

Earthing Design Instruction

Earthing design risk assessment

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EARTHING DESIGN INSTRUCTION

ASSET STANDARDS AND DESIGN

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EDI 001 EARTHING DESIGN RISK ASSESSMENT

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1.0 PURPOSE

To establish the company's minimum earthing risk assessment design criteria and methods by which earthing hazards are to be assessed throughout the company's network as one means of safeguarding workers and the public from hazards that may be caused by exposed differences in electric potential.

2.0 SCOPE

This instruction provides the earthing risk assessment process and criteria for the company's network assets. Assets include all distribution equipment with high voltage earths as well as all transmission assets and major transmission and zone substations and major switching stations. This instruction also applies to assist a designer in deciding when the earths of the various network voltages are safe to be shared.

This instruction also applies to associated earthing hazards on metallic non-power system infrastructure parallel to or within proximity to the company's network assets.

3.0 REFERENCES

Internal

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 Ratings
Company Policy (Governance) 2.0.5 – Risk Management
Company Policy (Governance) 2.0.3 – Compliance
Company Procedure GRM 0003 – Risk Management
Company Procedure GSY 0026 – Work Health and Safety Risk Assessment
Division Procedure GNV 1119 – Quantitative Determination of Reasonably Practicable Risk
Control Measures When Assessing Health and Safety Risks
Earthing Design Instruction EDI0005 – Distribution earthing test
Earthing Design Instruction EDI0004 – Earthing design, construction and testing of overhead transmission mains
Earthing Design Instruction EDI 100 – Distribution earthing design, construct and test
Earthing Design Instruction EDI 516 – Major substation earthing design, construct and commissioning
Mains Design Instruction MDI0044 – Easements and Property Tenure Rights
Mains Design Instruction MDI0047 – Overhead transmission mains design
Mains Design Instruction MDI0028 – Underground distribution network design
Mains Design Instruction MDI0031 – Overhead distribution: Design standards manual
Substation Maintenance Instruction SMI 100 – Minimum requirements for maintenance of transmission and zone substation equipment
Substation Maintenance Instruction SMI 101 – Minimum requirements for maintenance of distribution equipment
Substation Maintenance Instruction SMI 104 – Major substation earthing system test
Endeavour Energy Electrical Safety Rules
Network Management Plan 2009-2014

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

AS/NZS 7000:2016 – Overhead line design – Detailed procedures

AS/NZS ISO 31000: 2009 – Risk management – principles and guidelines

AS/NZS 3000: 2007 – Wiring Rules

AS/NZS 3007: 2013 – Electrical Installations – Surface mines and associated processing plant

AS/NZS 4853: 2012 – Electrical hazards on metallic pipelines

AS/NZS 3835: 2006 – Earth potential rise – Protection of telecommunications network users, ENA

AS/NZS 1768: 2007 – Lightning Protection

AS 2067: 2016 – Power installations exceeding 1kV a.c.

AS 1824: 1995 – Insulation Coordination

AS/NZS 60479: 2010 – Effects of current on human beings and livestock

CJC5/HB101:1997 – Coordination of power and telecommunications – low frequency induction – Standards Australia

Cigre TB290 – AC Corrosion on Metallic Pipelines due to Interference from AC Power Lines - Phenomenon, Modelling and Countermeasures

Cigre TB095 – Guide on the influence of high voltage AC power systems on metallic pipelines

Doc 001-2008 National Electricity Network Safety Code

ENA EG1 – 2006 – Substation Earthing Guide

ENA EG0 – 2010 – Power System Earthing Guide: Management Principles personnel and plant

IEEE80: 2013 – IEEE Guide for Safety in AC Substation Grounding

IEC 61936: 2010 – Power installations exceeding 1 kV a.c. - Part 1: Common rules

NSW Planning: Hazardous Industry Planning Advisory Paper No.4; Risk Criteria for Land Use Safety Planning; January 2011

Safe Work Australia: Guide for Major Hazard Facilities: Safety Case: Demonstrating the Adequacy of Safety Management and Control Measures

Safe Work Australia: How to determine what is reasonably practicable to meet a health and safety duty; May 2013

Safe Work Australia: Safe design of structures: Code of Practice; July 2012

Safe Work Australia: How to Manage Work Health and Safety Risks: Code of Practice

State Environmental Planning Policy (Infrastructure) 2007 – NSW

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 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.

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, communications systems and CB's.

CMEN

Common Multiple Earth Neutral System (CMEN) is a system where the combined high voltage and low voltage distribution 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.

Company

The company referred to in this document is Endeavour Energy.

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.

Contact criteria: backyard

An area with a contactable metallic structure (e.g. 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 (e.g. 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.

Document Control

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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

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.

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 Conductor

Ellipse

The company's asset management database

Embedded earth

The use of steel reinforcing bar in concrete structures to interconnect with, and to augment the earthing system. Its purpose may be to lower the earth resistance and create an equipotential plane.

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

Equipotential bond

A bonding conductor applied to maintain continuity of conductive structures and conductors with the main earth grid or structure in order to prevent voltage differences the equipotential bonding conductor may not be designed to carry fault current.

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 must 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

HV

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

ICAR

Implied cost of averting risk/fatality; a risk management tool to aid the decision making in regard to adopting control measures to determine methods that are highly effective against those where cost or effort are to be diverted to alternative, more effective safety improvements.

IDMT

IDMT stands for Inverse Definite Minimum Time – and is the normal type of time/current graded over-current/earth-fault protection used in the HV distribution of electricity.

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.

LV

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

MEN

Multiple Earthed Neutral. A system of earthing in which the parts of an electrical installation required to be earthed in accordance with AS/NZS 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's electrical network of poles, wires, substations and other assets by which electrical power is transmitted/distributed to its customers.

Non-power system assets

Metallic non-power system assets refer to assets which could present a voltage hazard to people when a power system asset is affected by an unbalanced condition.

Not practical

Economically not viable in the risk cost benefit analysis framework (refer ALARP)

OHEW

Overhead Earth Wire. This 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.

Recordkeeping

Making and maintaining complete, accurate and reliable evidence of business transactions in the form of recorded information (Source: AS Records classification handbook – HB5031 – 2011).

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.

Residual risk

Risk remaining after implementation (or as a result of) risk treatment

Resistance to earth

Real part of the impedance to earth

Review date

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

Risk

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 probability 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 criteria

Terms of reference by which the significance of risk is assessed

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.

SEF

Sensitive earth fault protection – 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 defined as the electric field strength (V/m) divided by the current density (A/m²) which represent the value to one (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 (loaded)

Voltage between two points on the earth’s surface that are 1m distant from each other while a person is making contact with these points.

Step voltage (prospective)

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. (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 the company’s network are typically 132kV, 66kV and 33kV.

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

Touch voltage (loaded)

Voltage between conductive parts and/or nearby soil at the feet when touched simultaneously influenced by the impedance of the person in electric contact with these conductive paths.

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 the company's network is typically, but not exclusively, 132kV.

UG/OH

Underground overhead – a connection between overhead and underground mains.

Unbalanced

Unbalanced system conditions in an earthed polyphase network imply the voltages and/or currents in each of the phases are not equal. Such conditions include the line to ground fault in a network with ground return.

Ventricular fibrillation (threshold)

Minimum value of electric current which causes ventricular fibrillation (cardiac fibrillation, limited to the ventricles), leading to ineffective circulation and then to heart failure.

Zero sequence source

The source of zero sequence currents in a circuit for instance the solidly earthed star point of a distribution transformer.

5.0 ACTIONS**5.1 General requirements****5.1.1 General**

During unbalanced network conditions and in particular phase to earth fault conditions, current will flow through metallic paths and into the general mass of the earth en route to the zero sequence source(s) – for instance the neutral point of the earthed star transformer. The resultant impedance of the earthed network including metalwork, conductive paths and the local soil surface with respect to “remote” earth can lead to a rise in voltage. If unmanaged, any difference in voltage between two metallic items or between a metallic item and the local soil/surface may pose a hazard to workers and the general public.

This instruction provides the design risk assessment methodology and minimum requirements for the company's assets and must be read in conjunction with the specific company earthing design and construction standards, depending on the application:

- Distribution equipment and distribution mains circuits: EDI 100;
- Zone and transmission substations and switching stations: EDI 516; and
- Transmission overhead mains: EDI 0004.

5.1.2 Earthing philosophy

The company's network is generally solidly earthed. The solidly earthed system is effective at minimising transient over-voltages, limiting insulation requirements of network equipment and providing appropriate protection earth fault grading and sensitivity. However, in order to improve safety for workers and the public, in particular circumstances consideration to limit earth fault levels on the transmission and distribution network must be given subject to approval by Manager, **Asset Standards & Design**.

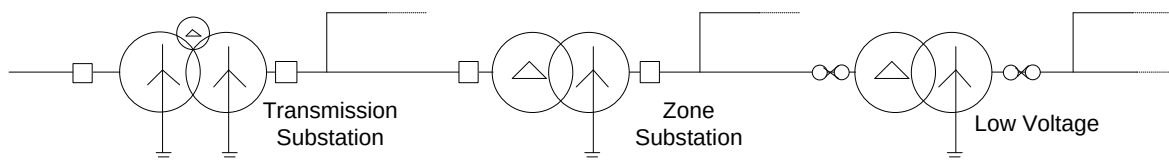


Figure 5-1: The company's typical simplified network configuration

Metal structures and equipment may be energised to dangerous voltage levels as a result of an earth fault. For this reason depending on access, location and exposure levels, metal structures and equipment must be bonded to earth by permanent connections to electrodes in contact with the general mass of the earth. The hazard to human beings of electric shock means all earthing systems must be designed to maintain acceptable levels of safety to electrical employees and the public.

The design, selection and installation of the earthing systems must meet the requirements of 5.1.2.1 and 5.1.2.2. When assets are augmented or improved, the integrity and safety of the existing earthing system must be evaluated in accordance with this standard.

5.1.2.1 Performance requirements

The performance requirements for an earthing system must meet the following requirements:

- proper functioning of electrical protective devices through an adequate earth impedance path for lightning, switching surges and unbalanced/faulted power frequency current; and
- managing the risks associated with step, touch and transfer voltages in accordance with this instruction, applicable regulations, standards and guidelines.

5.1.2.2 Functional requirements

In addition to the performance requirements, it is imperative that the integrity of the earthing system and values of earthing impedance are continuously effective over the planned lifetime of the installation. This means the earthing design must address the following:

- fault current can be conducted without damage to the earthing system components;
- the possibility of mechanical damage is minimised;
- inadvertent interference and theft can be avoided; and
- chemical deterioration is minimised.

It is also essential that an asset be designed to the ultimate conditions that could be reasonably expected at a site. This requires consideration or design to changes in network/earthing conditions such as increases in fault level, clearance times, reduced easement sizes, urban interface with electrical systems, prevalence of conductive structures and/or the continual replacement of the conductive water reticulation system with insulating pipe.

5.1.3 Hazardous conditions

An informative discussion of the hazardous conditions associated with power systems under fault and transient conditions is provided in Annexure B: Hazardous scenarios. These hazardous conditions must be managed by the earthing design.

5.1.4 Earthing risk management

The occurrence of earth faults on power systems causing hazardous voltage differences and the presence of human beings in simultaneous contact with these differences in voltage are both probabilistic in nature.

This standard has adopted the risk based assessment criteria for the company developed by Energy Networks Australia. This is to align the safety requirements and assessment processes throughout the electricity supply industry based on the guide EG-0.

Risk assessments must be conducted by those who both create and those who control the extent of the risk. At the time of inception, it is the responsibility of the designer to assess and provide evidence through calculation and/or test of the risk level caused by the asset and appropriate mitigation applied. In the case of new transmission or distribution systems, an analysis of hazardous events must also take into account hazardous events occurring during construction, commissioning, maintenance, operation, testing and decommissioning. For the calculation of “low risk” step and touch voltages, primary protection clearing times must be used.

Details of the earthing risk assessment requirements for the company’s assets are provided in 5.2 and must be followed. A simplified design flow diagram is provided in Annexure A: General earthing design management process.

5.1.5 Earth conductor ratings

The conductors and associated joints used for earthing must be rated to withstand the maximum short circuit currents without damage or deterioration for the life of the asset. The ratings must be calculated using the backup protection clearance time.

The maximum short circuit fault current for distribution assets can be gathered from the company’s standards website. Transmission, Distribution and Major Substation assets protection information must be requested from protection.enquiries@endeavourenergy.com.au.

For conductor rating calculations, ambient temperatures of 25°C must be used for underground or embedded conductors and 40°C for overhead and aboveground conductors. For bolted or compression joints, the maximum temperature that the earthing conductor will reach must not exceed 250°C. A maximum temperature of 450°C is allowed for earthing conductors that are welded (cad weld) or brazed. A maximum temperature of 90°C is allowed for steel reinforced conductors embedded in concrete (applicable for indoor substations and GIS installation). Due to the melting of insulation and risk of ignition, insulation degradation and emission of gases, the allowable maximum temperature of insulated conductor is 160°C.

Table 5-1: Maximum conductor/joint temperature allowance

Limitation	Maximum temp (°C)
conductors embedded in concrete	90
insulated conductor	160
bolted or compression joints	250
welded (cad weld) or brazed	450

The temperatures above are not applicable for overhead lines under tension. Refer to MDI0047 for more information.

Buried conductors in an earth grid can be rated to lower fault currents as the fault current will disperse through the ground or into bonded metallic paths. For this reason bare buried conductors can be rated to 70% of the maximum envisaged fault energy.

Connections that may be a primary current path during foreseeable earth fault events require a conductor redundancy of N-1. Connections that are not a primary current path or have sufficient number of parallel current paths normally require a redundancy of N. In order to maximise the benefit of multiple connections and for redundancy to be maintained, multiple connections made to the same structure must be made at physically displaced locations.

Where fault levels and backup clearance times are known, the following table can be used which has been derived from the formulae from ENA EG-1 (section 10.2.2.2). This provides the minimum cross sectional area per kA of fault current to be considered adequate. It has been based on ambient conditions of 40°C.

Table 5-2: Earthing materials and required ratings (per kA of fault level)

Limitation	Material	Clearing time – Required CSA (mm ² /kA)				
		0.5 s	1 s	2 s	3 s	10 s
PVC	Standard annealed soft copper wire	5.2	7.4	10.4	12.8	23.4
	Commercial hard drawn copper wire	5.3	7.5	10.6	12.9	23.6
	Commercial EC Aluminium wire	7.8	11.0	15.6	19.1	34.9
Bolted or compression	Standard annealed soft copper wire	4.2	5.9	8.3	10.2	18.7
	Commercial hard drawn copper wire	4.2	6.0	8.4	10.3	18.9
	copper clad steel core	6.3	8.8	12.5	15.3	28.0
	copper clad steel wire	7.2	10.2	14.4	17.7	32.3
	Commercial EC aluminium wire	6.2	8.8	12.5	15.3	27.9
	Zinc coated steel core wire	12.9	18.3	25.9	31.7	57.8
	Stainless steel No. 304	22.2	31.4	44.4	54.3	99.2
Welded/Brazed	Standard annealed soft copper wire	3.3	4.7	6.6	8.1	14.7
	Commercial hard drawn copper wire	3.3	4.7	6.6	8.1	14.9
	copper clad steel core	4.9	7.0	9.8	12.1	22.0
	copper clad steel wire	5.7	8.0	11.4	13.9	25.4
	Commercial EC aluminium wire	4.9	7.0	9.9	12.1	22.1
	Zinc coated steel core wire	10.1	14.3	20.2	24.7	45.1
	Stainless steel No. 304	16.7	23.6	33.3	40.8	74.5

Recommended connection equipment and conductors is simplified and provided in EDI100, EDI0004 and EDI516 depending on the applicable use.

5.1.6 Soil electrical resistivity

The soil electrical resistivity model and possible seasonal variations are a vital aspect of any earthing system design. Soil electrical resistivity testing must be carried out for all earthing designs and performed in accordance with EDI0005.

Sensitivity to soil electrical resistivity variations must be taken into consideration. When determining the appropriate operation of protection devices and therefore impedance of the earthing system a higher value of resistivity can be encountered on site which may reduce the ability to drive sufficient fault current and therefore increase clearing times. When considering safety criteria a lower soil resistivity may be encountered which could result in higher body current due to lower soil contact resistance and therefore increased risk. Sensitivity must be considered in any earthing system design.

5.1.7 Works as executed

Where any aspect of the design is not met during construction, the designer must be consulted to determine the implications of the change. For instance where the design earth grid resistance is not met or alternatively is met with fewer electrodes relative to the designed electrode configuration, the designer must be consulted. The construction crew must not alter the electrode configuration without the endorsement of the designer, and works as executed drawings must be marked to show the ultimate compliant layout.

5.1.8 Augmentation and modification to an asset

Any augmentation or modification to a network asset(s) will require a review of the impacts on the existing earthing system associated with that asset(s) to confirm that the integrity of the earthing system is retained and the safety requirements of this standard are met. This will require the identification of additional works required to maintain earthing integrity and safety requirements under the new conditions based on this standard.

5.2 Earthing design risk assessment

5.2.1 Health and safety requirements

Earthing risks associated with the company's network and metallic infrastructure in the vicinity of the network must be **as low as reasonably practicable**. This requires:

1. the implementation of risk controls reasonably expected to be good practice by the industry; and
2. the identification of all reasonable additional controls in the form of risk reduction measures.

Once all risk controls are considered, it is required to demonstrate that the cost or sacrifice, in terms of resources, effort and money would be **grossly excessive** to the risk reduction benefits achieved for that control to not be used. This means that rather than balancing risk with costs; all hazard reduction strategies need be considered and only control strategies ruled out if they involve grossly excessive cost.

