

# DISTRIBUTION EARTHING DESIGN MANUAL

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## GUIDELINE ON MIMIMUM REQUIREMENTS FOR THE SAFETY EARTHING OF EVOENERGY DISTRIBUTION NETWORK ASSETS

This document provides standard design guidelines for managing the design of distribution network earthing systems using a risk based approach.

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# 1. SCOPE

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This document provides guidelines on minimum requirements that should be followed for earthing of all standard approved components, equipment and systems in the Evoenergy distribution network including but not limited to:

ABS (Air break switch) handles

- 📁 Cable screens, sheaths and armour
- 📁 Conductive poles
- 📁 Enclosed Load-Break Switches
- 📁 HV switching stations
- 📁 Pole, pad and chamber type distribution substations
- 📁 Reclosers
- 📁 Surge arresters
- 📁 UGOHs (Underground to overhead mains connections)
- 📁 Voltage Regulators

This document covers the following aspects:

- 📁 Design criteria for earthing systems
- 📁 Overview only of construction and testing procedures and requirements. Details of earthing construction practice, testing and verification procedures are covered in Earthing Construction Manual SM 4668
- 📁 Application of Australian standards and guidelines

## 2. NOT IN SCOPE

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### 2.1 Complex and non-standard distribution network earthing designs

Where safe earthing design is unable to be delivered through the requirements and considerations identified in this document the designer may choose to depart from these standard design guidelines and develop a solution based on appropriate engineering analysis. Such non-standard designs may be developed in consultation with external subject matter experts. Approval by the Asset Owner is required for any departures from this earthing standard manual.

### 2.2 Transmission earthing requirements

Earthing of transmission network assets including Zone Substations, 132kV towers and poles is not covered in this document. These generally involve complex earthing solutions more effectively managed by external service providers specialised in this area. The design work for this shall only be carried out by suitably trained personnel competent in conducting earthing studies for transmission network assets.

The scope of work to carry out an earthing system design for transmission network assets shall include:

- A risk assessment to identify all likely earthing related hazard scenarios both inside and outside the asset boundary. The area beyond the asset boundary shall encompass a reasonable extent to account for transfer-in and out of zone substation grid fault voltage and EPR. Examples are:
  - Metallic fence outside a zone substation boundary but still within its EPR zone;
  - Transfer potential to and from remote distribution substations with bonded cable screens.
- Safety targets derived using ENA EG-0 and AS2067 guidelines
- Validation of all input data to ensure these reflect site conditions and account for future changes
- Basis for assumptions
- Soil resistivity testing and interpretation of results
- Modelling and calculations using proven software tools
- Current injection testing and interpretation of results
- Consideration of asset life-cycle phases – procurement, construction, maintenance and disposal
- Estimate of costs and project timeline.

### 2.3 Maintenance, Testing and Inspection

Refer to **Earthing Construction Manual**.

**'Asset Specific Earthing (Distribution)** provides details of Evoenergy's practices and activities to manage its distribution earthing assets.

## 3. PURPOSE

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This manual is intended to:

- promote standardisation and a uniform risk based design approach
- be practical and ensure earthing is cost effective to design, install, supervise and maintain
- provide a convenient reference for design parameters, standards and policies
- support designers with limited 'first-principles' line engineering expertise
- support training of new designers (not as complete training material, but as an underpinning reference)

- support any future auditing of designs submitted by external design consultants

## 4. FUNCTION OF EARTHING SYSTEM

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Distribution earthing system should –

- Reduce the electrical hazard to staff and public as low as reasonably practical during the transfer of earth fault energy and load imbalance conditions;
- Ensure adequate earth fault current to allow protection equipment to operate satisfactorily under normal HV fault conditions;
- Be adequately rated to meet stated mechanical, thermal and electrical requirements and function under all anticipated adverse environmental conditions (corrosion, physical abuse);
- Provide low impedance earth for surge protection;

Outcomes achieved through a properly designed earthing system are –

- Ensures that the step and touch potentials that result from an earth fault are within the limits set out in this document.
- Limits the level of abnormal transient and power frequency voltages impressed on the electrical distribution system and equipment during operation.
- Ensures that all HV earthing systems are designed so that the backup earth fault protection also will be activated, at its programmed setting times.
- Ensures that the LV earthing is always accompanied by a sound MEN system to carry earth fault currents, and that the LV circuit design is such that the fault currents will activate the respective protective devices.
- Stabilises the voltage under normal operating conditions. That is, maintains the operating voltage at one level relative to earth so that any equipment connected to the system will experience the same operating voltage or potential difference, subjected to allowable variation due to conductor voltage drops.

