk profile and methodology used for transmission earthing design to the Chief Operating Officer and the Board; and
- approving any design with a risk profile exceeding the minimum requirements of Company Policy 9.2.5 – Network Asset Design upon recommendation from Manager Primary Systems and Earthing & Power Quality Manager provided the risk is considered as low as reasonably practicable.

Manager Primary Systems has the authority and responsibility for:

- verifying that this standard meets company policy, regulatory and the health and safety obligations of Endeavour Energy;
- advising on the risk management methodology for earthing hazards associated with Endeavour Energy's network; and
- endorsing any design with a risk profile exceeding the minimum requirements of Company Policy 9.2.5 – Network Asset Design upon recommendation from Earthing & Power Quality Manager provided the risk is considered as low as reasonably practicable.

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

- verifying that the content of this instruction is kept up to date based on industry best practice and current research and literature regarding major substation earthing risk management;

- reviewing earthing design and reports and providing earthing solutions and risk treatment based on the requirements of this and other relevant standards;
- reviewing and recommending any design with a risk profile exceeding the minimum requirements of Company Policy 9.2.5 – Network Asset Design to Manager, Primary Systems and the Chief Engineer provided the risk is considered as low as reasonably practicable; and
- providing design information as appropriate on request from the earthing designer.

Asset Data Manager has the authority and responsibility for updating and maintenance of network earthing information in Ellipse and GIS in accordance with this instruction.

Protection Manager has the authority and responsibility for providing the appropriate protection information for the transmission line design.

Earthing Engineers have the authority and responsibility for:

- reviewing earthing design and reports and providing earthing solutions and risk treatment based on the requirements of this standard:.
- recommending earthing design reports and drawings to the Earthing & Power Quality Manager for approval; and
- reviewing transmission mains earthing tests and identifying means to confirm risks are maintained or reduced to as low as reasonably practicable.

Manager Network Connections has the authority and responsibility for seeing that the following are applied to customer funded contestable works:

- earthing designs are carried out for all network projects in accordance with the design and the standard;
- ASPs construct/install the earth systems in accordance with the design and this 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.

Accredited Service Providers (ASPs) and **Earthing Designers** have the authority and responsibility for:

- verifying their earthing designs comply with this standard;
- seeking clarification of this instruction, where necessary from the Earthing & Power Quality Manager, either directly or through the Network Connections contacts;
- verifying that work performed is carried out in accordance with local and statutory requirements;
- verifying that standard risk management principles and procedures are followed and public safety is not unduly compromised within their reasonable capability;
- preparing and advising on associated SWMS, SDR and risk management plans for construction and commissioning support;
- 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;
- constructing the line as designed; and

- undertaking an appropriate test on the transmission line to confirm compliance to this standard.

Network Planners have the authority and responsibility for planning the network with due regard to earthing system safety compliance in accordance with this instruction.