5.2.2 Controlling power frequency earthing risk

In all circumstances the design of the earthing system must be a key component to the overall design of an asset at a given location. In order of preference the following must be considered in an assessment of risk, weighing in each circumstance what new risks any controls or substitutes may pose:

- a) Elimination, Substitution and Isolation: Remove the hazard entirely, place the asset away from metallic non-power system plant, use non-conductive structures etc.
- b) Design and physical controls: Mitigation by engineering controls to eliminate or reduce the hazard magnitude and/or duration. Refer to 5.2.4 for a list of associated engineering controls.
- c) Administrative controls: Policies, procedures and practices to reduce the risk and risk practices.
- d) Procedural controls: Employee Protective Equipment, Operating controls, warning signs etc.

5.2.2.1 Quantifying earthing risk exposure

The calculation of earthing risk exposed to electrical workers and the general public for the company is based on the ENA guide EG-0. It is based on two fundamental components. The basic equation is:

$$(E1) \quad \text{Risk} = P_{\text{fib}} \times P_{\text{coin}}$$

Where,

- P_{fib} is the probability that a voltage incident will occur in the critical part of the cardiac cycle which is sufficient to cause ventricular fibrillation. This is a value based on the current path through the body, the body impedance and any additional series impedance that can be expected (shoes, asphalt, soil contact resistance etc.).
- P_{coin} is the probability based on the frequency and duration of any voltage incident being present at a location as well as a consideration of the frequency and duration of any person being coincident with the voltage hazard.
- Risk is the risk being assessed, in this case the probability of an individual fatality which is annualised.

Note: *Electrical accidents that do not involve ventricular fibrillation can also be fatal. Other effects may affect respiration which might in fact prevent someone from shouting for help. In other circumstances, if current flows through critical parts such as the spinal cord or the respiratory control centre, death can occur. These effects are under consideration in literature but thresholds are not yet defined. At the time of EDI001 am1 review, only ventricular fibrillation is recognised by the industry as being the most sensitive impact on human beings.*

5.2.2.2 Probability of coincidence

Network changes and the exposure to workers and the general public of electrical hazards require careful assessment. The probability of coincidence is the probability of someone being exposed to the influence of an earthed asset and the probability of a voltage hazard occurring concurrently. This is factored by:

- Fault frequency (f_n) – the number of faults per annum of the type being considered;
- Fault duration (f_d) – the duration of the fault prior to clearance from the closest upstream protection;
- Contact frequency (p_n) – the number of contacts expected over a year at the asset being considered; and
- Contact duration (p_d) – the duration of time each contact is expected to last each time.

The following standard individual probabilities of coincidences are expected based on the exposure of an asset to areas accessed by the general public. They are detailed in Table 5-3.

Table 5-3: Probability of being coincident with a fault (per fault per annum)

Probability of being touch coincident ($\times 10^{-3}$) per fault per annum			
Contact Scenario (per annum):	135 contacts / 4 sec	416 contacts / 4 sec	2000 contacts / 4 sec
Fault Duration (s)	Urban	Backyard	MEN
0.1	0.0176	0.0541	0.2600
0.2	0.0180	0.0554	0.2664
0.3	0.0184	0.0567	0.2727
0.4	0.0188	0.0580	0.2790
0.5	0.0193	0.0594	0.2854
0.6	0.0197	0.0607	0.2917
0.7	0.0201	0.0620	0.2981
0.8	0.0205	0.0633	0.3044
0.9	0.0210	0.0646	0.3108
1.0	0.0214	0.0660	0.3171
1.5	0.0235	0.0726	0.3488
2.0	0.0257	0.0791	0.3805
2.5	0.0278	0.0857	0.4122
3.0	0.0300	0.0923	0.4439
3.5	0.0321	0.0989	0.4756
4.0	0.0342	0.1055	0.5074
5.0	0.0385	0.1187	0.5708
6.0	0.0428	0.1319	0.6342
7.0	0.0471	0.1451	0.6976
8.0	0.0514	0.1583	0.7610
9.0	0.0557	0.1715	0.8245
10.0	0.0599	0.1847	0.8879

The coincidence assumption assumes the occurrence of an earth fault is; random, independent of the presence of a person, independent of the occurrence of past earth faults, occurs one at a time and have approximately equal probability of occurring at any given time. Where the occurrence of an earth fault is not independent of the presence of an individual, such as operational switching, it is a requirement to consider special precautions and mitigation accordingly based on the associated risks.

5.2.2.3 Probability of fibrillation

The main risk to humans is the exposure of the body to currents that are sufficient to cause ventricular fibrillation. Refer to AS/NZS 60479 for further detail on body current risks.

Based on AS/NZS 60479 and the assumptions provided in ENA guide EG-0, a set of expected fibrillation probabilities for a general population are provided in B.3 of ENA EG-0 and may be used to ascertain the risk of fibrillation. Alternatively Argon (refer 5.6) can be used.

Other risks associated with the exposure of the body to power frequency current include risks associated with muscle contraction, muscle damage, respiration difficulties and the risk of falling due to electric shock. These conditions can occur during unbalanced load conditions and must be managed accordingly. For this reason the limits regarding these conditions are more restrictive.

5.2.3 Safety criteria

In setting risk criteria, the underlying principle is that people must not involuntarily be subject to a risk which is significant in relation to the background risk associated with what could be realistically expected to be 'normal movements'.

5.2.3.1 Individual risks

The ENA established earthing guide EG-0 assesses the individual fatality risk level for those persons exposed to earthing related hazards into three categories along with their associated risk treatment considerations shown below. This is based on limits in common use in NSW.

Table 5-4: Individual Risk Treatment Options

Risk Level (individual p.a.)	Risk Classification	Risk Treatment
≥ 1 in 10,000	Intolerable	Must prevent occurrence regardless of costs.
1 in 10,000 to 1 in 1,000,000	Intermediate (ALARP)	Must minimise occurrence unless risk reduction is impractical and costs/effort are grossly disproportionate to safety gained.
< 1 in 1,000,000	Low	Risk is low but risk treatment must be applied if the cost is low and/or a normally expected practice.

5.2.3.2 Societal risks

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

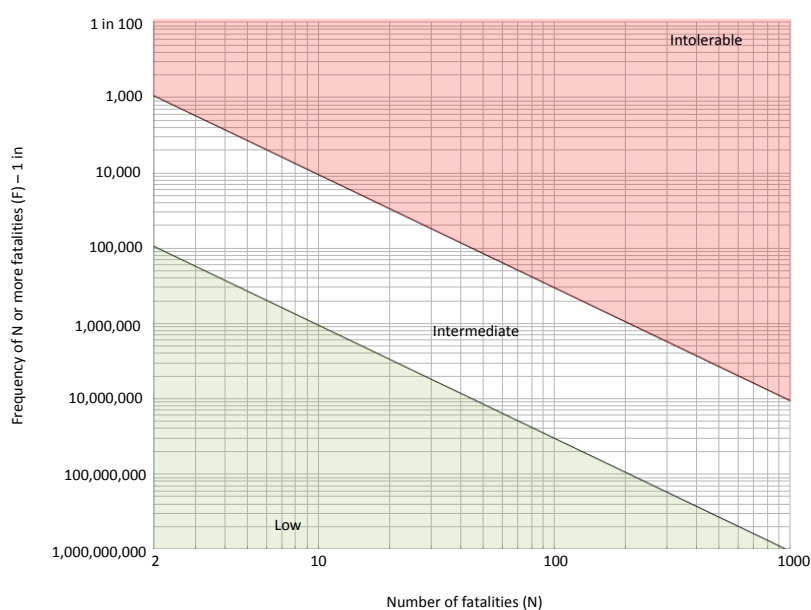


Figure 5-2: Societal risk limits

Table 5-5: Societal Risk Treatment Options

Risk Classification	Risk Treatment
Intolerable	Must prevent occurrence regardless of costs.
Intermediate (ALARP)	Must minimise occurrence unless risk reduction is impractical and costs/effort are grossly disproportionate to safety gained.
Low	Risk is low but risk treatment must be applied if the cost is low and/or a normally expected practice.

When calculating societal risks, account must be taken of possible future increases in population density, particularly in cases where assets are in areas where there is surrounding residential land that has not yet been fully developed.

5.2.3.3 Remote assets and 'remote risk'

The definition of assets that are considered "remote" is a location where the present and future potential probability of a person being coincident with a hazard is sufficiently low (less than "low" from the individual risk assessment of 5.2.3.1) that calculated risk associated with that asset will therefore be less than or equal to "low" of 5.2.3.1. This is a contact coincidence assessment to the earthing system and assessment of associated metallic non-power system plant in the vicinity of the asset. This is typically reserved for assets in remote locations not near a customer's gate, shed or fence. In all cases, a designer must provide calculated evidence as proof.

The maximum allowable monthly number of 4 second contacts allowed for P_{coin} to be less than or equal to 1 in 1,000,000 per annum individual is provided in the table below for associated fault duration and fault frequency. Where sufficient evidence of the fault frequency is not provided, a fault rate of 1 in 10 years may be used as detailed in Annexure C: Individual 1 in 1,000,000 p.a. risk level standard design cases. An asset can only be considered remote if all contact scenarios including those transferred by voltage induced gradients are below the maximum contact level provided below.

Table 5-6: Maximum average monthly allowable 4 second contacts to be considered "remote" risk

Fault Duration	1 risk in 10 years
0.1 sec	6.41
0.2 sec	6.26
0.5 sec	5.84
1 sec	5.26
1.5 sec	4.78
2 sec	4.38
3 sec	3.75
4 sec	3.29
5 sec	2.92
6 sec	2.63
7 sec	2.39
8 sec	2.19
9 sec	2.02
10 sec	1.88

In all cases, an assessment of an asset considered remote must still require a minimum design assessment to confirm the operation of associated upstream protection equipment and equipment ratings are maintained in the event of a fault.

5.2.3.4 Low risk design safety curves – touch voltages

Fixed safety curves provided in this standard reflect an individual risk level of “low” from 5.2.3.1 or societal risk level of “low” based on the F-N curve of 5.2.3.2. Details of the derivation are provided in Annexure C: Individual 1 in 1,000,000 p.a. risk level standard design cases. The standard curves have been developed to cover key design cases. They have been devised using the Monte Carlo analysis provided in the ENA Argon tool. The curves embody a range of probabilistic factors including percentiles of population current withstand and body resistance, footwear resistance and voltage withstand, and likelihood of presence at the time of a fault. This design risk level is considered low but in circumstances where the applied cost of risk reduction is considered low, that method of risk reduction must be applied (refer 5.2.4).

When utilising these “standard” curves to ascertain risks associated with a faulted asset, Annexure C: Individual 1 in 1,000,000 p.a. risk level standard design cases must be reviewed to confirm the design case conservatively applies to the asset under consideration. Where it doesn't, the Argon tool may be used to assist in the calculation of site specific risk.

As a result of earth fault current flow, the transfer of potential to nearby metallic objects may occur. Given a fault event occurring, the risk exposure at the asset and at nearby metallic infrastructure depends on the likelihood of contact with the various metallic objects, the magnitude of the touch voltage at that object, the clearance time and any insulating paths associated with the body. For this reason, different criteria apply at each object for the same fault event representing the same “low” level of risk. This is represented in Figure B-2 (Annexure B: Hazardous scenarios).

Standard touch voltages (hand to feet) must be assessed where any conductive object is in the vicinity of the earthing system, eg metallic signs, street light columns, pillars, metallic buildings, taps, conductive poles, stainless substation cubicles, etc. The touch voltage must be assessed as the difference between the voltage on the metallic structure and the soil voltage at a distance of 1m from the structure being touched, in the worst direction (ie largest electric potential difference) related to the earthing system. Loaded touch voltages can be proposed in the design in consultation with the Earthing and Power Quality Manager.

The representative contact scenarios for any risk event are as follows:

- a) *Remote*: A location where the contact frequency is sufficiently low that the probability of coincidence alone meets the “low” risk profile and therefore assessment of touch voltages is not required unless the indicative cost or effort is low.
- b) *Urban interface*: Asset outside normal public thoroughfare with low frequency of direct contact by an individual.
- c) *Backyard*: An area with a contactable metallic structure (eg 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.
- d) *MEN*: contact with LV MEN interconnected metalwork (eg 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.
- e) *Special*: 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. Examples include schools, pre-schools, day care centres, aquatic centres, recreational swimming areas and beaches. This classification must be assessed on a case-by-case basis and may not involve a societal assessment depending on the scenario.

Table 5-7: Normal/frequented touch voltage “low” risk standard curves

Figure	EG-0 Coincidence	Description	Risk Frequency	Contact Scenario	Footwear
Figure I-1	Transmission & Distribution Urban (TDU)	Contact with transmission asset in urban interface location (not typical public thoroughfare)	0.1 p.a.	135 x 4 sec	Standard
Figure I-2	Transmission & Distribution Backyard (TDB)	Area with a contactable conductive structure (gate/fence etc.) subject to transfer voltage or fault induced voltage gradients.	0.1 p.a.	416 x 4 sec	Standard
Figure I-3	Transmission & Distribution MEN (TDMEN)	Contact with MEN connected metalwork (household taps etc.) subject to transfer voltage or fault induced voltage gradients.	0.1 p.a.	2000 x 4 sec	Standard

Table 5-8: Special location touch voltage “low” risk standard curves

Figure	Description	Risk Frequency	Contact Scenario	Footwear
Figure I-4*	Contact with affected metalwork in locations with societal impact with low probability of shoes (people exposed all year)	0.1 p.a.	Societal based gathering with population size of 50 People exposed all year.	None/Wet

*This figure must be used in situations where the contact scenario is close to the description in Table 5-9. For smaller or larger population sizes and fractional exposures of the year, use Argon to calculate prospective touch voltage limits.

5.2.3.5 Design safety curves – step voltages

Step voltages must be assessed for both conductive and non-conductive structures. The step voltage is the maximum voltage that will be present between a person’s feet in the event of an earth fault so is defined as the difference between the soil voltage at any location and the soil voltage one (1) metre away from that location. While the risk of fibrillation due to step voltages is significantly lower than that of touch voltages, they are generally exposed to a greater number of “contact” scenarios in the vicinity of the asset.

The standard curves of 5.2.3.4 can be conservatively used for step voltages or Argon may be utilised, refer to 5.6.

5.2.3.6 Simplified design requirements

In some circumstances, such as areas with low soil resistivity, limited fault level, metallic return to source and strong urbanisation (MEN network), a site may meet the requirements for a ‘simplified design’. In these circumstances if the simplified requirements are met, the design conservatively meets the “low” risk classification of 5.2.3.1 and 5.2.3.2.

5.2.4 Risk reduction measures

A list of various engineering risk reduction measures is supplied in Annexure F: Engineering controls for risk mitigation and a framework for risk cost benefit analysis is found in Annexure G: Risk cost benefit analysis framework.

5.2.5 Safe design for asset life-cycle

In the case of new or improved transmission or distribution systems, an analysis of hazardous events must also take into account hazardous events occurring during construction,

commissioning, maintenance, operation, testing and decommissioning. This includes the duty to provide adequate information to affected persons necessary for works to be safely performed. This information must feed into the Safe Design Report for the asset or structure under consideration.

5.2.5.1 *Design for safe construction, commissioning, dismantling and decommissioning*

During construction and commissioning, particularly of major transmission lines and/or substations, the increased exposure to construction workers of electrical shock hazards requires particular care. As part of the design of an asset it is essential that the construction safety requirements be identified and controls listed for them to appear in the appropriate safe work method statement (SWMS) and safe design report (SDR) documentation for consultation and implementation. This includes but is not limited to the following items for a site:

- a) Power supply to construction areas and site sheds and offices:
 - i. Substation auxiliary power supply can be used
 - ii. LV street supply
 - iii. Appropriate use of portable generators and inverters
 - iv. Use of isolation transformers
- b) Location of site sheds and offices
 - i. Within the earth grid and substation boundary
 - ii. Outside the substation at a minimum separation
- c) Material storage areas (especially for conductive construction material)
 - i. Within the earth grid and substation boundary
 - ii. Outside the substation at a minimum separation
 - iii. Guidance and requirements on carrying the materials
- d) Vehicle earthing requirements for plant such as:
 - i. Cranes near exposed HV
 - ii. Concrete pumping vehicles
 - iii. Trucks and motor lorry in live yards
- e) Earthing requirements for temporary fencing and scaffolding
- f) Employee Protective Equipment
 - i. Insulating gloves
 - ii. Footwear (use of rubber boots)
 - iii. Equipotential bonding loads
 - iv. Isolating/ insulation mats
- g) Specific controls for specific work area
- h) Manual handling of long metallic objects in the vicinity of existing earthing systems

Particularly for major substation brownfield sites, the commissioning and staging of the works has a big impact on the risk of shock to workers and the public. The staging of the works must consider, but not be limited to the following:

- staging of bonding of OHEW, cable sheaths, ECC etc;
- bonding of existing to new earth grid(s); and
- bonding of fencing.

A risk management staging program must be provided for all major brownfield projects and be included in the safe design report.

Mitigation of associated hazards during construction may include sectionalising bus sections to reduce prospective earth fault current, installation of temporary high-speed protection and the disabling of auto-reclose functions where the risk of supply can be managed.

5.2.5.2 Design for safe initial use (future and leapfrog development)

The primary earthing design consideration is for the safe continual use of the asset for the public it serves. It is often the case however that an asset will be designed for a future development. For instance when a new subdivision is being built and therefore the LV MEN system is not yet fully developed prior to distribution substation commissioning, additional risk can be expected during early stages of development. When an earthing design cannot meet the “low risk” limits of 5.2.3 initially but in the ultimate arrangement will, an earthing risk program must be provided to manage the risks associated with the chosen earthing configuration(s) therefore any higher or residue risks during development expansion are effectively managed. In these circumstances, the waiving of metallic infrastructure exclusion zones around earthing assets can be granted provided an adequate risk management program is developed, metallic infrastructure encroachment is managed and the ultimate earthing configuration is compliant. When considering the MEN system size, consideration must be given to the staging of development and growth in the MEN when reviewing earthing risks. Where this arrangement is proposed, a dispensation must be submitted to the Earthing and Power Quality Manager for approval and must include the risk levels at each stage up to the final arrangement.