## 5. POLICY

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The recommended design standards and guidelines for earthing design of distribution installations are AS/NZS7000 and ENA EG-0. Refer to Sections 15 and 16 for discussion on selection of these documents.

Earthing design will be based on risk management of touch voltages. (Note the step voltage limit is typically ten times the touch voltage limit.)

The risk management process follows AS/NZS ISO 31000. Refer to Appendix C – Risk Management Process. The particular earthing risk management process for earthing design is provided as a list of steps and flowcharts in the sections that follow.

The earthing system must conform to the design criteria in this document over the operational life of the distribution asset. It must be designed so that it can be operated, maintained and tested over its service life. Earthing systems must be revised for any network augmentation, modification or where new conductive infrastructure is constructed in close proximity.

For telecommunications personnel and equipment the EPR compliance limits in AS/NZS 3835 will be applied.

For metallic pipelines the EPR compliance limits in AS/NZS 4853 will be applied.

Primary protection clearing time is to be used for electrical safety limits. Where it can be reasonably inferred that an 11kV earth fault at the distribution substation will be cleared by an immediate upstream protection device (e.g. dropout fuse) rather than the feeder protection relay at the zone substation the faster clearing time will be used to avoid an overly conservative design.

Only the initial fault is considered for electrical safety. Subsequent auto reclose events are to be taken into account for sizing of earthing components. Backup clearing time is to be used for sizing of earthing components.

Earthing design based on IEEE formulae and assumptions that are valid for small simple earth grids will be carried out by Evoenergy designers. This covers typical distribution substations and poles in the LV and 11kV network.

## 6. OVERVIEW OF THE EARTHING SYSTEM DESIGN AND MANAGEMENT PROCESS

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The process for deciding on the extent of earthing design required for the project is outlined in Figure 1.

An earthing design **for personnel safety** is not required if it can be established upfront that the risk of fatality due an earthing related hazard is negligible. In general an earthing design for personnel safety is not required if:

- the coincidence probability of individual risk is negligible and
- the likelihood of public gathering around the item (societal risk) can be excluded

Coincidence probability  $P_{\text{coinc}}$  is defined as the probability that a person is present and is in a situation to receive a shock voltage from an item at the same time that the item is affected by a fault. This includes touching the item (local or transferred touch voltage) or standing on a surface subjected to a voltage profile created by the fault (step voltage). Figure 2 taken from AS 2067 illustrates the various hazard situations associated with a substation earth fault.

$P_{\text{coinc}}$  can be worked out using the ENA's safety risk assessment tool ARGON. See Section 6.2.3 for a discussion on ARGON and its usage.

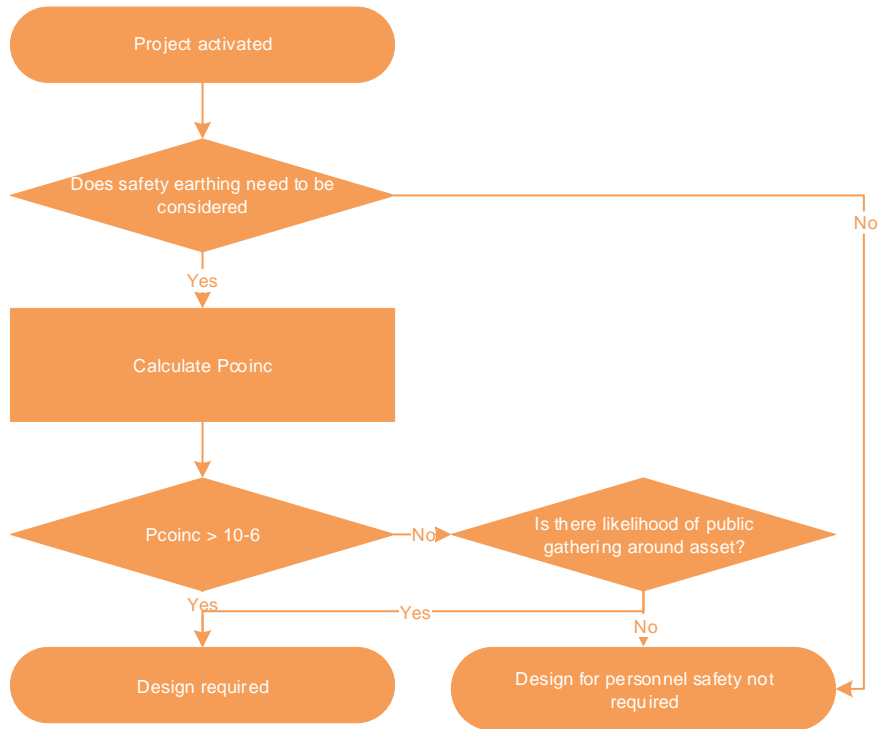
Note that design work is still required to assess risk of equipment damage due to an earth fault and for the control of hazards associated with exposure of third party assets such as telecommunications and metallic pipeline equipment to an EPR event.