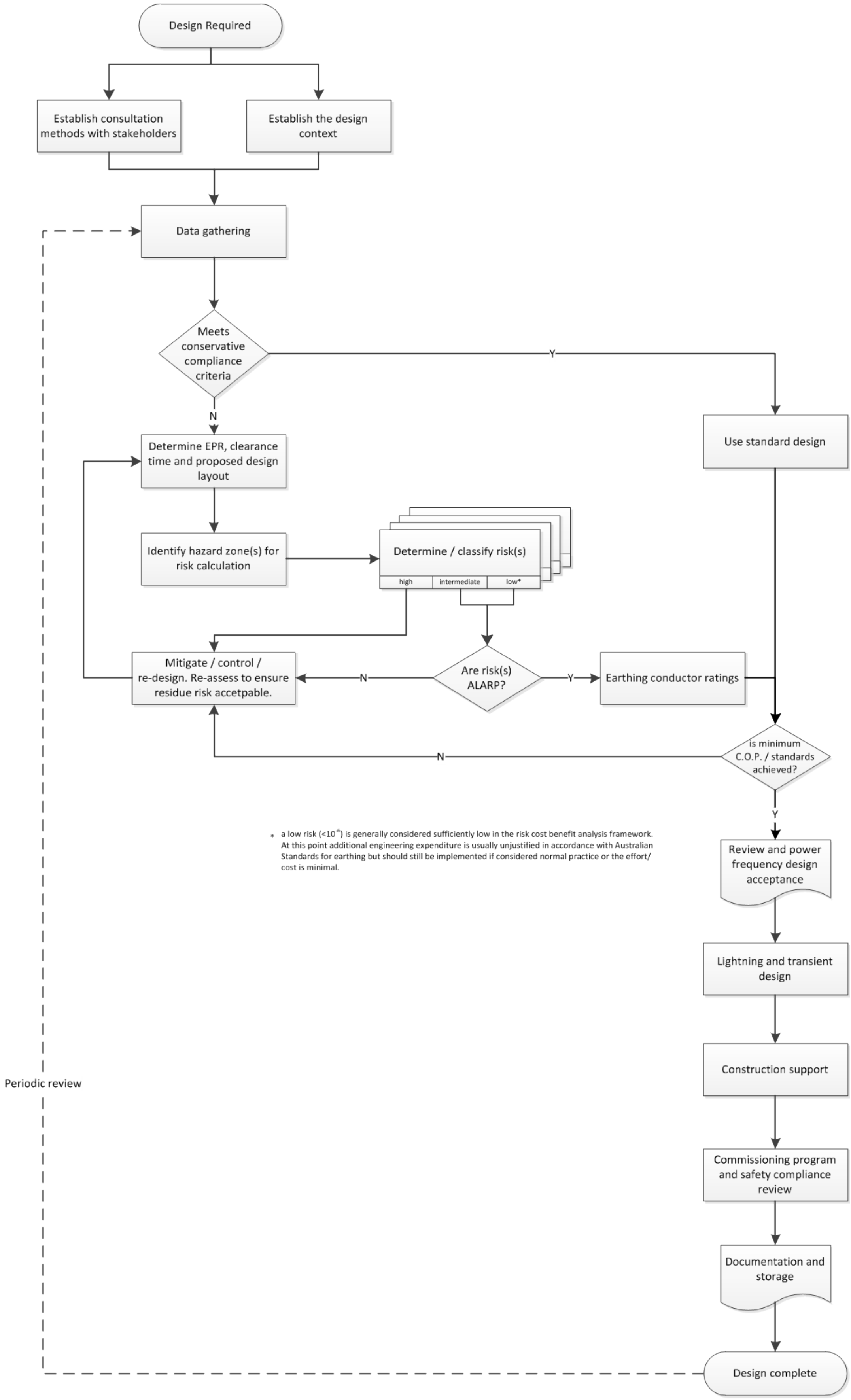
Trans Mains Development Manager has the authority and responsibility for seeing that earthing designs are undertaken by capable employees and comply with the requirements of this standard.

Operations Manager, Testing and Instrument has the authority and responsibility for testing the earthing systems of transmission lines in accordance with this document

7.0 DOCUMENT CONTROL

Documentation content coordinator: Manager Primary Systems
Documentation process coordinator: Standards Process Coordinator

Annexure A - Transmission line earthing design process



Annexure B - Technical calculation of pole EPR with homogenous soil assumptions

Where a pole does not meet the conservative compliance criteria of a level 1 design additional modeling is required to verify compliance. The initial stages of the level 2 design can make a few broad assumptions if more accurate software is not available. This shall be based on the assumptions are listed below, and must be confirmed in the report to be conservative. Where this modeling cannot prove compliance more accurate modeling shall be used.

Assumptions:

- Soil is homogeneous. A sensitivity analysis is required for the modeling against the measured soil resistivity to determine which will be the most conservative for the design.
- The fault is usually considered to bolted (R_c=0)
- The section of line being analysed is more than 10 spans from any underground section.

Pole step and touch voltage modeling

The figure below gives an electrical circuit which can help in the calculations. All calculations shall be done considering resistance and reactance in complex form.