Methods of interim risk mitigation may include the initial installation of the asset as a separately earthed asset (and assessed accordingly), providing a metallic return to the source zone substation, installation of counterpoise conductor, temporarily excluding the installation of nearby higher risk assets (such as private swimming pools), installation of earth rods at LV pillars and/or temporary high-speed protection inclusions. Methods of interim risk mitigation are subject to the approval by the Earthing and Power Quality Manager. Further engineering risk reduction measures are provided in Annexure F: Engineering controls for risk mitigation.

5.2.5.3 Consideration for future modification

When designing an asset the designer must consider the implications of future development around an earthed asset as well as the potential for increased fault levels, clearance times, future encroachment or other earthing impacts. Fault level data sourced from the company must include provisions for network changes, however management of the development around electricity assets is the responsibility of the designer and a sensitivity analysis must be part of the design to cater for future adequacy. Additional risk mitigation measures must be adopted to appropriately manage future foreseeable risks.

5.2.5.4 Design for safe maintenance

The earthing design of an asset must confirm that maintenance or modification of the asset and the impact of assets nearby can be carried out safely. As asset owners, the company will take all practicable steps for the condition and risks associated with an asset continue to perform as designed and to be continually reviewed. This includes a maintenance, inspection and testing regime that occurs on a recurring basis. Details of the associated maintenance regimes are provided in the SMI and MMI series of standards on the company's standards website.

5.2.5.5 Design for test and inspection

All earthing terminations must be located with provisions for reasonable test access. This includes locating terminations such that employees can reach the termination without additional equipment. Cables must be spaced from each other and from fixed walls and objects to allow test instruments to be temporarily installed around the conductor.

5.2.6 Documentation and design approval

In all circumstances documentation is required for an earthing system. The specific requirements and storage of design information are detailed in EDI100, EDI0004 and EDI516 depending on the installation but must include the physical description and layout, electrical assumptions, design decisions (including risk management decisions), commissioning data and any monitoring and maintenance requirements.

Designs must be verified prior to certification by competent persons to meet construction, health and safety requirements. Depending on the risk classification of 5.2.3.1 and 5.2.3.2 – further approval may be required as follows:

Table 5-9: Risk classification and approval requirements

Risk Classification	Approval process
Intolerable	Will not be approved for connection to the company's network – immediately implement risk management assessment and controls to reduce risk.
Intermediate (ALARP)	Requires approval from General Manager Asset Management supported by a risk cost benefit analysis using process described in GAM 0114 and this standard.
Low	Risk is low and may be approved but risk treatment must be applied if the cost is low and/or a normally expected practice.

5.2.6.1 Metallic bond to zone substation

In some circumstances (typically urban) the local MEN network and/or the network of HV earthing electrodes will be bonded back to the supply zone substation through cable screens and via overhead neutrals and earth wires. This large interconnection of earthing systems is effective at reducing EPR magnitude considerably but increases the range of exposure to the public to earthing related hazards associated with a zone substation. The determination of the zone substation bonding strategy is based on an assessment of risk provided in 5.3. In these circumstances it is appropriate to consider in an earthing design the reduced magnitude of current expected in the distribution earthing electrode system and therefore reduced EPR hazards as HV fault current returns to the neutral point of the ZS transformer predominately through metallic paths rather than but in addition to the general mass of the earth.

When a significant development takes place in proximity to a zone substation, this may prompt a review of the zone substation bonding strategy to manage minimum risk and cost. Thirty (30) weeks' notice must be provided in this circumstance subject to receipt of a suitable Earthing Design Report in accordance with EDI516 providing the need for change. For all such developments, in order to reduce risks associated with the distribution network, approval by the Earthing and Power Quality Manager must be obtained to determine any required changes at the substation accordingly.

5.2.7 Shared use assets

Distribution and low voltage lines must not be installed on conductive poles containing transmission or sub-transmission voltages. Any new or modified proposal for distribution lines on transmission or sub-transmission poles must consider the effect and be insulated from power frequency and lightning flashover due to transmission related EPR on the distribution network. This is subject to approval by both the Earthing & Power Quality Manager and Overhead & Underground Mains Manager.

5.3 Transmission and zone substations and major switching stations

Transmission and zone substations, as the typical zero sequence source for their associated supply systems, are subject to frequent faults of varying magnitudes and durations. The hazards caused by, and those in close proximity to the zone substation require a detailed assessment and analysis of associated risks.

This section must be read in conjunction with EDI516 for specific requirements of these assets. The overriding risk management concept for these assets requires two assessments:

1. A maximum allowable prospective touch, step and transfer voltage limit based on the simplified design requirements of ENA EG-1. This is detailed in 5.3.1.
2. A detailed assessment of possible fault scenarios and associated assessment of individual risk based on risk management principles of ENA EG-0. This is detailed in 5.3.2.

5.3.1 Maximum limits applicable to step, transfer and touch voltages associated with a zone or transmission substation

The limits stated in ENA EG-1 must apply to all step, touch and transfer voltage hazards associated transmission and zone substations and to the fences, distribution system and metallic non-power system infrastructure surrounding them. The worst case touch voltages and higher risk exposures may occur at the edges of the MEN system and not near the zone-substation. Therefore it is important to understand and assess the worst case risk zones associated with major substations for appropriate risk management.

Within a transmission or zone substation, the 70kg body mass limit is applicable, generally along with a crushed rock layer per the requirements of EDI516 and SDI523. The calculation of this limit must be performed as detailed in ENA EG-1 which has been repeated in the table below. The fence and area surrounding a transmission or zone substation must be assessed to the 50kg body mass limit prescribed in ENA EG1 as these areas are considered publicly accessible.

Table 5-10: ENA EG-1 substation compliance limits

Body Type	Prospective Touch Voltage (V)	Prospective Step Voltage (V)
50kg body mass (Publicly accessible areas)	$= \left(\frac{0.116}{\sqrt{t}} \right) (1000 + 1.5C_s p_s)$	$= \left(\frac{0.116}{\sqrt{t}} \right) (1000 + 6C_s p_s)$
70kg body mass (Restricted areas within a substation)	$= \left(\frac{0.157}{\sqrt{t}} \right) (1000 + 1.5C_s p_s)$	$= \left(\frac{0.157}{\sqrt{t}} \right) (1000 + 6C_s p_s)$

Where,

t is the duration of shock current (in seconds)

p_s is the resistivity of the surface material (Ohm.m) – soil or crushed rock. In areas directly exposed to grid conductors such as an earthed steel reinforced concrete floor the resistivity of the surface is assumed to be zero (0).

This value must also be set to zero (0) for associated hand-hand prospective touch voltages. Refer SDI 523.

C_s is the derating factor relating to surface layer thickness and resistivity (refer EDI516). A value of one (1) must be used when no additional surface layer is used, ie soil only.

5.3.2 Additional assessment and coordination of risk

There is a significant change in approach across the industry to the assessment of power frequency earthing hazards associated with a major substation and the assets they supply. In

accordance with company risk management policy, the assessment of risks associated with major substation requires consideration of:

- The likelihood/frequency of associated primary and secondary faults/hazards occurring.
- The degree of harm that might result from each of the potential faults/hazards occurring including:
 - Magnitude of voltage expected at a given location due to fault associated with a zone or transmission substation
Note: *The magnitude of fault current and expected shielding will vary the magnitude of the voltage hazard at any given location. This requires an assessment of the expected line impedance as well as the earth impedance (COM/SEP) and earth return paths associated with the distribution network.*
 - Duration of voltage exposed either through IDMT OC/EF protection including any reclose attempts or associated fuse operations.
 - The likely exposure to the general public and workers either through MEN bonded metallic objects or any other metallic objects (non-MEN) associated with or in the vicinity of the substation and any resistive paths that can be expected in series with the body.
- The availability and suitability of ways to eliminate or minimise the risk
- After assessing the extent of the risk and the available ways of eliminating or minimising the risk, the cost associated with available ways of eliminating or minimising the risk, including whether the cost is grossly disproportionate to the risk.

In certain circumstances, consideration must be given to fast reclose attempts and any heightened risk that can be expected.

It is essential that any major substation earthing assessment is balanced with the possible reductions in hazards associated particularly with the secondary network supplied by the substation. For instance, the bonding of major substations into the distribution earthing and/or further LV MEN system can have significant safety benefits in and around the substation and around the distribution assets under fault by significantly reducing EPR. This is done by providing a metallic path to allow fault current passage to the zero sequence sources but also through reduction in earthing system impedance associated with the low impedance distribution earthing system. Such a decision must be made with care, as this can also introduce hazards onto the MEN system due to the increased number of hazards that may be seen on the distribution network, particularly in close proximity to the major substation. Where voltage rises are seen on the LV MEN system or publicly accessible metallic plant either through deliberate bonds or through voltage induced gradients associated with major substations, it is essential that the safety of the public is carefully assessed.

The limits of 5.3.1 must be met for all possible fault/hazard scenarios associated with a major substation. In order for this to be achieved economically, coordination with the distribution system is essential when assessing faults and hazards associated with major substations. To be compliant with the requirements of 5.3.1 a coordinated method must be used and documented by the earthing designer.

A coordinated design methodology requires the determination of a fault level/energy threshold (for instance, the industry commonly used distribution bus + 1 ohm fault level) at which coordination of zone substation secondary and distribution primary earthing design is of paramount importance. Within the coordination threshold, the major substation and/or distribution system must be assessed and mitigated where appropriate to meet safety compliance. Methods include enabling adequate and redundant metallic return to source for affected assets or the inclusion of instantaneous protection elements at high fault levels. Below a certain threshold, coordination is no longer essential at the major substation as the fault level is low enough to warrant only distribution earthing design consideration. This methodology applies similarly to transmission substations and assets also.

The method by which earthing designs of major substations are coordinated with distribution systems must be consulted and agreed with the Earthing and Power Quality Manager prior to any individual design acceptance.

The final bonding strategy and overall design of a zone or transmission or major switching substation is subject to Earthing and Power Quality Manager's approval based on the above assessment of risk. This is to provide the most appropriate risk management strategy for the substation and associated distribution network.

5.4 Limits on other utilities assets

5.4.1 Telecommunications infrastructure

In all circumstances, when applying these limits, coordination between the appropriate telecommunications authority and the company must occur to apply a common understanding and risk based approach to mitigating hazards.

Where issues are identified, contact the Earthing and Power Quality Manager.

5.4.1.1 EPR (surface voltage) limits

Conductive telecommunications assets can be considered as earthed at the telephone exchange. This means workers accessing conductive paths of telecommunications plant can be exposed to remote earth potential and a rise in soil potential voltage concurrently and therefore be exposed to potentially lethal body currents. Additionally, excessive surface voltage gradients can pose a conductive voltage hazard to telecommunications equipment and cause insulation failure and damage.

The limits upon telecommunications equipment in the field are based on Code of Practice and AS/NZS 3835.1:2006. For the company's assets, the surface voltage limit caused by our assets must be less than the requirements repeated from AS/NZS 3835 and tabled below.

Table 5-11: Telecommunications EPR limits

Asset Voltage	EPR Hazard Voltage Limits
Distribution Voltages LV, 11kV and 22kV	430V
Transmission Voltages 33kV, 66kV and 132kV with total clearance time exceeding 500ms	430V
Transmission Voltages 33kV, 66kV and 132kV with total clearance time less than or equal to 500ms	1000V

This does not apply to telecommunications cables and assets that comprise only non-conductive elements such as non-metallic optical fibre cables.

5.4.1.2 Induced voltage hazards

Metallic telecommunications cables and assets running in parallel to the power system can be subject to induced voltage in the event of unbalanced current flowing in the power line. The generation of longitudinally induced voltages in telecommunications assets can be hazardous to employees and equipment and must be mitigated as far as reasonably practical.

The limits defined in Code of Practice and HB101 are detailed below. Means to apply this are provided in Application Guide HB102. These limits also apply to catenary circuits used for mechanical strength of communications assets.

Table 5-12: Telecommunications assets LFI limits

Asset Voltage	Induced Voltage Limits
Distribution Voltages LV, 11kV and 22kV	430V
Transmission Voltages 33kV, 66kV and 132kV with total clearance time exceeding 500ms	430V
Transmission Voltages 33kV, 66kV and 132kV with total clearance time less than or equal to 500ms	1000V
Full load conditions (no fault)	60V

This does not apply to telecommunications cables and assets that comprise only non-conductive elements such as non-metallic optical fibre cables.

5.4.2 Metallic pipelines

AS/NZS 4853:2012 applies to risks associated with metallic pipelines parallel to or in proximity to power system plant. It applies to all metallic pipelines used for transmission and distribution of fluids or gases, both buried and above ground. The responsibility for the application of AS/NZS 4853:2012 rests with the owner, licensee or the operating authority of the pipeline. It is the responsibility of the company to identify and mitigate any hazards in consultation with the pipe line authority for any new or modified assets, or where issues are identified in due course.

Note: *Metallic pipelines also include metallic pipes with an insulating coating, pipe carrying conductive materials, cathodic protection and metallic operating points and plastic pipes manufactured with a built in metal trace wire.*

The standard applies the risk based design approach to hazards on and/or along metallic pipelines under the influence of the power system. The design process involves assessment of the risk against three criteria, based on increasing levels of complexity.

- 1) Level 1 – Conservative compliance criteria
- 2) Level 2 – Predetermined voltage limit criteria
- 3) Level 3 – Risk based (personnel safety) compliance

Conservative compliance (Level 1) limits are adapted to the company's network conditions and are provided in Annexure H: Conservative compliance limits for pipeline assets accordingly. For Level 2 and Level 3 assessments, refer to AS4853 for guidance.

A pipeline electrical hazard risk management plan must identify locations where there is potential for electrical hazards to the pipeline, pipeline operating and maintenance employees or the public.

In some locations, the requirement for risk treatment of steady state LFI for control of pipeline corrosion for voltage compliance may be more stringent than the requirements assessed for human safety. Under the influence of steady state LFI, for protection of the pipeline against corrosion requires that the induced voltage limits below are maintained:

- a) 4 V a.c. for soil resistivity ≤ 25 ohm.m
- b) 10 V a.c. for soil resistivity > 25 ohm.m

Aboveground pipes need investigation of capacitive coupling also to limit exposure to persons of the influence of electric field gradients from above ground conductor placement and voltage. Guidance from AS/NZS 4853:2012 must be used for this assessment.

5.4.3 Quarries and Mines

AS 2067:2016 applies to electrical hazards associated with supply within mines and associated processing plant. The mine operator is responsible for the risk management of earthing related hazards associated with the mine and processing plant. While these limits do not apply to the company's assets themselves directly, transfer hazards to associated mining and processing plants need be considered for assets supplying such plant.

In almost all circumstances, below ground mines must not share earths with above ground plant to limit the probability of lightning transferring to below-ground and associated hazards.

5.5 Additional limits on public infrastructure

This section must be read in conjunction with MDI0044. Where applicable, the limits discussed in this section are the maximum allowable to be considered "low" risk. Refer to section 5.2 for additional risk control requirements.

5.5.1 Conductive fences

Touch voltage hazards may be introduced where a conductive fence is within close proximity to an earthed asset or parallel to power system lines for a sufficient length. Conductive fences under the influence of the power system must be effectively earthed at frequent intervals and have occasional breaks in electrical continuity to reduce hazards associated with transfer voltages and low frequency induction.

The following touch voltage limits apply to conductive fences.

Table 5-13: Fence touch voltage limits

Coincidence Factor/Location Category	Condition	"low" risk figure ref.
Remote	Assets and non-power system plant which meet the conditions of 5.2.3.3 are considered to be remote and their associated coincidence alone meets the "low" individual risk profile of 5.2.3.	N/A
Urban	Assets outside normal public thoroughfare with low frequency of direct contact by an individual.	Figure I-1 (Appendix I)
Backyard	For metallic objects only in contact with the ground (not bonded into the MEN system such as signs, fences and gates), touch voltages will be present due to the proximity to the separate earthing system.	Figure I-2 (Appendix I)

Breaks in electrical continuity are required for the EPR of the fence to remain equipotential with the surrounding soil with touch voltage maximum limits based on the table above. This will depend on the separation between the electrode(s) and the fence, the overall electrode arrangement associated with the power system asset and the resulting EPR of the power system asset.

Metallic gates require particular care. Metallic gates require assessment to the full reach extent of the gate – fully open, fully shut and the range in-between whichever is the most onerous.

Under the influence of steady state LFI, 10V (loaded touch voltage) must not be exceeded. This is based on the threshold in which muscular control is lost. This value is largely dependent on the geometric configuration and separation to line conductors, the magnitude of the load current and any normal current imbalance expected under load.

5.5.2 Swimming pools and spas

This clause is only applicable for bodies of water where swimming is likely to occur.

The associated earthing of swimming pools is covered in AS/NZS 3000. The requirements are typically provided for protection of members of the public from LV faults/insulation failure. Swimming pools require particular care and assessment near HV earthed power system assets due to an increased risk of electric shock by reduction in apparent body impedance and the increased likelihood of contact of the body with earth potential. Where concrete pool reinforcing is used and/or conductive paths are present, equipotential bonding and earthing and/or appropriate isolation may be a requirement in accordance with AS/NZS 3000.

The main hazards with swimming pools are experienced when climbing in and out of pools, touching above ground pool surfaces or touching metallic fences surrounding. The following limits present a “low” risk for pools. Given the nature of pool bonding, these limits must be considered an EPR limit 1m from the pool or associated fencing, whichever is the most onerous.