If an earthing design is required the process shown in Figure 3 (taken from ENA EGO) shall be followed. This manual covers Step 2 'Power Frequency Design'.

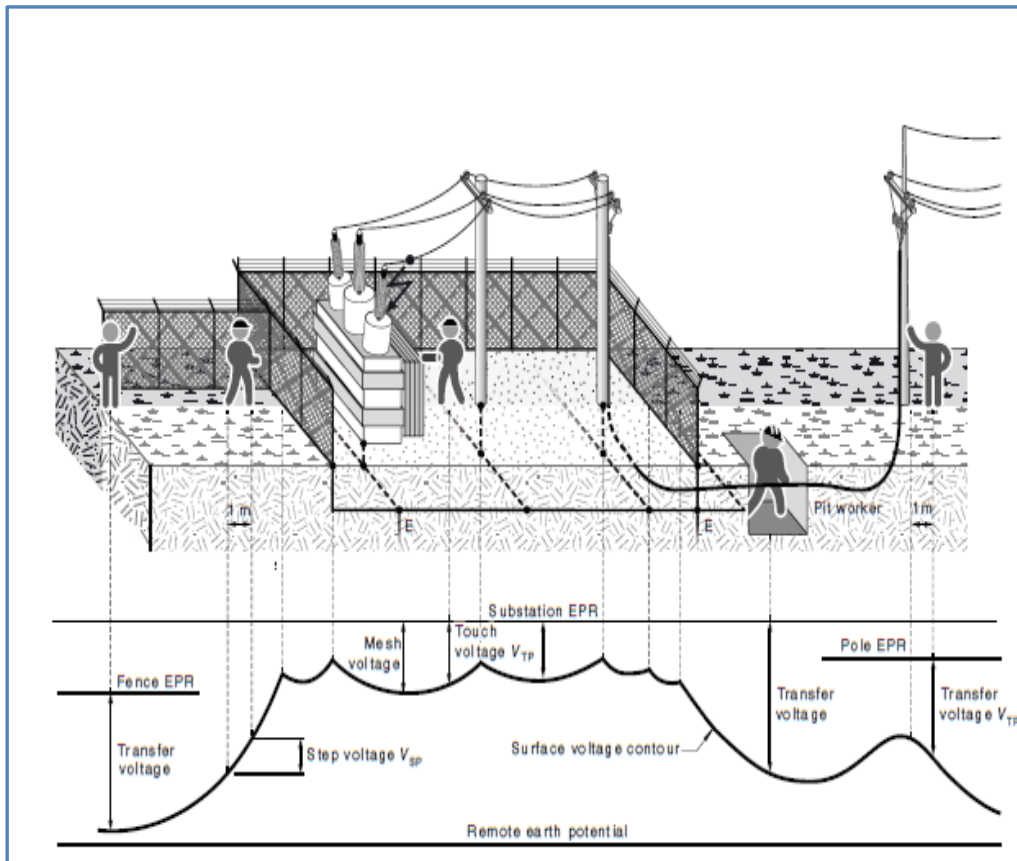
Generally design is to be based on Evoenergy's standard construction drawings. If design targets cannot be met other solutions may be considered by the designer to achieve compliance whilst adhering to the recommendations in this document.

All design work shall be reviewed and approved by an approved examiner and review and approval records included in the design documentation.