In all cases the EPR at the pole will be equal to

$$EPR = I_{pole} * R_p$$

The soil voltage transferred from the pole can then be calculated to be

$$V_{Soil} = EPR * \frac{R_e}{x + R_e}$$

$$where\ R_e = \frac{l}{\ln\left(\frac{4l}{r}\right) - 1}$$

$$and\ x\ is\ the\ distance\ from\ the\ pole, l\ is\ the\ rod\ lengthand\ r\ is\ the\ radius\ of\ the\ rod$$

This value can be used to calculate both the touch voltage to a conductive pole (see below) and touch voltages to surrounding metal objects.

$$V_{TouchPole} = EPR - V_{soil}(x = 1)$$

The resistance of a single pole electrode can be calculated to be

$$R_p = \frac{\rho}{2\pi l}\left[ln\frac{8l}{d} - 1\right]$$

$$where\ l = rod\ length(m) and\ d = rod\ diameter\ (m)$$

Where multiple electrodes are used the equations of EG1 shall be used.

If the OHEW is not continuous between the source and receiving substations (labeled TS and ZS in the figure below) the pole current is simply the sum of the fault current from both substations and the circuit below has the switches open.

Where the OHEW is continuous the fault current needs to take into account the current that will be dissipated in the alternate paths. In this case the pole current can be calculated as

$$I_{pole} = \left[\frac{Z_t}{2R_p + Z_t}\right] * kI_f$$

Where

$$k = 1 - \frac{OHEW\ mutual\ impedance}{OHEW\ self\ impedance} = shielding\ factor$$

According to AS/NZS: 4853:2012

$$OHEW_{self} = 3 * \left[R_{cond} + 988.2 * 10^{-6} * f + j2.893 * 10^{-3} * f * \log_{10}\left[\frac{658368 * \sqrt{\frac{\rho}{f}}}{GMR_{cond}}\right]\right]$$

$$OHEW_{mutual} = 3 * \left[988.2 * 10^{-6} * f + j2.893 * 10^{-3} * f * \log_{10}\left[\frac{658368 * \sqrt{\frac{\rho}{f}}}{\sqrt[3]{3 * GMD_{diff}}}\right]\right]$$

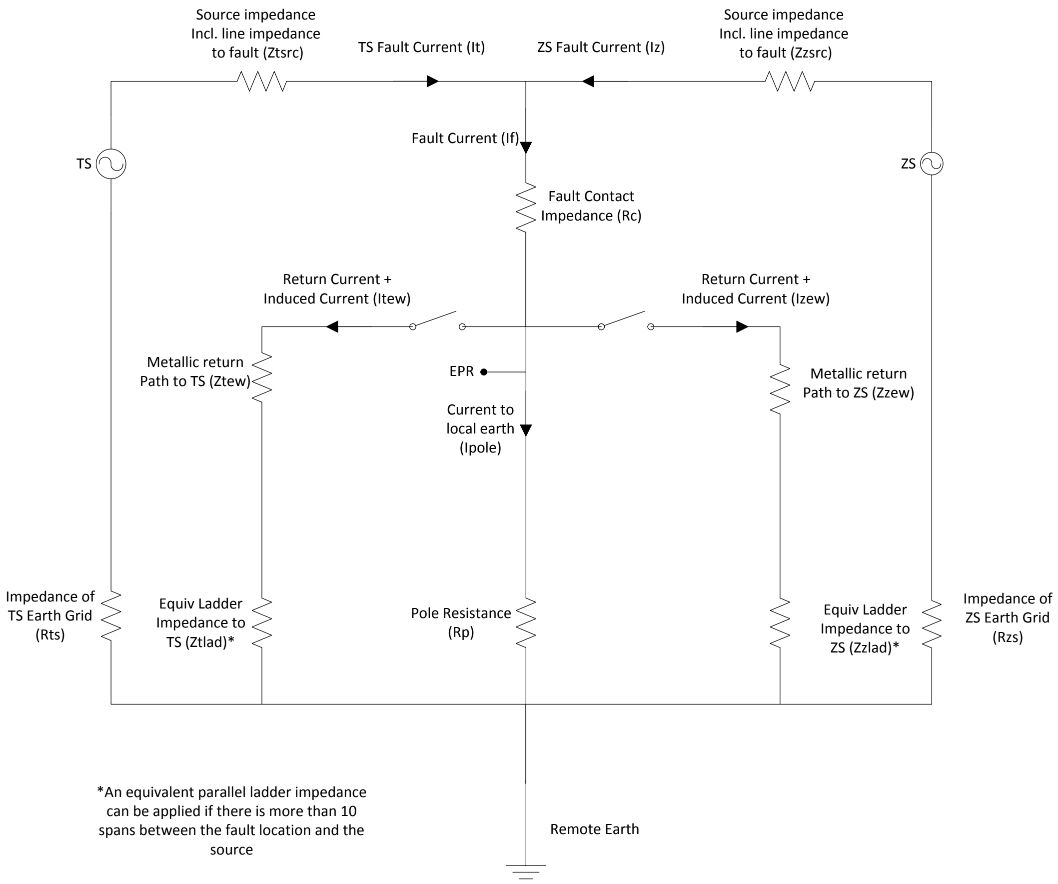
$$R_{cond} = AC\ resistance\ of\ the\ OHEW\ at\ 75°\mathrm{C}$$
$$GMR_{cond} = the\ geometric\ mean\ radius\ of\ the\ OHEW\ (mm)$$
$$GMD_{diff} = the\ distance\ between\ the\ faulted\ conductor\ and\ the\ OHEW\ (mm)$$