Table 5-14: Pool touch voltage limits

Condition	Description	“low” risk figure ref.
Domestic swimming pools	Limits on fences, pool structures, surfaces and other metallic infrastructure associated with a swimming pool (individual assessment).	Figure I-3 (Appendix I)
Aquatic centres / public swimming pools	Limits on fences, pool structures, surfaces and other metallic infrastructure associated with the aquatic centre (societal assessment).	AQ12 Figure I-4 (Appendix I)

Note: *For pools, small voltages and therefore currents can cause a loss of muscular control and therefore increase the risk of drowning before the limits of ventricular fibrillation are realised. Risk management principles and the principles of prudent avoidance must be adopted so far as reasonably practicable.*

Where transmission earths or separately earthed distribution assets are in proximity, the size, EPR and separation to the pool of the electrode system and whether the pool is bonded into the MEN system (and the MEN system size) will impact on the magnitude of potential hazards. In commonly earthed areas, the exposure to hazardous voltages around the pool are limited due to a low overall EPR experienced for such assets. However the frequency of hazardous events will increase for a significantly dense distribution network through bonded earths and cable sheaths particularly in close proximity to a zone substation.

5.5.3 Sheds, garages, carports and other conductive structures

Earthed or unearthed conductive structures pose a hazard of touch and step voltages associated with the building.

Table 5-15 applies to these assets depending on whether the MEN is also bonded to the structure.

Note: *Concrete is considered a conductive material.*

Table 5-15: Metallic structure touch voltage limits

Coincidence Factor/Location Category	Condition	"low" risk figure ref.
Remote	Assets and non-power system plant which meet the conditions of 5.2.3.3 are considered to be remote and their associated coincidence alone meets the "low" individual risk profile of 5.2.3.	N/A
Urban	Assets outside normal public thoroughfare with low frequency of direct contact by an individual.	Figure I-1 (Appendix I)
Backyard	For metallic objects only in contact with the ground (not bonded into the MEN system such as signs, fences and gates), touch voltages will be present due to the proximity to the separate earthing system.	Figure I-2 (Appendix I)
MEN	For objects bonded to the LV MEN system (metallic buildings, taps, street light pillars etc.) touch voltages must be assessed as the soil voltage 1m from the MEN bonded metallic object in the direction of the earthing system.	Error! eference source not found. Figure I-3 (Appendix I)

5.6 Software

The Argon tool can be used to assist in the design of an earthing system particularly in the assessment of risk. Argon is available from the ENA website. The program must be used to perform the risk assessment associated with an asset and generate any safe design report. Using this methodology, the probability of single fatality must not exceed the "low" risk profile of 5.2.3.1 and 5.2.3.2.

6.0 AUTHORITIES AND RESPONSIBILITIES

General Manager Asset Management has the final authority and responsibility for:

- Approving this standard and the risk management methodology for earthing hazards associated with the company's network;
- Advising the risk profile and methodology used for engineering decisions to the Chief Operating Officer and the Board;
- Approving any design with a risk profile exceeding "low" from 5.2.3.1 and 5.2.3.2 upon recommendation from Manager Asset Standards & Design.
- Approving any major substation with proposed use of neutral earthing impedance that results in the network becoming "ineffectively earthed" provided a suitable justification report is provided by the Manager Asset Standards & Design and agreed.

Manager Asset Standards & Design has the authority and responsibility for:

- Confirming this standard meets company policy, regulatory and the health and safety obligations of the company;
- Advising on the risk management methodology for earthing hazards associated with the company's network;
- Endorsing any design with a risk profile exceeding "low" from 5.2.3.1 and 5.2.3.2 upon recommendation from Earthing and Power Quality Manager;

- Approving any major substation with proposed use of neutral earthing impedance that results in the network remaining “effectively earthed” provided a suitable justification report is provided by the Earthing and Power Quality Manager and agreed.

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

- Confirming that the content of this instruction is kept up to date based on industry best practice and current research and literature regarding earthing risk management;
- Reviewing relevant earthing designs and reports and providing earthing solutions and risk treatment based on the requirements of this standard;
- Approving and endorsing any major substation bonding strategy on review of the risks associated.
- Reviewing the use of any major substation proposed use of neutral earthing impedance provided a suitable justification report is provided and agreed.

Electrical Engineers - Earthing are responsible for:

- Reviewing earthing design and reports and providing earthing solutions and risk treatment based on the requirements of this standard.

Manager Network Connections is responsible for:

- All earthing designs carried out for contestable network projects are in accordance with this standard.

Regional Service Managers are responsible for:

- All earthing designs carried out for network projects are in accordance with this standard

Accredited Service Providers (ASPs), Designers and Consultants are responsible for:

- Confirming their earthing designs comply with this standard;
- Seeking clarification of this instruction, where necessary from the Earthing and Power Quality Manager, either directly or through the Network Connections contacts;
- 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;
- Preparing and advising on associated SWMS, SDR and risk management plans for construction and commissioning support.
- Consulting with those exposed to earthing risks associated with the plant being designed such as owners of nearby telecommunications infrastructure, pipelines and construction crews.

7.0 DOCUMENT CONTROL

Documentation content coordinator: Earthing and Power Quality Manager

Documentation process coordinator: Standards and Process Administrator

ANNEXURE A: GENERAL EARTHING DESIGN MANAGEMENT PROCESS

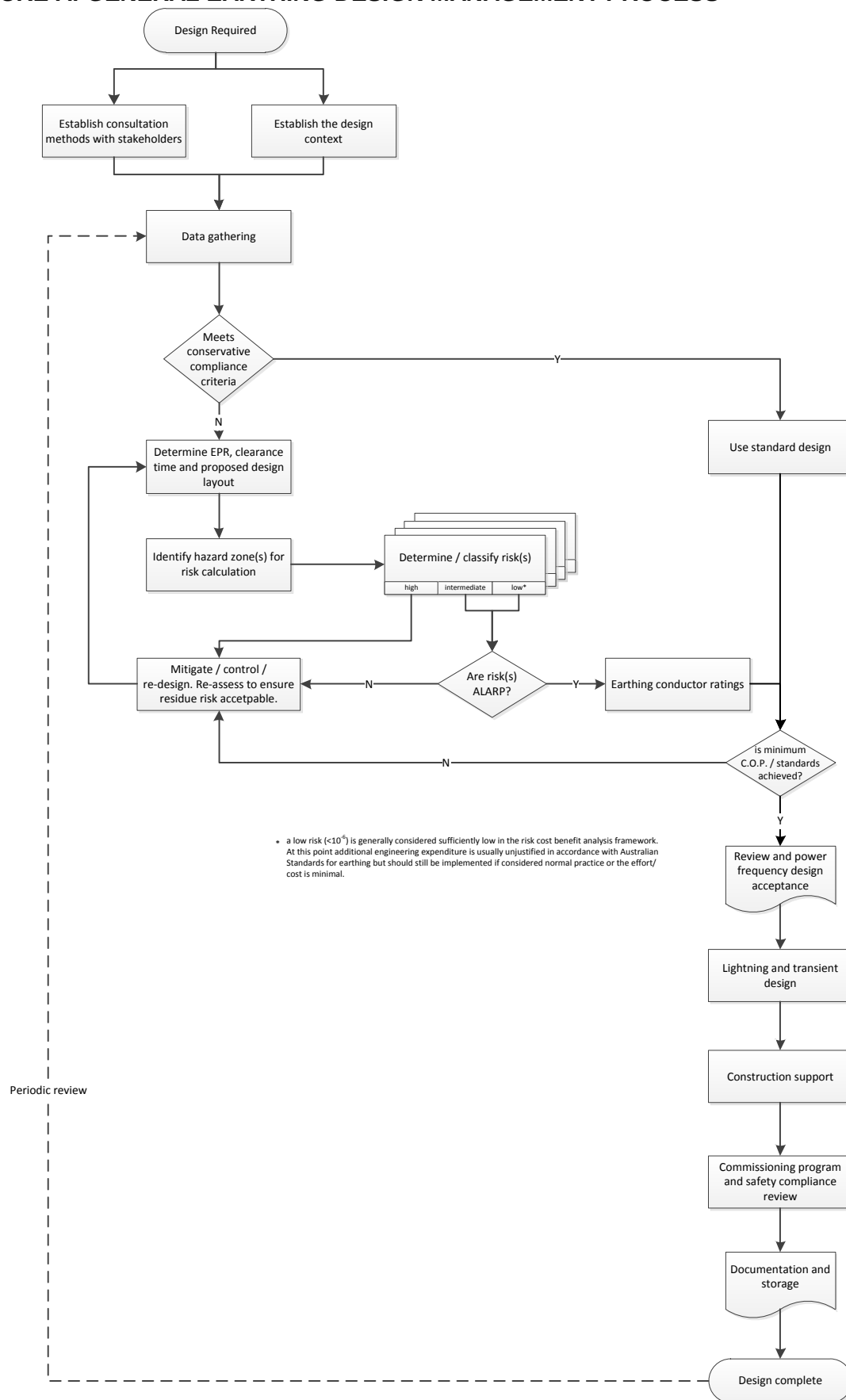


Figure A-1: Earthing design management process overview

ANNEXURE B: HAZARDOUS SCENARIOS

B.1 Sources of hazards

There are multiple hazard scenarios associated with the distribution of electricity. Namely:

- a) Earth potential rise on power system infrastructure due to an earth fault at that asset or nearby asset bonded by OHEW, Cable Sheaths, ECC, Earthing Electrode System, LVMEN network and/or through the soil.
- b) Transfer potential on non-power system metallic infrastructure due to metallic bonds between power system plant and non-power system metallic infrastructure subject to earth potential rise.
- c) Earth potential rise on non-power system metallic infrastructure due to proximity (transferred by soil) with high voltage power lines, underground cable joint bays, substation earth grids, and any other earthing current discharge points.
- d) Low frequency induction onto both power system plant and metallic non-power system plant due to parallel flowing current under load and fault conditions.
- e) Capacitive coupling due to the placing, temporarily or permanently, of metallic power system plant or non-power system plant adjacent to power system plant.
- f) Earth Potential rise due to lightning current following lightning strikes at or adjacent to power system plant.
- g) The accidental contact of non-power system infrastructure with the electrical power system.

In the case of new transmission or distribution systems, an analysis of hazardous events must also take into account hazardous events occurring during construction, commissioning, maintenance, operation, testing and decommissioning.

B.2 Effect on non-power system infrastructure

While it is best practice to have power system assets and their associated earthing systems installed as far away from publicly accessible metallic non-power system infrastructure, it is often impractical and an assessment of the transfer hazards must be made. Assets that require particular assessment include:

- a) Conductive pipelines
- b) Telecommunications assets
- c) MEN connection points (includes pits, pillars, substations, taps etc.)
- d) Metallic fences
- e) Metallic sheds
- f) Swimming pools and spas
- g) Metallic water storage tanks
- h) Flammable gas or liquid storage tanks
- i) Electric railway lines
- j) Medical facilities
- k) Communications facilities

B.3 Earth potential rise (EPR)

When an earth fault occurs at a power system asset, the current flowing through the earthing system to the general mass of the earth will produce an increase in the electric potential of the earthing system with respect to a remote earth. This current then returns to the source through the ground surrounding the source. Soil as an electrolyte with inherent resistivity under the influence of current behaves like a resistance which causes voltages to appear on the soil surface. These voltages can appear on metallic structures in the vicinity of the earthing system.

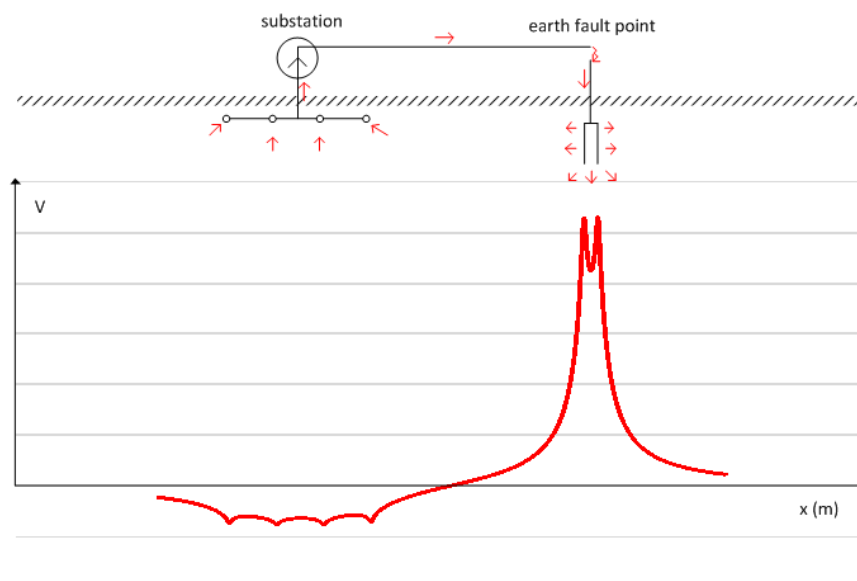


Figure B-1: EPR earth fault example

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

Large or long electrode system	Small electrode system, ie single rod
○ Lower EPR magnitude ○ Lower touch voltages at the asset ○ Lower step voltages near the asset ○ Larger EPR hazard zone ○ Problematic with large soil voltage transfer hazards to nearby metallic infrastructure	○ Higher EPR magnitude ○ Higher touch voltages at the asset ○ Higher step voltages near the asset ○ Small EPR hazard zone ○ Fewer problems with soil voltage transfer hazards to nearby metallic infrastructure

B.4 Touch, step and hand-hand voltages

If a person contacts two different voltages simultaneously, a voltage difference will be applied across the body. Depending on the resistance of the body and any insulating layers (ie shoes) between the voltage exposures, a current will flow through the body. The main hazard to human beings is the potential for this power frequency current to flow through the region of the heart which is sufficient to cause ventricular fibrillation. This hazard depends on a number of factors including the body current path, duration of exposure (fault duration), the contact area, the impedance of the body and any insulating paths.

Hand-to-hand or more typically **hand-to-feet** voltages are known as **touch voltages**. Touch voltages are most concerning because they provide a path for current to flow through the heart. Touch voltages typically occur where there is contact with a conductive structure where a current path occurs through the body to a location at a different potential during an earth fault (such as the local soil).

Transferred 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 say 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.

Foot-to-foot voltages are known as **step voltages**. A step voltage occurs when a stride is taken and the soil voltage simultaneously under each foot is at different voltages. While step voltages produce a lower risk of fibrillation since they do not cause sufficient current to flow through the region of the heart, the risk of muscular damage and risk of falling and exposing the body to a touch voltage due to the current exposure must be adequately managed.

An example of the application of all of the various touch voltage scenarios for the same earth fault event is provided in the figure below.

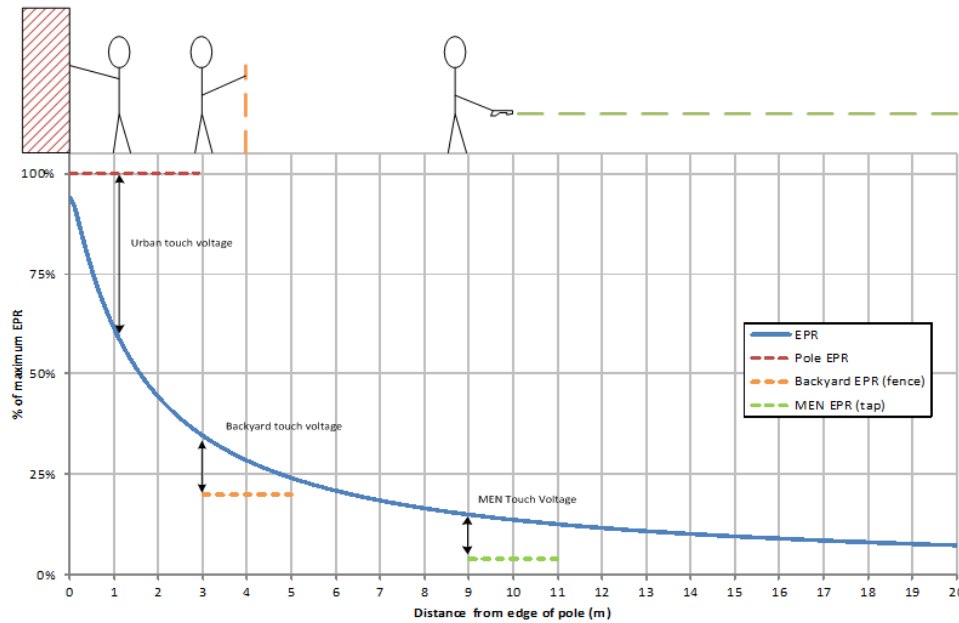


Figure B-2: touch voltage hazard example

B.5 Electromagnetic induction

Alternating current on a high voltage power line can induce a voltage on an adjacent pipeline, fence, power system conductor, telecommunications asset or any other parallel metallic path. The induction results in a voltage over the exposure length due to the electromagnetic field produced by the alternating current. This voltage is proportional to the length exposed to the magnetic field.

Induced voltage hazards always have a reference to earth either through direct bonds to earth or in the case of insulated parallel metal, through its capacitance with earth.

When assessing hazards on metallic plant run in parallel with power lines due to power frequency electromagnetic induction, two cases must generally be considered, single phase to ground fault conditions and maximum load (including any typical unbalance) conditions. In situations where an OHEW is present, its presence has a shielding effect on parallel metallic plant and can reduce induced voltage hazards considerably in most circumstances.

Items that are particularly exposed to issues of electromagnetic induction include:

- Gas, oil or other pipelines running in parallel to high voltage distribution and transmission lines
- Fences exposed to the public running parallel with power lines
- Telecommunications equipment (including catenaries) that runs in parallel with power lines.