**FIGURE 1. PROCESS TO DECIDE IF AN EARTHING SYSTEM DESIGN IS REQUIRED**



**FIGURE 2. HAZARD SITUATIONS ARISING FROM A TYPICAL SUBSTATION EARTH FAULT (SOURCE: AS 2067)**





**FIGURE 3.** DESIGN MANAGEMENT PROCESS OVERVIEW (SOURCE: ENA-EG0)

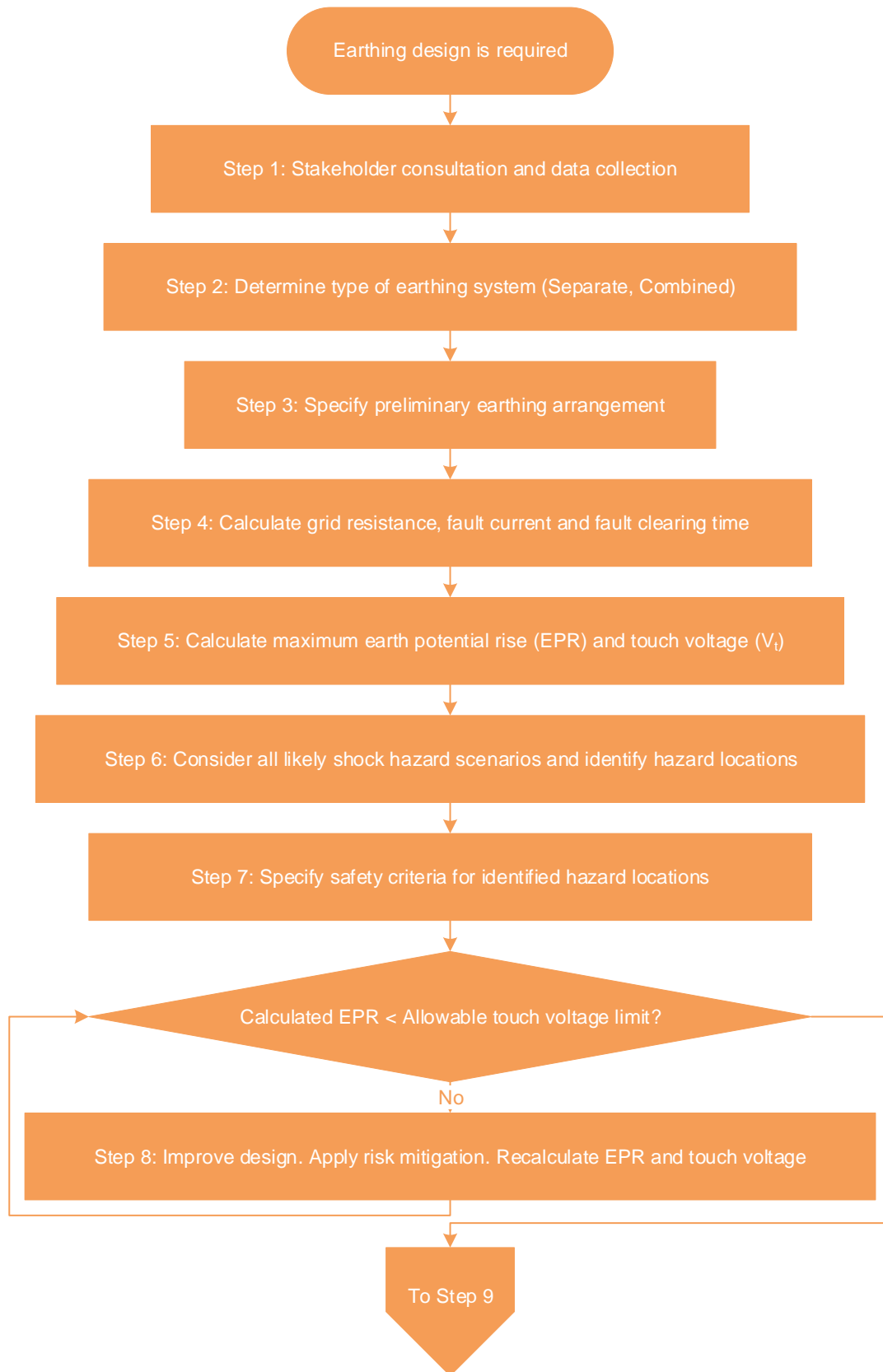


## 6.1 Power Frequency Design

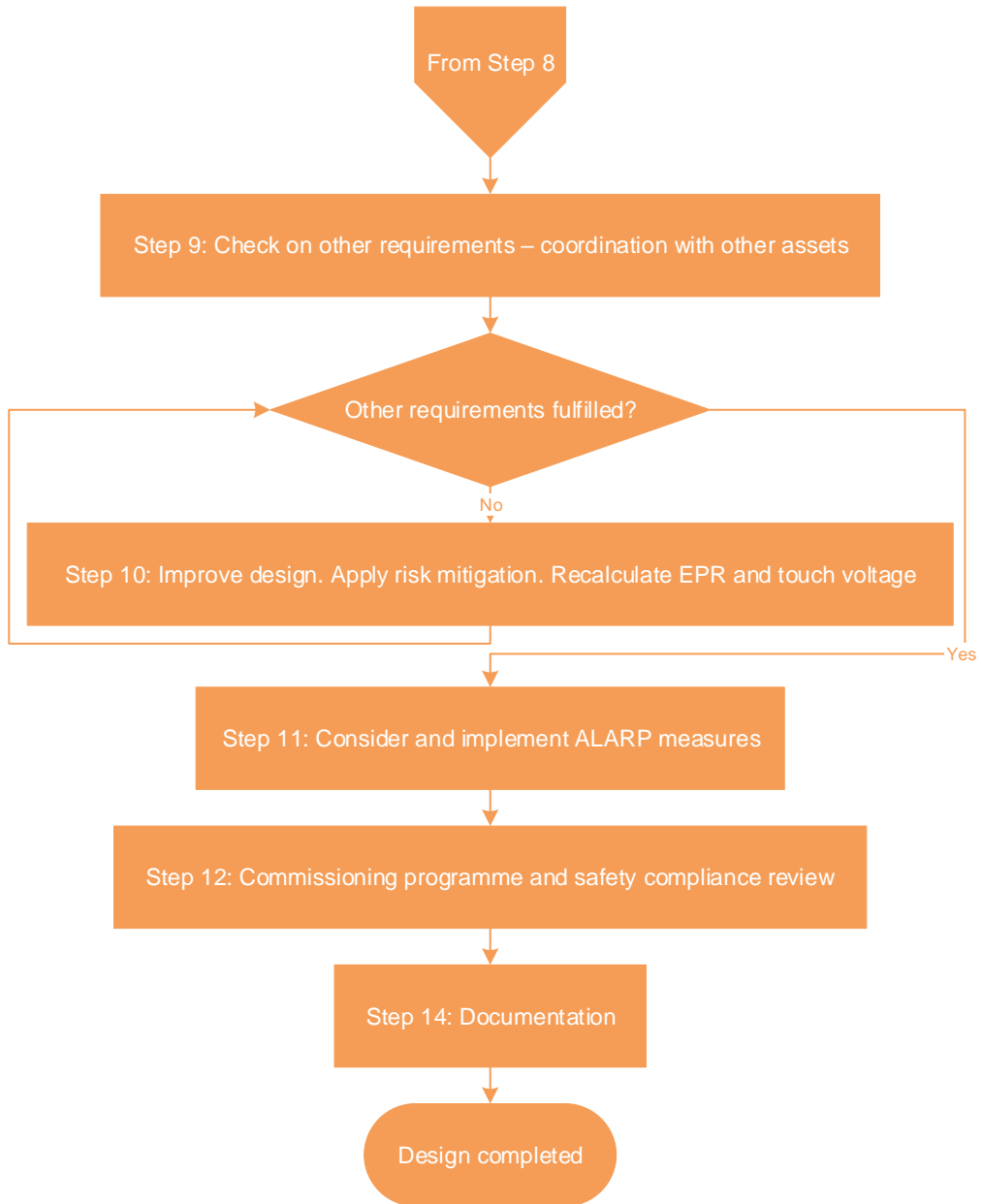
Power frequency earthing design deals with earthing of assets to manage hazards associated with fault voltages in the normal network operating frequency range (nominal 50Hz). The process for carrying out a power frequency design is outlined in Figures 4 and 5.

Power frequency design procedure steps 1 to 14 describes the various steps in further detail.