And

$$Z_t = equivalent\ impedance\ of\ the\ parallel\ pole\ or\ substation\ resistances\ along\ the\ OHEW\ or\ Z_{tlad}\ and\ Z_{zlad}\ in\ the\ figure\ below$$

Where the number of spans between the pole and any UGOH or substation is greater than 10 then the following equation can be used

$$Z_{tlad} = Z_{zlad} = \frac{OHEW_{self}}{2} + \sqrt{\frac{OHEW_{self}^2}{4} + OHEW_{self}R_p}$$



Electrical equivalent circuit for calculating transmission pole earthing requirements

Voltages due to low frequency induction can be calculated using the information found in Annexure E of EDI 001 –Earthing risk assessment.

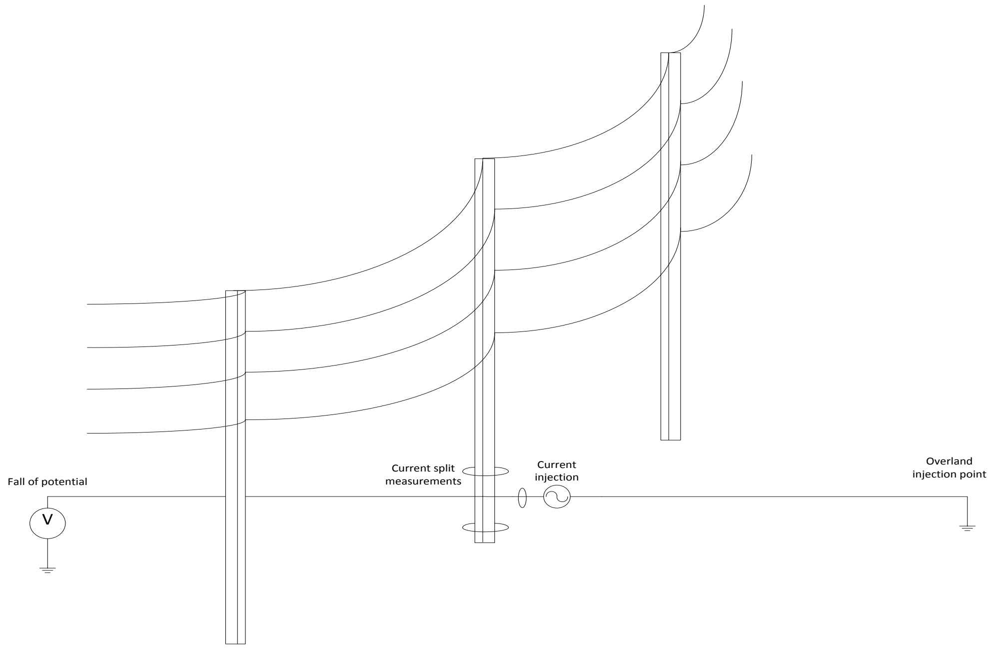
Annexure C Overland injection testing of pole earthing performance

Where a small number of poles are required to be tested the most economical means of testing is usually to undertake an overland injection onto the pole required to be tested. The figure below gives guidance on the set up of this test. Note that this test will be conservative as the mutual coupling effects are not taken into account.
Note that where possible, or where there is no test point available the individual pole test shall use two coils, one to drive current and the other to measure voltage. Further details can be found in EDI 100 – Distribution earthing design, if required.
The placement of the overland injection point shall consider the following:

- The injection point shall be at least half the span length away from the foot of any pole on the feeder.
- The impedance of the injection point must be low enough so that sufficient current can be driven by the test set so that voltage and current measurements are meaningful. In some cases it may be beneficial to utilise an existing earth grid, such as the HV earth on a distribution substation, or multiple stakes in the ground.