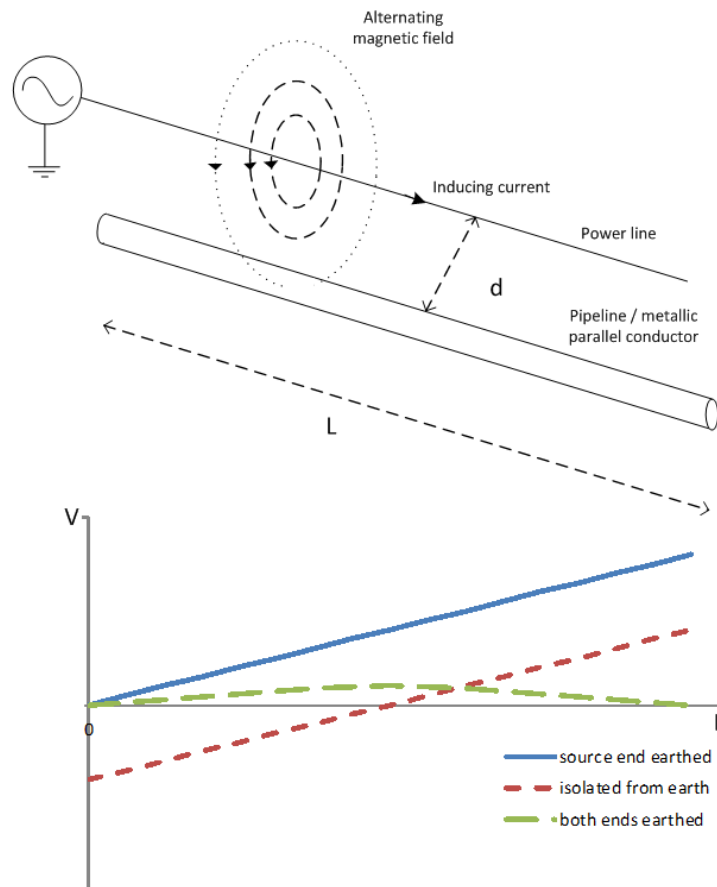


Figure B-3: Electromagnetic induction hazard example

Further discussion on electromagnetic induction hazards is provided in Annexure E: Assessment of low frequency electromagnetic induction.

B.6 Electric field (capacitive) coupling

Capacitive coupling applies to any metal object in the electric field that is isolated from earth. The capacitance that exists between the phase conductors and earth continually exists while the power line maintains voltage. Any object insulated or suspended from earth in the vicinity of the power line will intercept the normal capacitance and a voltage will be present which is proportional to the voltage of the power line and the ratio of the capacitances between each object and earth.

For small objects, while these discharges may be painful, the lack of significant current flow makes them not harmful in themselves. Hazardous steady currents can only arise for very large or very long objects and/or where they are high above the ground in the vicinity of conductors. The danger to persons with electric fields, however, is the fact that they can surprise someone not expecting them at a critical time.

B.7 Lightning strikes

Lightning strikes direct to a person or close by may cause death or serious injury. Due to the high current magnitude and rate of rise for lightning conditions and the fact that lightning transient voltages and current can travel a significant distance over overhead lines, it is impractical to provide adequate protection to employees and the public in the form of earthing and equipotential bonding due to lightning.

All employees must stop handling all conductors including those associated with any earthing system until the lightning hazard has passed. The threat to personal safety is greatest for persons outdoors during local thunderstorms. In the absence of specific weather radar, lightning location systems or specialised lightning warning devices, the “30/30” safety guideline detailed in AS/NZS 1768:2007 must be followed. An approaching thunderstorm is considered to be local when the time interval between seeing a lightning flash and hearing the thunder is less than 30 seconds. A receding local thunderstorm is no longer a significant threat when more than 30 min have elapsed after the last thunder is heard. During lightning storms persons must stay within dry areas of larger permanent buildings and avoid access to electrical conductors, electrical equipment, metal objects and water (including showers).

ANNEXURE C: INDIVIDUAL 1 IN 1,000,000 P.A. RISK LEVEL STANDARD DESIGN CASES

The following table details the assumptions used in the derivation of curves associated with network assets in normal/frequented locations:

Scenario	EG-0 Coincidence	Description	Risk Frequency	Contact Scenario	Footwear
Touch	Transmission Urban (TU)	Contact with transmission asset in urban interface location (not typical public thoroughfare)	0.1 p.a.	100 x 4 sec	Standard
Touch	Distribution Urban (DU)	Contact with distribution asset in urban interface location	0.1 p.a.	135 x 4 sec	Standard
Touch	Transmission and Distribution Backyard (TDB)	Area with a contactable conductive structure (gate/fence etc.) subject to transfer voltage or fault induced voltage gradients.	0.1 p.a.	416 x 4 sec	Standard
Touch	Transmission and Distribution MEN (TDMEN)	Contact with MEN connected metalwork (household taps etc.) subject to transfer voltage or fault induced voltage gradients.	0.1 p.a.	2000 x 4 sec	Standard

The company's historical distribution fault rates are:

- 7 faults per 100km of underground feeder and associated substations per year conservatively inflated to 10 faults per 100km per year. **Note:** *For underground cables, the earthed screen or earth continuity conductor will conduct EPR to adjacent sites.*
- 33 faults per 100km of overhead feeder and associated substations conservatively inflated to 40 faults per 100km per year. **Note:** *For overhead lines, an overhead earth wire (if available) will conduct EPR to adjacent structures and associated assets.*

The standard curves provided relate to a range of distribution assets, namely:

- 2 by 100m overhead HV spans without earthwire either side of a pole mounted substation at 40 faults/100km/year.
- 2 by 100m HV spans without earthwire at 40 faults/100km/year.
- 2 by 500m HV underground cable feeding a substation at 10 faults/100km/year.
- 1km section of isolated HV underground cable at 10 faults/100km/year.

ANNEXURE D: ASSESSMENT OF EPR

Introduction

When an earth fault occurs at a power system asset, the current flowing through the earthing system to the general mass of the earth will produce an increase in the potential of the earthing system with respect to a remote earth. This potential rise will affect the local soil and other metallic structures in the vicinity of the earthing system.

The magnitude of the EPR which is the maximum voltage expected on any earthed conductive paths of the asset is given by;

$$(D1) \quad EPR_e = I_e R_e$$

Where,

EPR_e is the earth potential rise at the power system asset

I_e is the current flowing into the earthing system

R_e is the resistance to remote earth of the earthing system of the power system asset

Distribution of fault current: Distribution Case Study

Where the earthing system at an asset has additional conductive paths (such as an OHEW, Cable Screen, LVN etc.) then the current flowing into the earth at the location of the fault I_e is only a portion of the total fault current I_f . This is indicated in the figure below for the common distribution substation case. Note; a decrease in the earthing system impedance or resistance of the earthing system will result in an increase in the overall fault level to some extent.

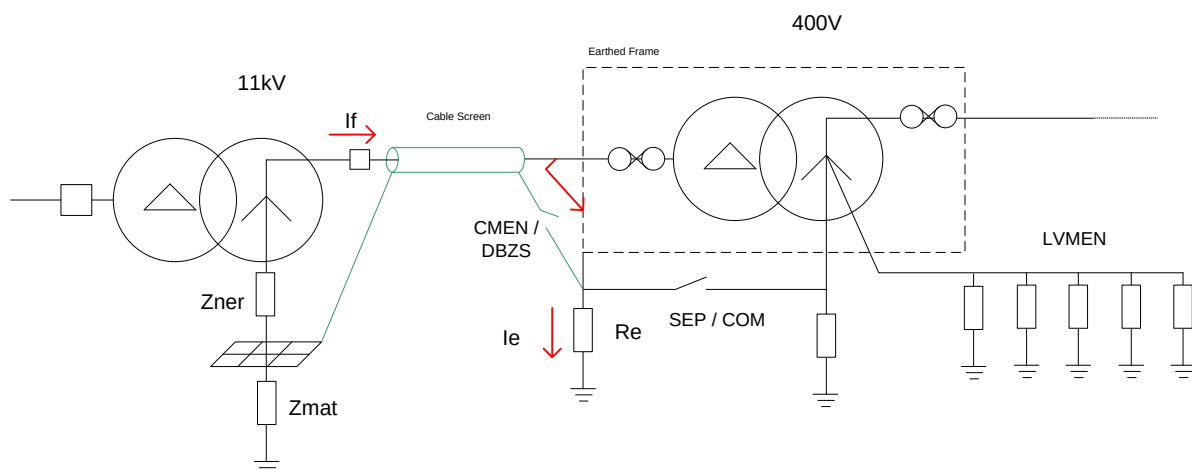
$$(D2) \quad EPR_e = I_f Z_{sys}$$

Where,

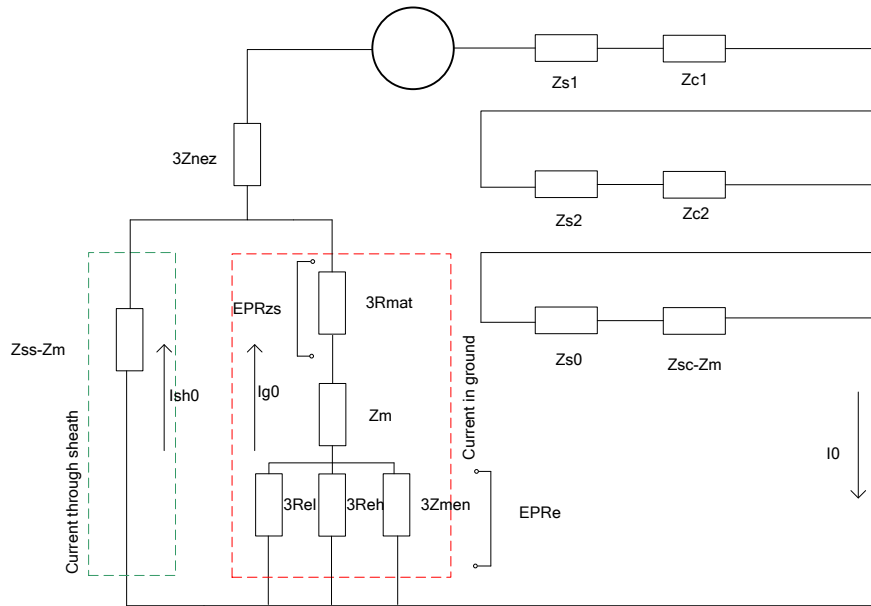
EPR_e is the earth potential rise at the power system asset previously defined

I_f is the total fault current

Z_{sys} is the equivalent impedance of the earthing system including in parallel with the resistance of the HV earthing system of the power system asset.



For the case where a common earthed distribution substation is also connected to the local LV MEN and an auxiliary network of cable screens which is bonded to the source substation, the sequence equivalent circuit of the above is indicated below:



Where,

Z_{s1}	positive sequence source impedance
Z_{s2}	negative sequence source impedance
Z_{s0}	zero sequence source impedance
Z_{c1}	positive sequence cable impedance
Z_{c2}	negative sequence cable impedance
Z_{c0}	zero sequence cable impedance
Z_{men}	the equivalent impedance of the LV MEN
Z_{nez}	neutral earthing impedance at the source substation
R_{mat}	zone substation earthing resistance

Where,

$$(D3) \quad Z_{c0} = Z_{sc} - Z_m + \left(\frac{1}{Z_{ss} - Z_m} + \frac{1}{Z_m} \right)$$

Z_{sc}	zero sequence self-impedance of the conductor
Z_{ss}	zero sequence self-impedance of the metallic cable sheath
Z_m	zero sequence mutual impedance between the conductor and the metallic cable sheath with ground return path
$Z_{sc} - Z_m = Z_{con0}$	zero sequence conductor impedance
$Z_{ss} - Z_m = R_{sh0}$	zero sequence resistance of the metallic cable sheath

Now the fault current can be calculated as,

$$(D4) \quad I_f = 3I_0 = 3 \frac{V_{l-n}}{Z_1 + Z_2 + Z_0 + 3Z_{nez}}$$

Where,

$$Z_1 = Z_{s1} + Z_{c1}$$

$$Z_2 = Z_{s2} + Z_{c2}$$

$$Z_0 = Z_{s0} + (Z_{sc} - Z_m) + \left(\frac{1}{Z_{ss} - Z_m} + \frac{1}{3Z_{eq} + Z_m + 3R_{mat}} \right)^{-1}$$

$$Z_{eq} = \left(\frac{1}{R_{eh}} + \frac{1}{R_{el}} + \frac{1}{Z_{men}} \right)^{-1}$$

The current flowing into the general pass of the earth can be determined by,

$$(D5) \quad I_e = 3I_{g0} = 3I_0 \left(\frac{Z_{ss} - Z_m}{Z_{ss} + 3Z_{eq} + 3R_{mat}} \right)$$

With the remaining current flowing through the cable sheath to the neutral point of the transfer

$$(D6) \quad I_{sh} = 3I_{sh0} = I_f - I_e$$

The maximum EPR in this case at the faulted asset is now,

$$(D7) \quad EPR_e = I_e Z_{eq}$$

Distribution of fault current: Transmission Case Study

Where a high voltage power line is equipped with one or more OHEW than the current flowing into the earth at the location of the fault depends on:

- Magnitude of the fault currents on both sides of the fault location and parallel circuit
- Fault location with respect to the source of fault
- Substation ground resistances at the source and/or remote ends
- Conductor arrangement on the structure and the location of the faulted phase
- Span length
- Ground resistance of the structure in the vicinity of the fault site
- Location, size, material and number of overhead earth wires
- Soil resistivity

$$(D8) \quad I_e = \left[\frac{Z_t}{2R_e + Z_t} \right] \kappa I_f$$

Where

κ is the shielding factor of the OHEW

Z_t is the impedance to earth via the OHEW and surrounding towers (ladder network).

For an infinitely long transmission OHEW,

$$(D9) \quad Z_t = \frac{Z_s}{2} + \sqrt{RZ_s + \frac{Z_s^2}{4}}$$

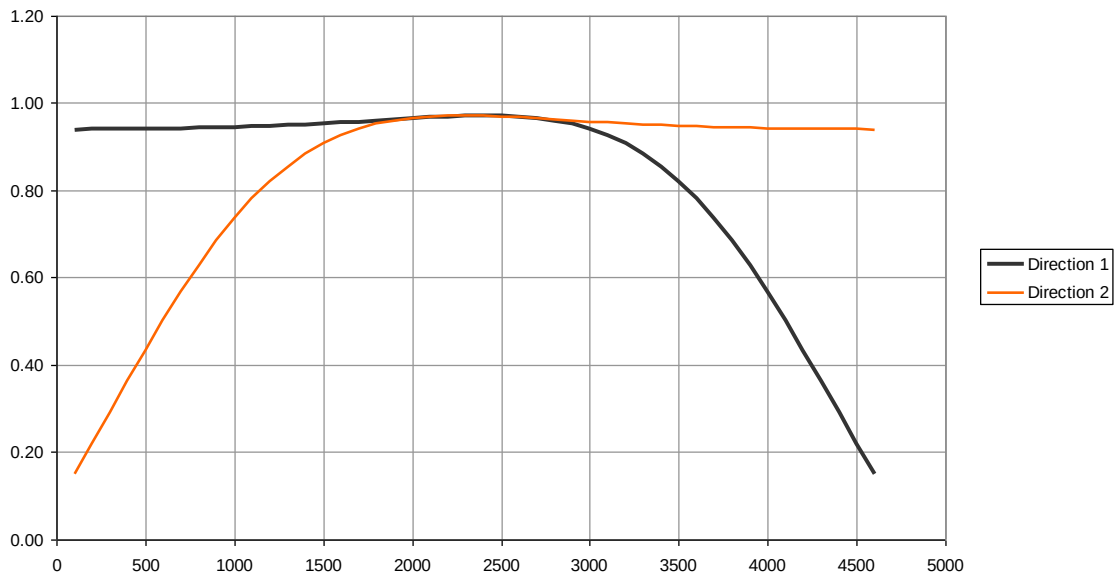
For transmission OHEW lines, the impedance via the OHEW and surrounding towers can be considered infinitely long a number of spans from the source. Provided OHEW is continuous between both sources, this value will generally be conservative. This is indicated in the figure below.

Where,

Z_s is the zero sequence (phase – earth) self-impedance of the OHEW with ground return, per span

R is the average tower or pole footing resistance

$$(D10) \quad EPR_e = I_e R_e$$



Earth Resistance of Primary Earthing System

Assuming homogenous resistivity, earth resistances can be calculated using simple equations, as follows:

For a vertical rod:

$$(D11) \quad R_e = \frac{\rho}{2\pi L} \left[\ln \left(\frac{4L}{r} \right) - 1 \right]$$

Where

- R_e is the resistance in ohms
- ρ is the earth resistivity in ohm meters
- L is the length of the rod in meters
- r is the radius of the rod in meters

For a buried horizontal wire:

$$(D12) \quad R_e = \frac{\rho}{2\pi L} \left[\ln \left(\frac{2L}{2dr} \right) - 1 \right]$$

Where

- L is the length of buried wire in meters
- d is the depth of burial in meters

For a buried large flat plate:

$$(D12) \quad R_e = \frac{\rho}{4} \sqrt{\frac{\pi}{A}}$$

Where

- A is the area of the earth grid in square meters

Surface Voltage Contours

Assuming uniform current flow (homogenous soil) the surface potential will fall inversely proportional to the distance from the grid. By superposition principle the number of rods and horizontal electrodes will modify the shape of the effective profile as indicated in the figure below for an equivalent radius of a hemispherical electrode (though the overall EPR will reduce for improvement to the earthing impedance).