The test requirements are:

- Fall of potential measurements. Note that these must be taken as close as possible to perpendicular to the feeder route and the injection site. The distance travelled shall be such that the voltage measurements do not significantly change from one measurement to another. Where there is no clearance to undertake this test a full circuit CIT will be required as described in section 5.4.1.
- Current splits. These must differentiate the current flowing into the local pole earth and up into the OHEW. The combination of the current into the local pole earth and the EPR measured with the fall of potential test can be used to calculate the local pole resistance.
- Touch voltages. Touch voltages must be measured to all local metallic objects where it is possible for hazardous voltages to be present.
- DC continuity. Where there is MEN connected assets close to the pole earth it shall be verified that the separation is sufficient and that there is no continuity. Where third party assets are installed on a pole/tower it shall be confirmed that all peripheral equipment designed to be bonded to the tower earth grid has a continuity of less than 20mΩ.



Example of a possible overland injection set up for the testing of a single pole

Annexure D - Approved products

GROUP	EE STOCK CODE	DESCRIPTION / DRAWING NUMBER	MANUFACTURER / PART #
CABLE		MERCURY 7/4.50 AAC/1350 OVERHEAD CONDUCTOR	
CABLE		CABLE INSULATED BLACK CU 70SQMM SD	
CABLE		CABLE ALUMNIMIUM 95mm^2 SDI PVC BLACK	
CABLE		CABLE INSULATED BLACK CU 70SQMM SD	
CABLE		CABLE BARE CU 70SQMM SD	
CABLE		CABLE BARE CU 95SQMM SD	
LUG-CLAMP	1556927	BIMETALLIC COMPRESSION CONNECTOR 95mm^2 AL TO 70mm^2 COPPER	
LUG-CLAMP		CLAMP GROUNDING ALM-TG-12	ALM-TG-12
LUG-CLAMP	1116870	CRIMPED CONNECTOR ‘C’ TYPE CO/70	
LUG-CLAMP	1104595	CRIMPED CONNECTOR ‘6’ TYPE E70	
LUG-CLAMP	SL12921	LUG CRIMP 7/4.5 SCREW M12	
LUG-CLAMP		M12 LUG FLAT	
FASTNERS	SS19581	SCREW S/STEEL HEX HD M12 X 25 LG	
FASTNERS	SW10523	WASHER STEEL FLAT SQ GALV 20 (50 X 50)	
FASTNERS	SW10531	WASHER STEEL FLAT SQ GALV 16 (50 X 50)	
FASTNERS	SW10159	WASHER S/STEEL FLAT RND 12	
FASTNERS	SN11738	NUT STEEL GALV M20	
FASTNERS	1001954	BOLT M12 X 25mm GALV	
FASTNERS	1003240	WASHER FLAT M12 GALV	
FASTNERS	1003896	WASHER SPRING M12 S/S	
FASTNERS	SS15934	STAPLE STEEL GALV 38 X 4	
FASTNERS	SC11194	COACHSCREW STEEL HEX HD GALV 10 X 80 LG	
CADWELD	1552710	CADWELD 90PLUSF20	
CADWELD	1552728	CADWELD 115PLUSF20	
CADWELD	1552736	CADWELD 150PLUSF20	
CADWELD	1552744	CADWELD 200PLUSF20	
CADWELD		CADWELD MOULD GT	
CADWELD		CADWELD MOULD TA	
CADWELD		CADWELD MOULD GF	
ROD AND ACCESSORY		END CAP M15	
ROD AND ACCESSORY	1020936	EARTH ROD M15X2400 STEEL COPPER CLAD	
ROD AND ACCESSORY	SC12360	EARTH ROD COUPLING M15	
ROD AND ACCESSORY	1554476	EARTH ROD LOCK PIN	
ROD AND ACCESSORY	SR10411	EARTH ROD DRIVING HEAD	
ROD AND ACCESSORY		HEXAGONAL CRIMPING DIE	UTILUX 38-142

GROUP	EE STOCK CODE	DESCRIPTION / DRAWING NUMBER	MANUFACTURER / PART #
ROD AND ACCESSORY		ANTI THEFT ASSEMBLY – CONCRETE POLE	ERICO - 615300GL03
ROD AND ACCESSORY		ANTI THEFT ASSEMBLY – WOODEN POLE	ERICO – 15800CW0505
GENERAL	1069858	EARTHING COMPOUND - GOOD EARTH 50KG BAG	FULTON OR MOLE
GENERAL		ANCHOR SADDLE SS-GRADE 316	SPECIALISED WHOLESALE CCLM10-316DS
GENERAL	1556059	EARTH BATTEN 3000MM PLASTIC	
GENERAL	ST10740	TAPE (DENSO 931) 10M	
GENERAL	ST10795	GREASE MASTIC (DENSYL 410)	
GENERAL		POLCO INSULATING MATERIAL	
GENERAL		NUKOTE INSULATING MATERIAL	
GENERAL	SC11526	CONDUIT PVC FLEXIBLE 25MM DIA	

Annexure E - Hazard mitigation techniques

The following contains information on methods to reduce the risks associated with earthing of transmission mains, note that this list is not exclusive and other mitigation methods are discussed in EDI 001 – Earthing risk assessment. The list is arranged in order of application preference.

Also note that in many situations a combination of the mitigation methods are required to make the situation safe.

Pole placement

The risks associated with transmission lines are proportional to the probability of a human being coming into contact with the object. By placing poles outside of high risk areas the likelihood of a fatality can be greatly reduced. Examples of high risk locations include, but are not limited to,

- Near metallic fences and gates
- Near houses
- Frequented areas, such as bus stops
- Third party assets
- Swimming pools

Obviously there is often constraints on pole placement due to location of the loads and mechanical stress on poles but where practical the line designer shall endeavour to place the pole in an area of low risk.

Metallic return path to source

The presence of a metallic return path to the source encourages more fault current to return via this path rather than through the ground, lowering the EPR. The metallic return path is typically the OHEW but can also be through distribution assets, see EDI100 for further details. If the OHEW is used there is the additional benefit of reducing the total fault current through mutual coupling between the faulted conductor and the metallic return path.

Pole earthing systems

The earthing of each pole not only has an impact on the local EPR and touch voltages but also on the overall earthing performance of the line. The preferred scheme will be dependent on the locations where the transmission line

A larger electrode system will reduce the earthing impedance and lower the EPR close to the pole. This may also help to reduce the overall line EPR and reduce the EPR of the connected substations as well as improving the lightning performance of the line. However large electrode systems extend the EPR hazard zone and will likely increase the risk to local infrastructure and as such care must be used when applying this design to lines intersecting urban areas.

Smaller electrode systems may result in higher EPR’s but with a smaller hazard zone as there is less fault current. In areas with where low impedance OHEW is used this may be preferred as an increased resistance will encourage more current to return to the source through the OHEW rather than being distributed to surrounding poles. In all cases where the pole earth impedance is increased the designer shall confirm that this will not affect protection operation or reliability due to lightning back flashover.

In some cases it may be determined by design that an individual pole will have higher pole earthing impedance than the rest of the transmission line, to minimise the hazard to local metallic objects. In all cases where this is used as for risk mitigation an assessment using earthing software is required to determine the optimal electrode arrangement for each project.

Where a non-conductive pole is used the electrode can be insulated to a designed depth to reduce the voltage levels seen at the surface.

Where a resistance greater than the MDI 0047 – Overhead transmission mains design, value is used the design shall be approved by the Earthing & Power Quality Manager.

Earthing nearby conductive objects

To mitigate hazards due to inductive and capacitive coupling it is generally best practice to suitable earth nearby conductive objects.

For parallel conductive objects, such as metal pipelines and long fences, it is generally best practice to earth each section or alternatively install an isolated section. The length and depth of rod required will need to be determined on assessment and will depend primarily on the fault level, soil resistivity and the proximity to the transmission line.