For most practical situations, the earth resistivity is not known but the grid resistance is along with the maximum prospective fault level. Accordingly, the surface voltage contours can be calculated using

$$(D13) \quad V(x) = EPR \frac{r_e}{x + r_e}$$

Where,

$V(x)$ is the voltage on the surface, x meters away from the edge of the grid
 r_e is the radius of the equivalent hemispherical electrode in meters

For a driven rod, the equivalent hemispherical earth electrode is:

$$(D14) \quad r_e = \frac{L}{\left[\ln\left(\frac{4L}{r}\right) - 1 \right]}$$

Where,

L is the driven depth of the rod in meters
 r radius of the rod in meters

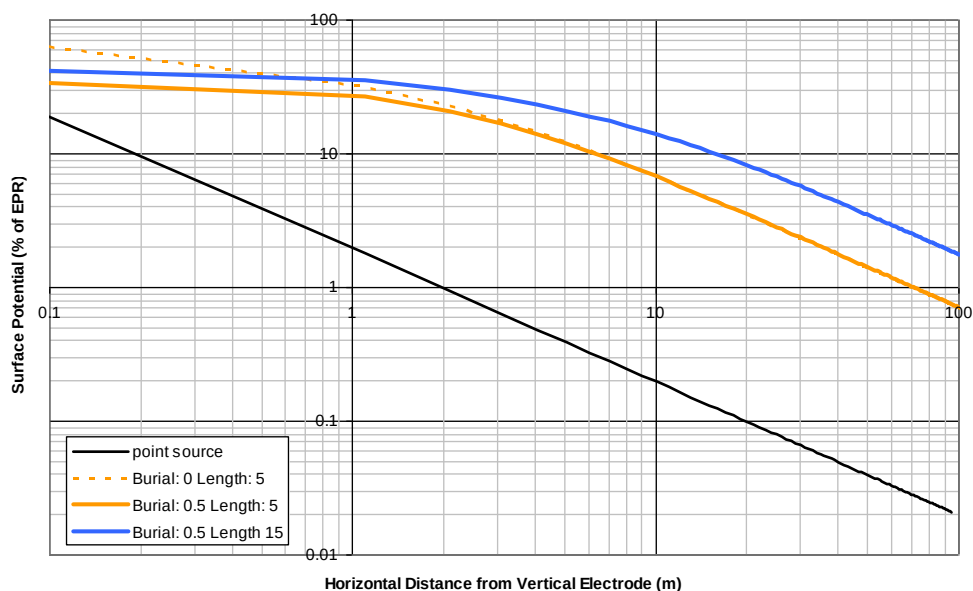
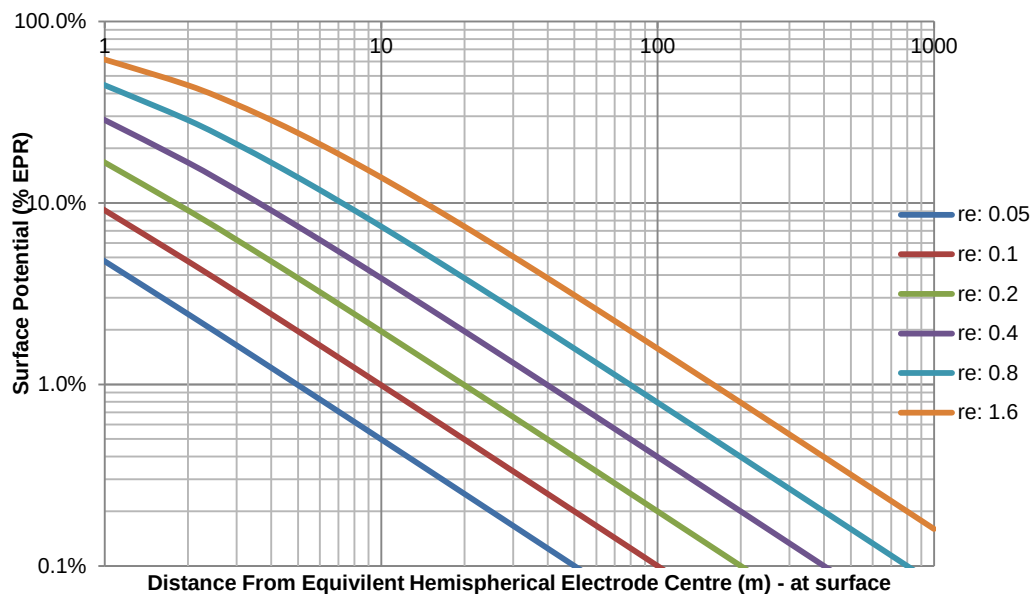
For a surface plate, the equivalent hemispherical earth electrode is:

$$(D15) \quad r_e = 0.3592\sqrt{A}$$

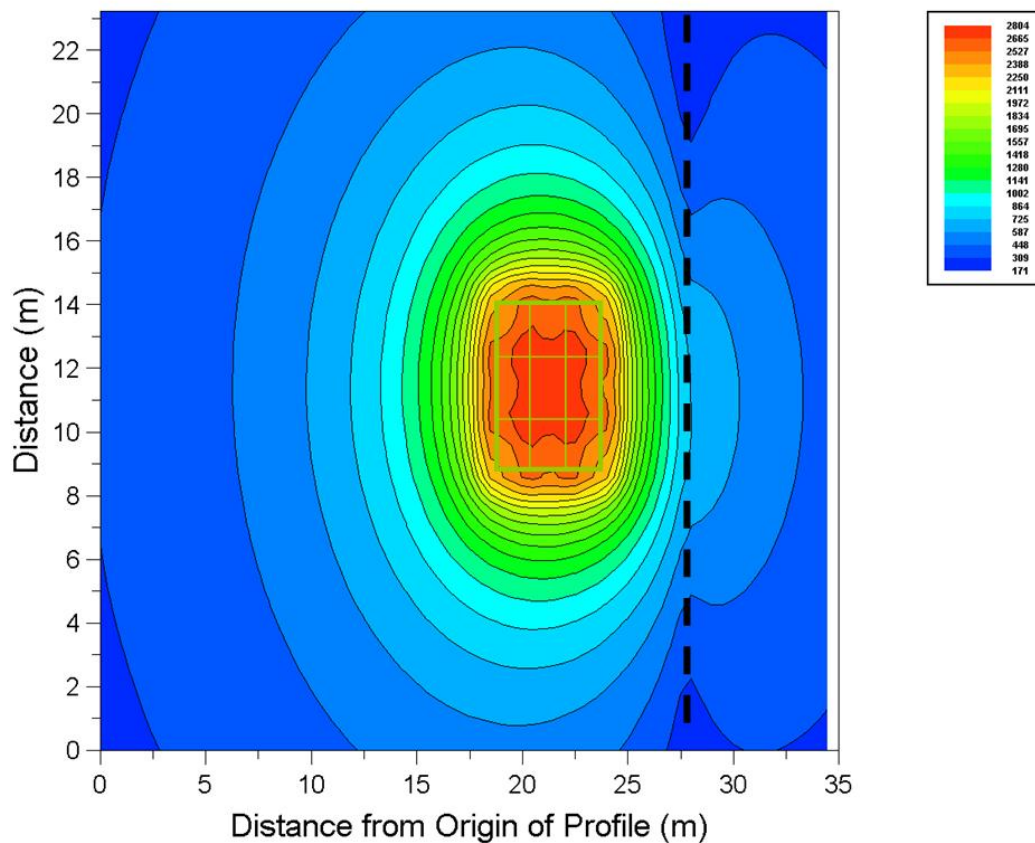
Where

A is the area of the earth grid in square meters

These surface voltage contour assessment methods are inaccurate in close proximity to the earth system since the earthing system is not a hemispherical electrode. These functions must only be used for distances greater than five times the maximum dimension of the earth electrode and in homogenous resistivity soil models. Beyond this distance, the contours closely resemble a hemispherical earthing system. Where accurate detail is required, it is preferential to use analytical software packages and/or injection testing.

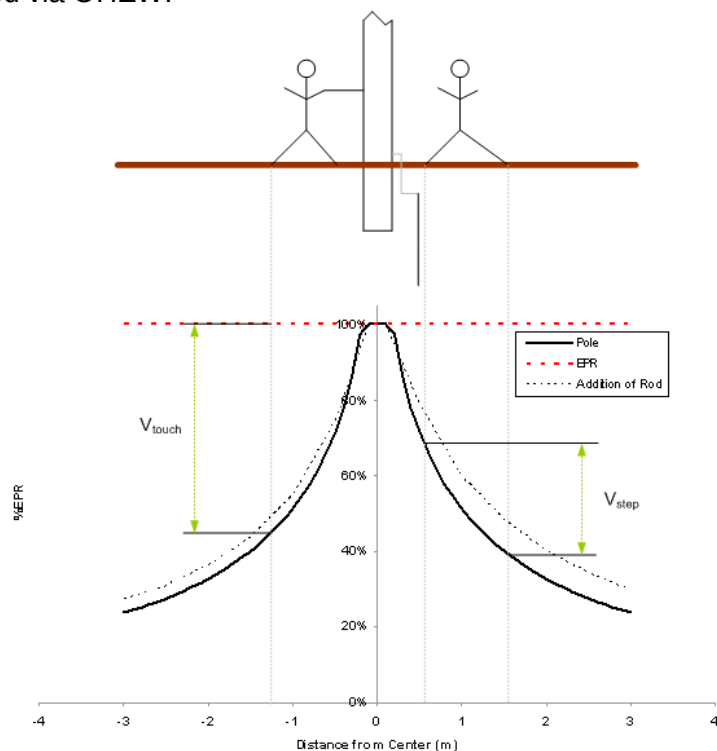


This voltage can be transferred onto conductive assets buried in the ground and not necessarily bonded to the local earthing system. The allowable voltage will then depend on the soil model, the likely contact scenarios, the earth grid/electrode arrangement and fault levels. Care must be taken in close proximity to buried earths of another system (such as metallic pipes), since such paths can attract earth currents and misshape the earth contours considerably. Consider for instance a small separately earthed grid (5 x 5m buried at 0.5m) with an EPR of 3000V in close proximity to a conductive water reticulation system.



Step and Touch Voltages

An assessment of the step and touch voltages associated with a faulted asset can now be made. An example is provided below for a conductive pole subject to a fault or transfer voltage due to nearby fault transferred via OHEW.



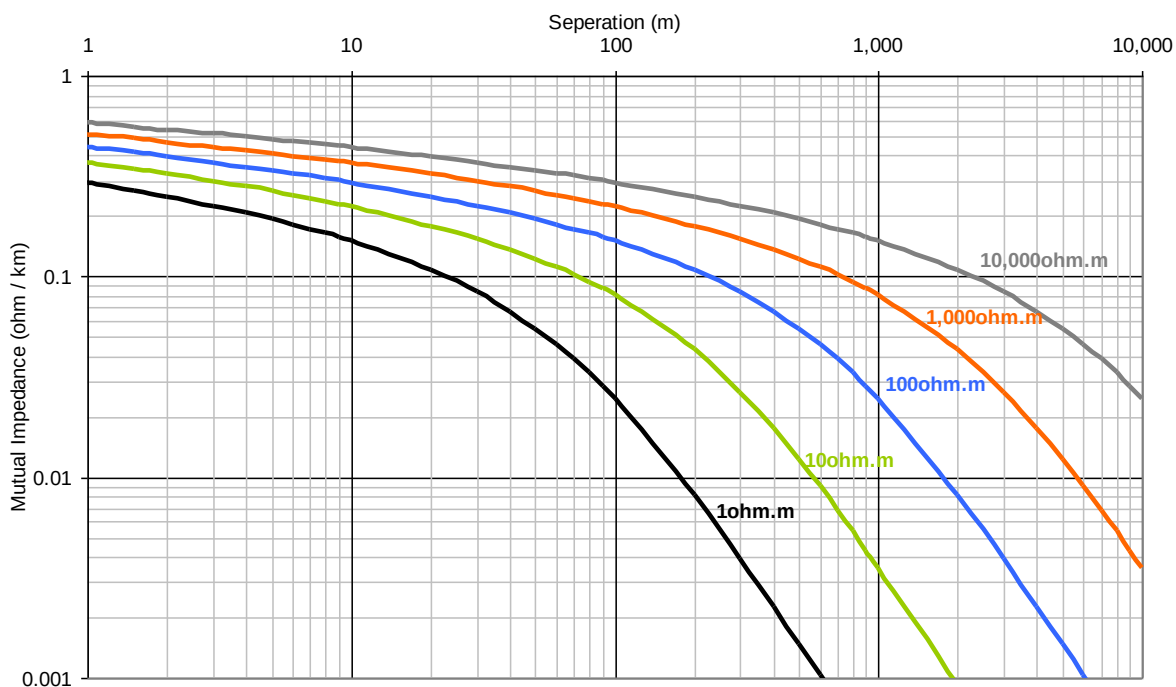
ANNEXURE E: ASSESSMENT OF LOW FREQUENCY ELECTROMAGNETIC INDUCTION

When assessing hazards on metallic plant run in parallel with power lines due to power frequency electromagnetic induction, two cases must generally be considered, single phase to ground fault conditions and maximum load (including any typical unbalance) load conditions. In situations where an OHEW is present, its presence has a shielding effect on parallel metallic plant and can reduce voltage induced hazards considerably in most circumstances.

Inductive coupling, particularly in fault conditions depend on a number of factors including:

- Type of fault
- Magnitude of fault current
- Geometric layout and mutual impedance between phase, earth and metallic plant circuits
- Length of circuit running parallel to the metallic plant
- Earth resistivity
- Vertical clearances from ground
- Leakage impedance from the metallic plant to ground

The figure below indicates the mutual coupling between a power line and metallic plant in the vicinity, both of which have in common an earth return. It is provided as a function of the geometric mean separation distance between the conductor and the plant for varying values of average soil resistivity.



Note: For soil resistivity values less than 25 ohm.m, the above can become misleading. Reference must be made to CIGRE 1995 in such cases.

The induced voltage for a single phase to earth fault parallel to metallic plant can now be calculated as:

$$(E1) \quad V_i = \kappa Z_{ci} I_c L_p$$

Where,

V_i the parallel metallic plant induced voltage (V)

- K the shielding factor associated with the metallic plant in question due to the presence of an OHEW or other metallic infrastructure in the vicinity. For the overhead case it is typically in the range of 0.7 to 0.9.
- Z_{ci} the mutual coupling from the chart above between the conductor and the metallic parallel plant (ohm/km)
- I_c the fault current flowing in parallel (A)
- L the length of the electromagnetic exposure (km)

Under steady state load conditions a similar expression can be developed, except this time the vector phase currents are required in the high voltage power line:

$$(E2) \quad V_i = (Z_{ai}I_a + Z_{bi}I_b + Z_{ci}I_c)L$$

Where from Carson's equation,

$$(E3) \quad Z_{ki} = 0.04935 + j0.14468 \log_{10} \left(\frac{D_e}{D_{ki}} \right) \Omega.km^{-1}$$

Where,

$$(E4) \quad D_e = 658.37 \sqrt{\frac{\rho}{f}} \text{ m}$$

- ρ average soil resistivity in ohm.m
- f frequency of power supply in Hz

In the presence of an OHEW the above equations become

$$(E5) \quad V_i = (Z'_{ai}I_a + Z'_{bi}I_b + Z'_{ci}I_c)L$$

Where,

$$(E6) \quad Z'_{ki} = Z_{ki} - \frac{Z_{kw}Z_{wi}}{Z_w}$$

Where equation G3 and G7 can be used to determine each of the terms,

$$(E7) \quad Z_w = r_w + 0.04935 + j0.14468 \log_{10} \left(\frac{D_e}{GMR_w} \right) \Omega.km^{-1}$$

- r_w the a.c. resistance of the earth wire "w" in ohm/km
- GMR_w the geometric mean radius of the earthwire "w"

The impact of transpositions and additional parallel metallic paths (additional OHEW or nearby pipes, fences etc.) the voltage can be reduced further but risk can be transferred to more parallel paths.

ANNEXURE F: ENGINEERING CONTROLS FOR RISK MITIGATION

The mitigation methods proposed in this section are based on the assumption that the preventative controls that avoid an EPR hazard have been fully utilised. This leaves the following mitigation control strategies to avoid as far as reasonably practicable the magnitude of the risk event by reducing the magnitude/duration of the hazard and/or its transfer/exposure to workers and the general public. The following mitigation methods are in no particular order and often a combination of these risk treatments will be required to control EPR hazards:

- a) Reduction of the impedance of the earthing system
- b) Reduction of the fault clearance times
- c) Surface insulating layers
- d) Installation of gradient control conductors
- e) Separation of HV and LV earth electrodes
- f) Isolation
- g) Installation of electrodes deeper into the ground

In each case it is essential to weigh any additional/residual risk caused by each treatment.

F.1 *Earth grid impedance reduction*

A reduction in earth system impedance at a local site only (ignoring bonded paths) is performed by burying additional rods and conductors in the soil to allow electrolytic flow to “remote” earth. The feasibility of such an option depends on the area available, the soil model and the ability to bury at depth. While this can be effective in reducing the EPR magnitude, the ability to drive fault current increases and therefore the effectiveness truly depends on the total earth circuit impedance.

If the earthing impedance is reduced by enlarging the earthing system, then 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 of the system. Care must be taken when designing a system in this manner since the hazard of transfer touch voltages on nearby metallic infrastructure may increase overall risk considerably.

The use of earthing rods and buried conductors is generally 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. Earth electrode enhancement by using conductive compounds and chemical treatment of the soil might be effective in improving local conditions also.

F.2 *Earth electrode enhancement*

If the soil resistivity is high and the available area for the grounding system is restricted, methods of enhancing the earth electrode may be required. Such methods include the encasement of the electrode in conducting compounds, chemical treatment of the soil surrounding the electrode and the use of buried metal strips, wires or cables.

These methods may be considered in certain circumstances as a possible solution to the problem of high electrode resistance to earth. They may also be applied in areas where considerable variation of electrode resistance is experienced due to seasonal climatic changes.

F.3 *Protection clearance time improvement*

EPR hazards can be mitigated considerably by the reduction of the fault clearing time. Instantaneous and fuse protection clearing times result in considerably low likelihood of being

coincident and can also limit exposure to a shock during the vulnerable period of the ventricles of the heart.

The company's traditional E/F protection settings have been designed to allow the single phase switching of full load current and also allows room for future downstream grading. A significant review of the company's standard settings is currently underway and a program is underway in conjunction with earthing system improvements to reduce clearance times of CB's and associated relays considerably.