Nearby metallic objects can accumulate enough capacitive charge to cause pain on discharge, which in itself is not hazardous. However the shock on discharge may cause the individual to inadvertently behave in a hazardous way for a short amount of time. Designer’s discretion must be applied to determine if a hazardous situation can be caused by capacitive coupling. If this is the case the object shall be earthed with a single 1m stake. An example being the earthing of distribution air brake switch handles.

Non-conductive poles/pole covering

Conductive poles can be exposed to full EPR, utilising a non-conductive pole, such as a wooden pole, mitigates this risk. An alternative would be to utilise a non-conductive covering, such as a polyeurea epoxy coating or plastic cover guard, on the pole to a height of at least 2500mm, covering all exposed conductive parts of the pole with the exception of the pole nameplate.

The thickness of the coating shall be such that the insulation level is a greater than the pole EPR, the insulation of a polyeurea coating can be assumed to be 10kV/mm of coating unless shown otherwise.

The coating should ideally be applied prior to the installation of the pole but can be applied retrospectively. The product used for insulation shall only be from the list of approved products.

Note also that this mitigation method does not reduce the ground potential. Hazardous voltage on other nearby conductive objects shall still be considered by the designer as well as step voltages in the surrounding area.

Downleads may also be insulated from the pole to achieve greater separation distances. Designs considering this option shall be approved by the Earthing & Power Quality Manager.

Pole grading rings

In situations where there is a substantial touch voltage to a conductive pole an appropriate mitigation method may be to use a grading ring in conjunction with the pole electrode system. This ring shall be installed at a depth of 0.5m and extend 1m from the pole, as well as being bonded to the pole itself. In this configuration earthing resistance will be decreased and the voltage between the pole and the feet of the individual being in contact with the pole will be minimised. The installation of a grading ring may impart high touch voltages to nearby metal objects, this effect will need to be considered in the design.

Concrete apron

Placing a concrete apron around a conductive object, such as a conductive pole, makes the individual's feet close to the same potential as the part of the body touching the conductive object. In this way little current will flow through the body and there is a much lower risk of fibrillation. Consideration will have to be given in the design to maintenance for both the pole and its electrode system.

If a concrete apron is utilised it must extend to a distance of at least one meter from the conductive object. The apron shall be steel reinforced with the steel bonded to the pole earthing system and must be at least 0.15m in thickness.

Where a concrete apron is used as mitigation the Earthing & Power Quality Manager must give permission.

Asphalt layer

Installation of an asphalt layer around a conductive object significantly increases the impedance between the feet and the ground allowing less current to flow through the body, reducing the risk of fibrillation. Where an asphalt layer is specified 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

Where an asphalt layer is used as mitigation the Earthing & Power Quality Manager must give permission.

Procedures to mitigate inductive coupling hazards

Where there is electromagnetic induction that causes hazards on third party assets the mitigation method shall be decided in consultation with the asset owner. Examples of mitigation measures include the relocation of access points and the periodic earthing of assets.

Where there is electromagnetic induction that causes hazards on non-utility infrastructure, such as fences, the best mitigation is the installation of non-conductive sections to break the circuit. Where this is not possible an alternative shall be proposed with the infrastructure owner as a part of a level 2 design.

Procedural controls

If all combinations of the above hazard mitigation measures have not been found to reduce the risk to acceptable levels then procedural controls shall be applied. These can include the installation of warning signs on poles or the erection of protective barriers and fences around the hazard source. In all situations where procedural controls are proposed approval is required from the Earthing & Power Quality Manager.

Annexure F - Transmission pole earth resistance measurement sheet

Transmission Pole Earth Resistance Measurement Sheet

Project: ______________________________________**Date:** ___/___/___ **Job Site / Location:** _____________________________**Time:**_____________

Tested by: ____

Test Unit Type: _____________Serial Number: _________________ Last Calibrated: ___/___/___ Site Observations: _____________________________________

Note the following table should be completed with reference to the earthing design. Results shall be submitted to the project manager and any required mitigations undertaken to comply with the design. Resistance measurements to be entered into Ellipse as a part of the works as executed package.

Pole Number	Resistance Reading (Ω)	Designed resistance (Ω)	Compliant separation to Telstra (Y/N)	Compliant separation to metal objects (Y/N)	Compliant separation to water pipe (Y/N)	Pole installed in line with standards (Y/N)	Notes