SEF Protection is important in detecting and disconnecting high impedance faults. The current SEF protection setting is designed at 10 second operation to allow for temporary unbalanced flow. A 10 second setting extends the exposure rate for earthing hazards by increasing the probability of coincidence considerably.

F.4 Overhead earth wires/earthing conductors

While the primary purpose of overhead shield wires is to provide lightning shielding for the substation, bonding of the shield wires to the substation earth grid can significantly reduce earth fault currents through the earth grid for faults at the station or at structures, towers and assets bonded to the shield wire. The bond via dedicated earth wire typically employed on transmission feeders significantly reduces EPR hazards at the fault site and substation by providing both inductive coupling and a conductive path, but this method also extends resultant hazards to bonded earthed assets. The use of dedicated shielding conductors is also useful throughout the distribution network in areas of high soil resistivity as a designed earth return path.

The rating of the shield wires is an important consideration if approving for bonding. Depending on the circuit configuration, up to 90% of ground fault current can return via the OHEW for a fault on the ground faulted circuit. Faults of different voltages can also be benefited by OHEW but typically result in a conductive path and therefore can only expect between 30% and 80% of fault current conducted back onto OHEW – depending on the fault location. The clearance time for both of these fault scenarios can be considerably different and must be assessed in the rating application.

F.5 Cable Screens

Cable screens, if adequately rated can provide a significant conductive and inductive path for fault current to flow for both cable and substation faults in the distribution network. The additional earth paths to the bonded points throughout the earth network can reduce EPR significantly. It is important to assess the sheath current flow due to unbalanced conditions and the impact on overall cable rating in such a design.

Bonding cable screens to distribution and zone substation earthing systems at both ends is usually beneficial to the transfer of EPR hazards from distribution faults back to ZS neutral points. In areas of the network where UGOH's segregate the local cable network or areas with only a few padmount substations, cable sheaths can transfer EPR hazards locally and investigation as to the merits of bonding both ends is required in such locations.

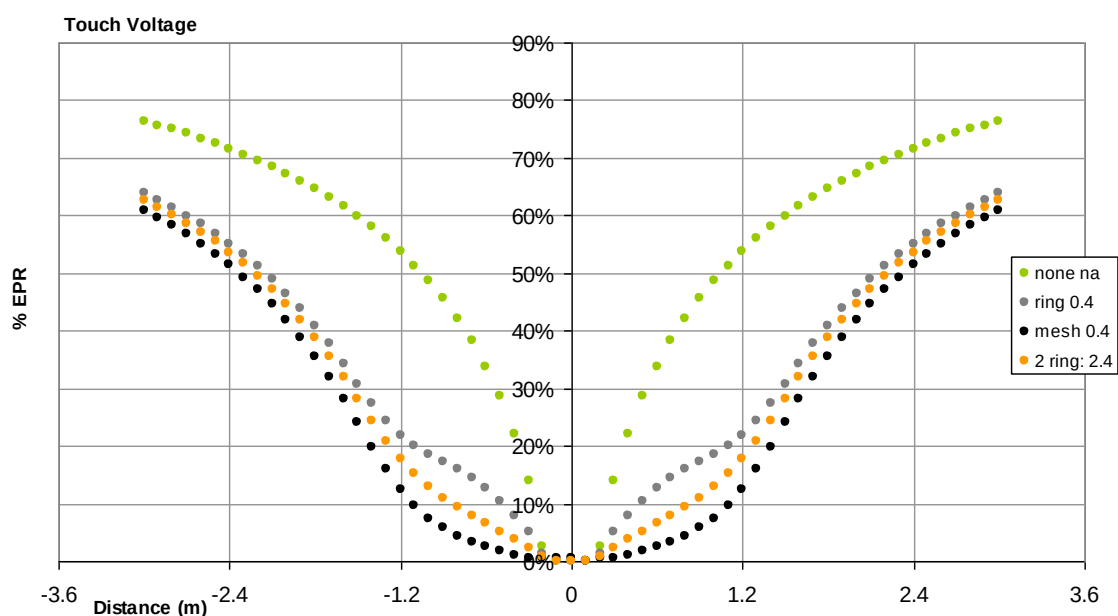
Bonding of cable screens at the ZS and padmount substations increases the fault rate experienced on bonded assets as all faults return to ZS. The bonding of cable screens at the ZS level must be assessed on a case by case basis to enable the safest outcome is provided for the local conditions.

F.6 Gradient control methods

Touch voltages from a conductive structure can be managed to some extent by burying “gradient control” conductor(s), grading meshes or concrete pads bonded into the earthing system. While this increases the EPR influence zone, it has the benefit of being able to manage touch voltages at specific locations to predefined limits. The extended EPR contours need to be considered in this case, particularly in close proximity to houses and other metallic infrastructure.

Around zone substations, the use of gradient control conductors is effective at mitigating touch potentials on the fence outside the substation boundary. It is therefore safer to have the substation earth grid extend beyond the fence (1.2m) for control of such a hazard. Around padmount substations, a grading control method is useful in limiting touch voltages potentially exposed to operators.

Depending on the soil model, a gradient control conductor/mesh can limit touch voltages to approximately 2-30% of the EPR. These are therefore one of the most useful and cost effective measure of mitigating touch potentials around conductive structures and poles in combination with an appropriately sized earth system impedance. This is indicated in the figures below.



F.7 Operating configuration

Traditional operating philosophy for the company’s network has been multi-TX operation to both increase reliability and improve power quality. A simple and effective way of improving earthing related hazards requires a change in operating philosophy. That is, single TX operation at ZS with split 11kV bus. While the lower fault level and typically better backup clearance time of related hazards can be improved, care must be taken as primary protection clearance times are generally slower. Consideration also need be given for large motor starting currents and other concerns with equipment sag immunity.

F.8 Soil insulation

Lining ground surfaces with a thin layer of high resistivity material is often used in zone and transmission substations throughout the company’s network. The thin layer of material helps limit the body current by adding series resistance to touch and step voltage paths.

Inside substations, crushed rock is typically used. This increases tolerable levels of touch voltages during earth fault conditions, eliminates weeds and provides a self-draining surface. The thickness of the layer inside substations can vary but as a minimum be 100mm in order to derive significant

effect. The resultant resistivity of the crushed rock layer must be at least 3000 ohm.m. Hot-mix asphalt can be used where required to limit public exposure impedance paths.

F.9 Insulating cover

Application of acceptable levels of insulation or barriers around conductive assets can be effectively used to mitigate touch potentials on the asset. A number of spray-on plastics have been approved on the company's network. While these methods are effective at considerably reducing body current flow to almost zero, their aging and maintenance requirements are currently under review. While these methods are in their infancy this method can be used where gradient control and local/bonded methods are ineffective at reducing the hazard to a level that is reasonably practicable or the placement increases hazard exposure by expanding EPR contours.

F.10 HV/LV separation

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 maintain 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

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 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 etc.).

F.11 Installation of electrodes deeper into 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. This also reduces the potential touch voltage exposures on surrounding metallic infrastructure. This method must not be used for conductive structures on the surface (concrete or steel poles, concrete substation footings) as current will leak from the conductive structure and will reduce its effectiveness.

ANNEXURE G: RISK COST BENEFIT ANALYSIS FRAMEWORK

When determining whether or not a risk is as low as reasonably practicable, a risk cost benefit analysis must be conducted assessing the indicative cost of averting risk. These calculations aid the decision making in regard to adopting control measures to determine methods that are highly effective against those where cost or effort are to be diverted to alternative, more effective safety improvements.

Where a risk has been determined to be in the “intermediate” region then it is essential to carry out a risk cost benefit analysis (RCBA) to establish the relative cost of risk treatment in accordance with 5.2.1. This assessment is also required in the “low” risk region to assist in establishing whether any possible risk treatment option is justifiable. Risk must be continually monitored and managed to remain as low as reasonably practicable.

Note: *Using this methodology, in most cases an individual risk level of less than 1 in 1,000,000 per annum is sufficiently low that it generally rules out any additional expenditure in the earthing context. This is due to the inherently high incremental cost of earthing with diminishing benefits. The designer will become more familiar with this as they adopt this methodology and satisfy themselves that a risk is ALARP.*

An assessment into the appropriateness of reducing risks associated with earth faults creating hazardous voltages must include a review of the possible mitigation techniques to only rule out those that involve excessive cost or effort. The Indicative Cost of Averting Risk (ICAR) can be calculated using the following formula:

$$ICAR = \frac{\text{Cost of Measure (NPV)}}{(\text{Asset Life in Years})(\text{Risk}_{\text{initial}} - \text{Risk}_{\text{reduced}})}$$

There is no value of ICAR, at which it can categorically be said that ALARP is justified. Rather, the case in favour of satisfying the ALARP test strengthens progressively as the ICAR value continues to increase.

An alternative method to estimate the value of reducing risks is to calculate the Value of Statistical Life (VoSL). This method can be used to aid the decision making in regard to adopting control measures to determine methods that are highly effective against those where cost or effort are to be diverted to alternative, more effective safety improvements. The use of this method must be carried out in consultation with the Earthing & Power Quality Manager and subject to approval by General Manager Asset Management.

Additional literature discussing the risk cost-benefit analysis framework for earthing systems is provided in ENA EG-0.

ANNEXURE H: CONSERVATIVE COMPLIANCE LIMITS FOR PIPELINE ASSETS

The conservative compliance requirements (Level 1) are repeated below. Because, experience has shown that it may not always be practical to achieve these limits, a detailed assessment will be required where conservative compliance cannot be met in consultation with the pipeline authority using the process described in AS/NZS 4853:2012.

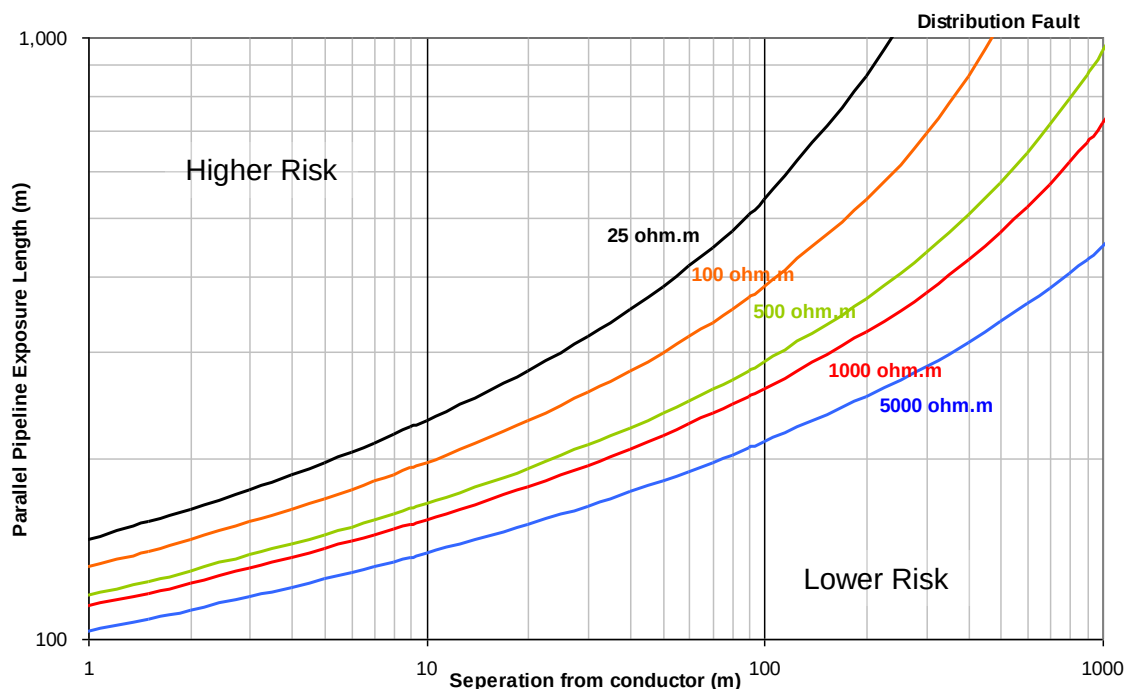


Figure H-1: Conservative exposure length for pipeline subject to LFI from distribution power lines

1. Separation is the shortest distance between the pipeline and the closest phase conductor.
2. Assumptions used in calculating exposure length (based on AS/NZS 4853):
 - No OHEW or shielding
 - Source substation resistance 0.35 ohm
 - Pole earth resistance 10 ohm
 - Fault current (1kA) flows through conductor and faulted power earth
 - Soil resistivity = deep layer values
3. Conservative allowable prospective touch voltage of 58V for distribution power lines

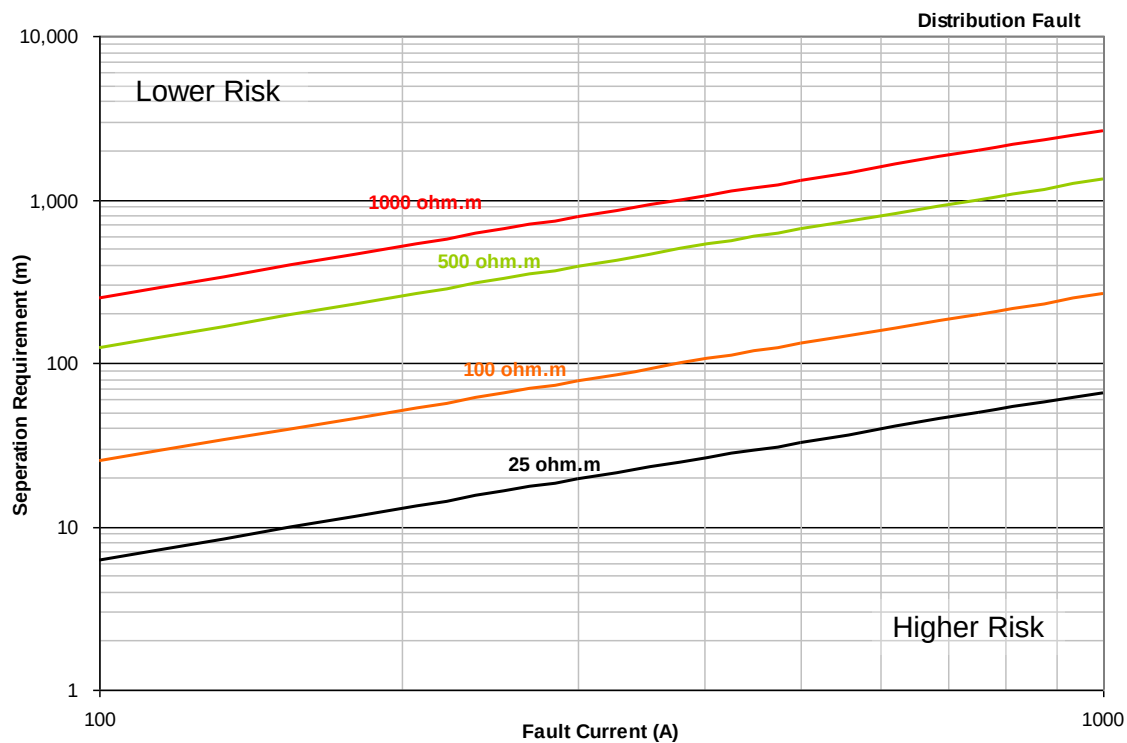


Figure H-2: Conservative separation distance for pipelines subject to EPR from distribution powerlines

1. Separation required is from the earthing system to the pipeline appurtenances, access points or earth points.
2. Assumptions used in calculating exposure length (based on AS/NZS 4853):
 - No OHEW or shielding
 - Pole earth resistance 10 ohm
 - Fault current flows through conductor and faulted power earth
3. Conservative allowable prospective touch voltage of 60V for distribution power lines

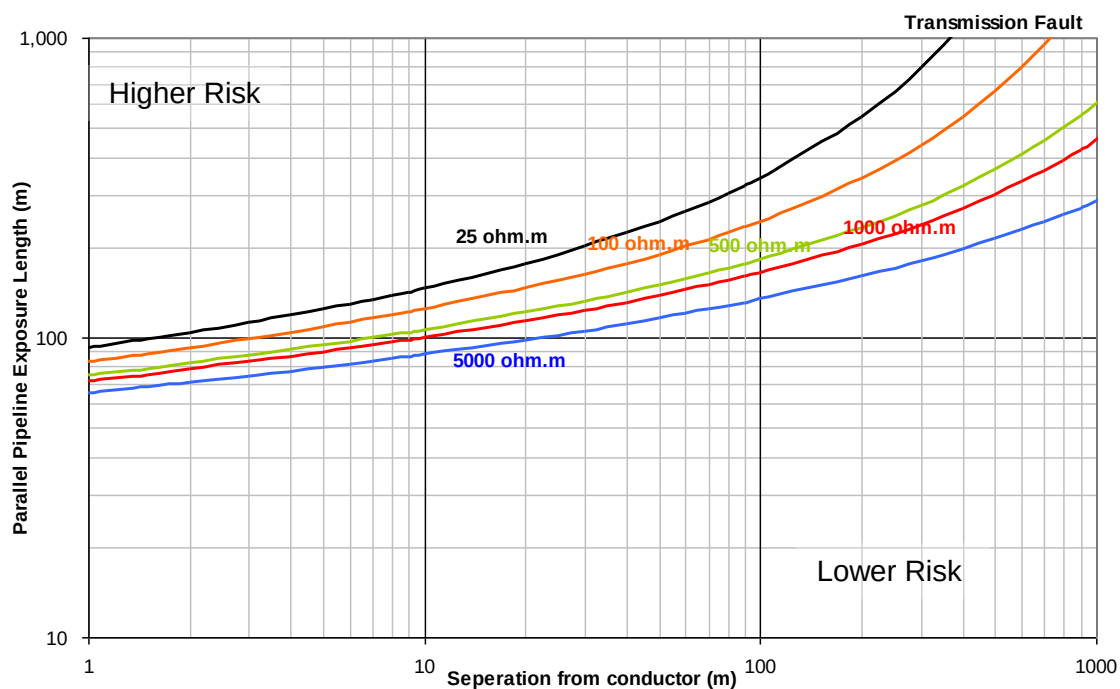


Figure H-3: Conservative exposure length for pipeline subject to LFI from transmission power lines

1. Separation must be the direct distance between pipeline and closest phase conductor.
2. Assumptions used in calculating exposure length (based on AS/NZS 4853):
 - Shielding factor of 0.8
 - Fault current of 8kA
 - Source substation grid resistance of 0.1 ohm
 - Tower resistance of 5 ohm
 - Fault current flows down several tower resistances
 - Soil resistivity = deep layer values
3. Conservative allowable prospective touch voltage of 220V for transmission power lines

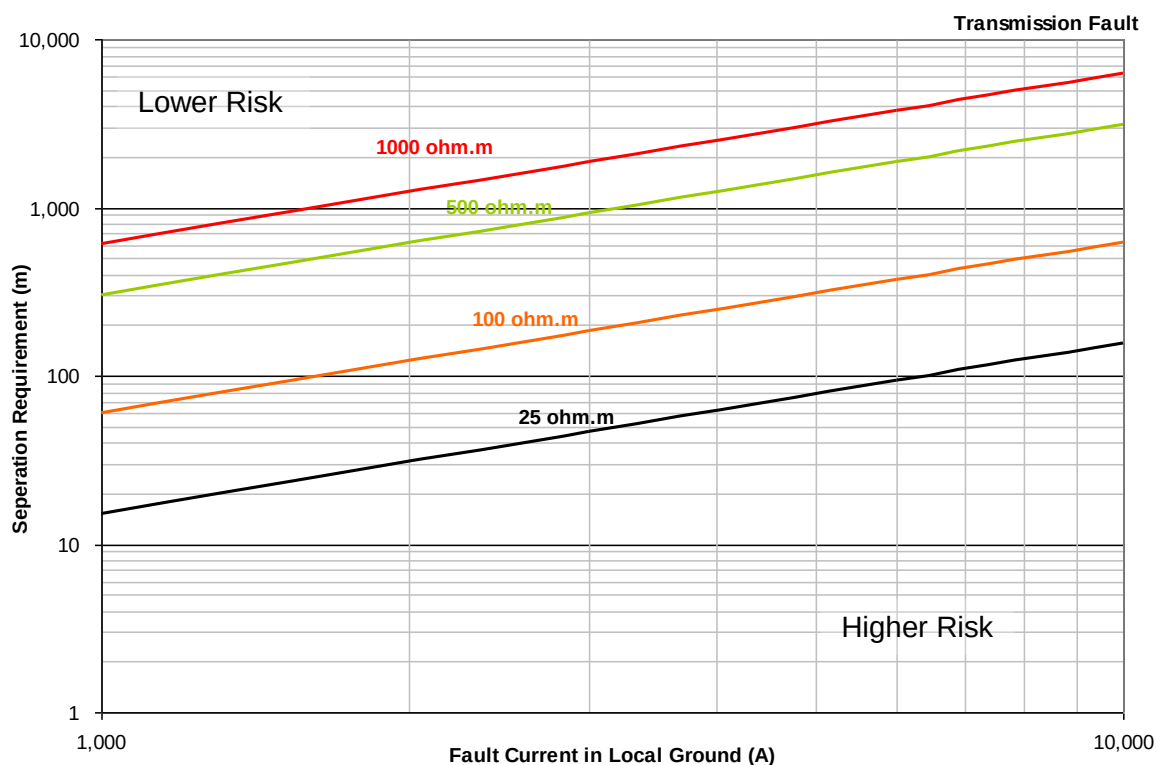


Figure H-4: Conservative separation distance for pipelines subject to EPR from transmission powerlines

1. Separation required is from the earthing system to the pipeline appurtenances, access points or earth points.
2. For lines with OHEW, 3kA (30% of 10kA, shielding and split) can be assumed in the ground at the faulted structure. For lines without OHEW, up to 10kA can be expected down the structure.
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
4. Conservative allowable prospective touch voltage of 220V for transmission power lines

ANNEXURE I: LOW RISK DESIGN TOUCH VOLTAGE SAFETY CURVES

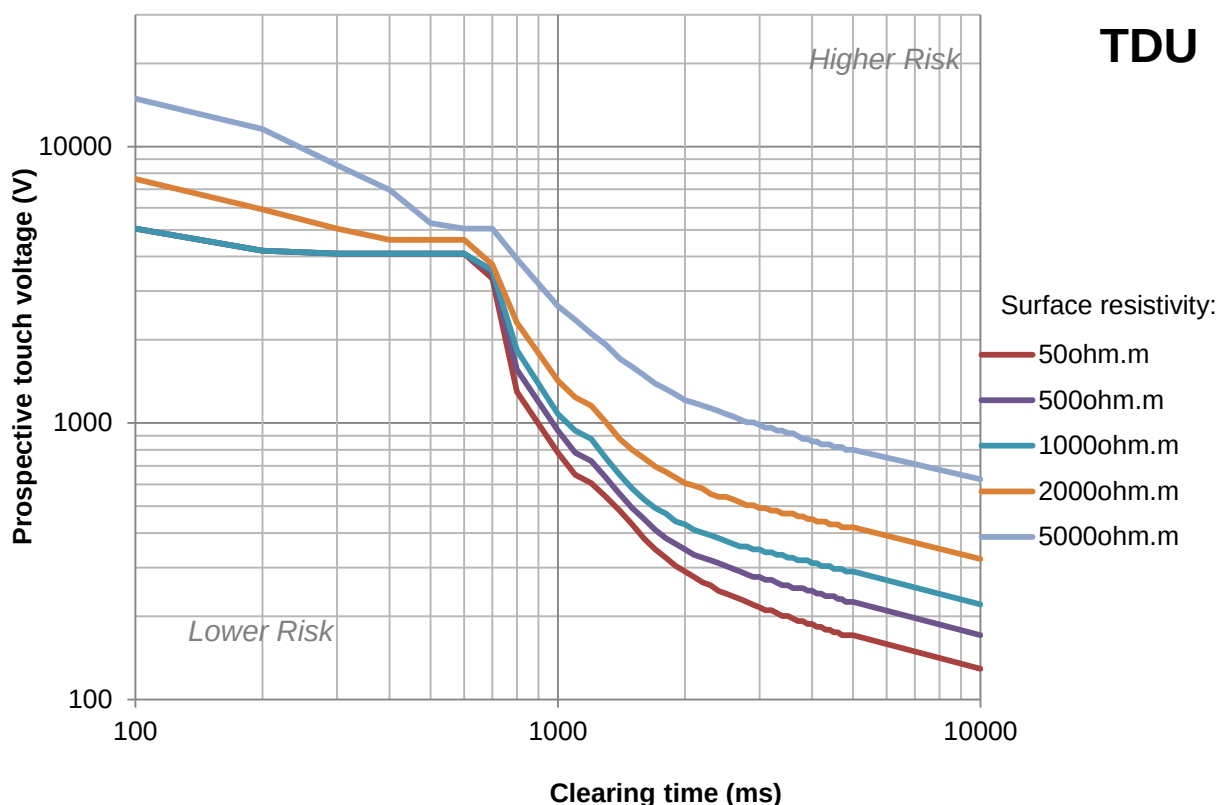


Figure I-1: Normal location "low" touch voltage risk limits: Transmission and distribution urban assets

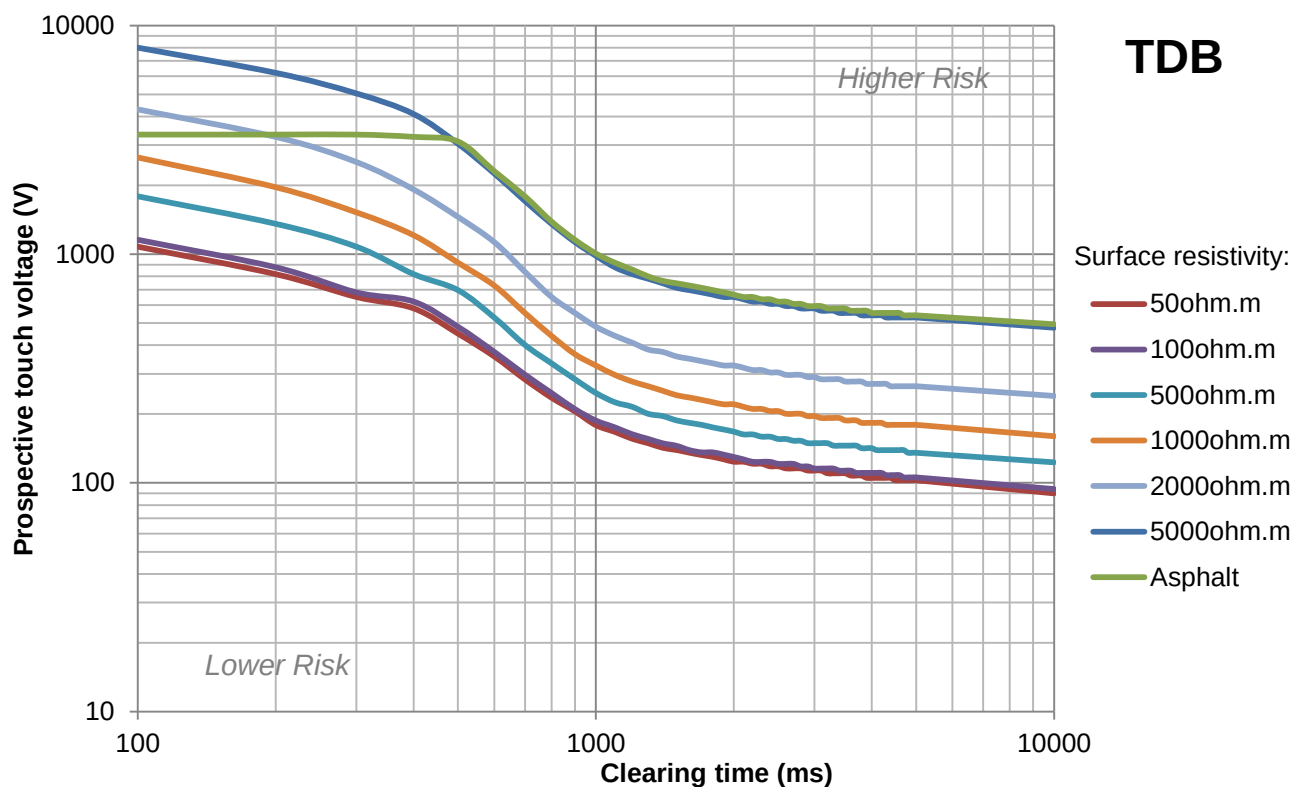


Figure I-2: Normal location "low" touch voltage risk limits: backyard items and metallic non-power system infrastructure in the vicinity of a HV asset (non-MEN)

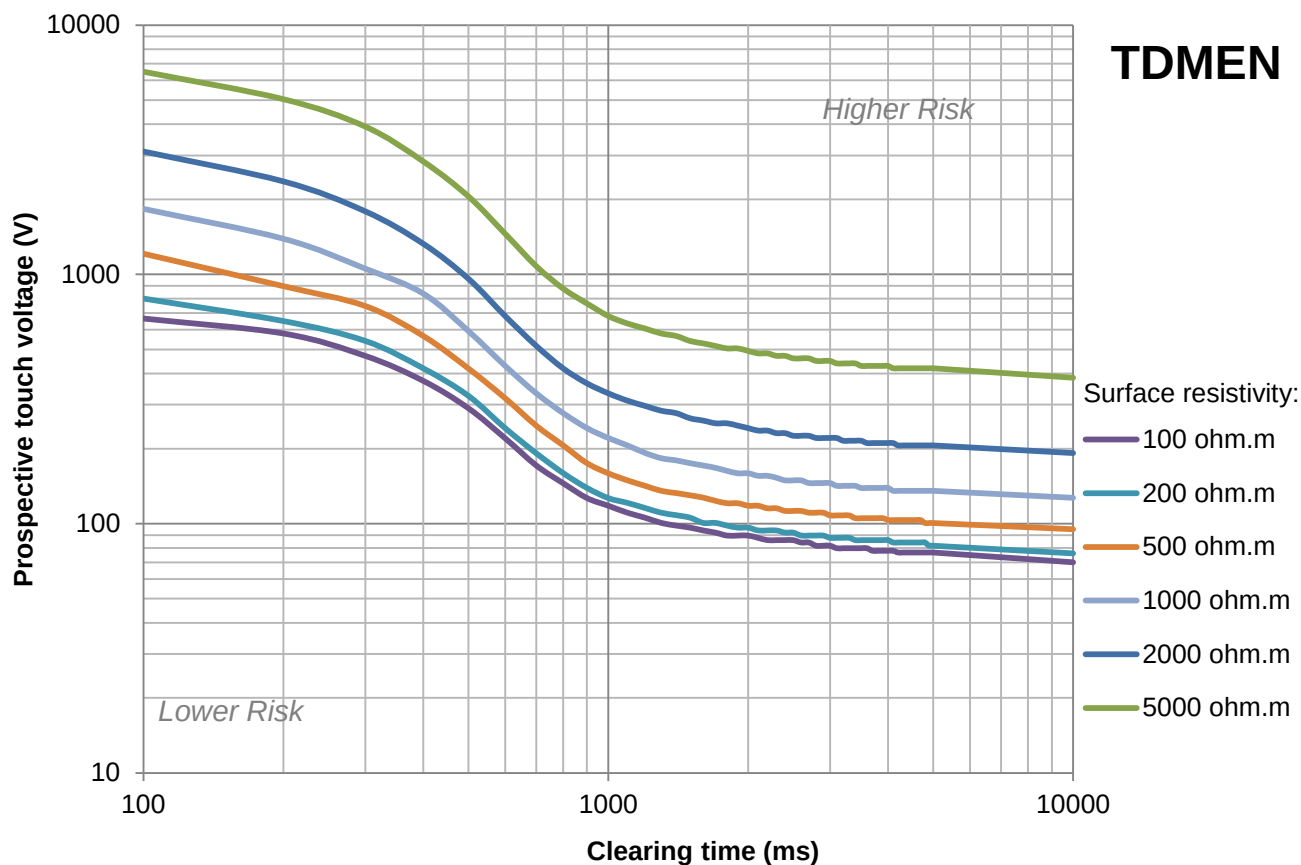
TDMEN

Figure I-3: Normal location “low” touch voltage risk limits: MEN assets and MEN bonded metallic non-power system infrastructure

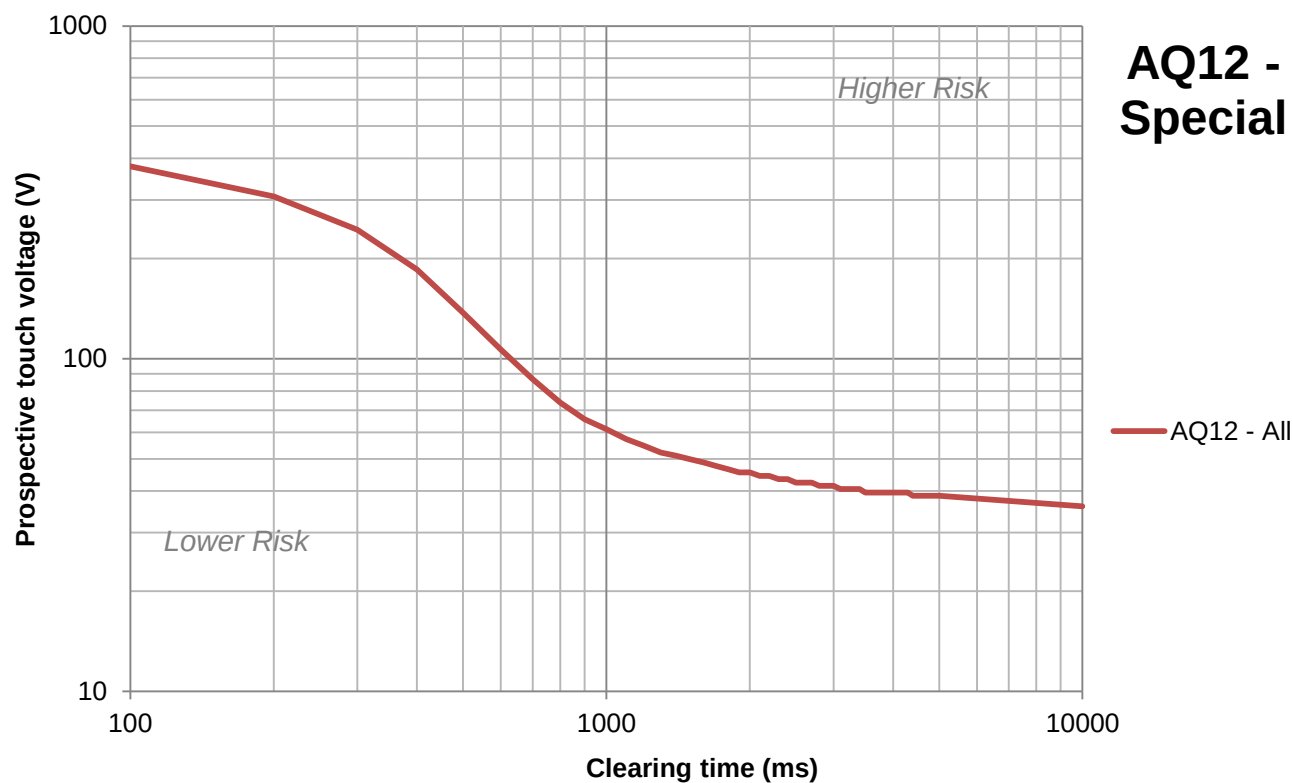


Figure I-4: Special location “low” touch voltage risk limits: special location affected metalwork