FIGURE 4. POWER FREQUENCY DESIGN PROCEDURE STEPS 1 TO 8



**FIGURE 5.** POWER FREQUENCY DESIGN PROCEDURE STEPS 9 TO 14



**Table 1.** POWER FREQUENCY DESIGN PROCEDURE STEPS 1 TO 14

STEP	PROCESS DESCRIPTION
1	<p><b>Stakeholder consultation and data collection</b></p> <p>Conduct joint site inspection with stakeholders (service delivery team, developers and other affected service providers). Site inspection is useful in checking for location of other services, site specific conditions and any constraints that may be imposed on the design. If these factors are not considered the final design may fail to comply. Collect pertinent data such as prospective earth fault current, fault clearing time, soil resistivity test results, location category, nearby infrastructure and Dial Before You Dig records.</p>

	Fault current contribution from embedded generation should not be ignored if network configuration supports earth fault current flow from these sources.
2	<p><b>Determine type of earthing system required – Separate or Combined (Section 7)</b></p> <p>Combined earthing is the preferred option. Also check configuration of existing interconnected substations (to a practical extent) and if justifiable include work to convert any separately connected substation to CMEN.</p>
3	<p><b>Specify preliminary earthing arrangement</b></p> <p>Distribution substation earthing arrangements are available from Evoenergy standard drawings.</p>
4	<p><b>Calculate grid resistance, fault current and fault clearing time (Section 8)</b></p> <p>The actual fault current will always be lower than the prospective fault current due to the additional series resistance of the earth grid (in parallel with the cable screen and other fault current return paths). Although a lower fault current produces a lower EPR the fault clearing time will increase and influence safety criteria selection.</p> <p>Confirm continuity of screen bonding to remote distribution substations before applying a screening factor.</p>
5	<p><b>Calculate maximum earth potential rise (EPR) and touch voltage</b></p> <p>The EPR is produced by the grid resistance and the proportion of fault current that flows through the grid. Touch voltage calculation is required at all identified hazard locations</p>
6	<p><b>Consider all likely shock hazard scenarios and identify hazard locations (Section 6.2)</b></p> <p>Consider all likely hazard scenarios; there could be others as well as those involving touching a pole or substation enclosure. Locations where many people congregate will require assessment of societal risk. A given location may present more than one hazard (e.g. touch voltage and transfer voltage).</p>
7	<p><b>Specify safety criteria (allowable touch voltage limits) (Section 6.2)</b></p> <p>Select safety criteria for all the hazards identified. Standard V/t (Voltage vs Time) curves from ENA EG0 should be used unless the hazard does not meet the conditions required for use of these curves. In this case ARGON may be used to work out safety criteria.</p>
8	<p><b>Improve design. Apply risk mitigation. Recalculate EPR and touch voltage</b></p> <p>If compliance to the selected safety criteria is not achieved at all locations implement mitigation measures to improve the design, recalculate EPR and touch voltage and re-assess. See Section 14 for typical mitigation techniques.</p>
9	<p><b>Check on other requirements – coordination with other assets</b></p> <p>Telecommunications and pipeline exposure and coordination - see Sections 8.7 and 8.8</p> <p>Lightning and other transients – see Section <b>Error! Reference source not found.</b></p> <p>Manage any likelihood of interaction of the earthing system with other buried services in the vicinity (e.g. corrosion issues)</p>
10	<p><b>Improve design. Apply risk mitigation. Recalculate EPR and touch voltage: See Step 8</b></p>

<b>11</b>	<p><b>Consider and implement ALARP (as low as reasonably practical) measures</b></p> <p>Consider further risk reduction options where implementation is practical, cost is not prohibitive and justifies the benefit gained. This is not a mandatory requirement but considered good and responsible engineering.</p>
<b>12</b>	<p><b>Construction support</b></p> <p>Resolve issues and discrepancies arising from design assumptions vs actual site conditions. Modify design if required to address constructability and safety issues that may arise.</p>
<b>13</b>	<p><b>Commissioning programme and safety compliance review</b></p> <p>As a minimum the resistance of the installed earth grid is to be tested and compared against design requirements. Steps shall be taken to redress instances where the measured value does not align with the design target. Steps include review of design assumptions, input data and calculations; validation of field test results. Final compliant data shall be recorded in City Works and Arc FM. Other tests, such as current injection testing, may be specified by the designer to manage particular risks or uncertainties identified during the design process.</p>
<b>14</b>	<p><b>Documentation</b></p> <p>Include description of physical installation (drawings and sketches, earthing schematics), design assumptions, constraints and decisions, calculated and measured earth resistance and soil resistivity data.</p>

## 6.2 Safety Criteria

A key element of risk based earthing system design is the correct selection of safety criteria against which the design risk level will be assessed.

There are three levels of risk, each covering a range of probability for fatality to humans as shown in Table 2

The safety criteria selected must be those that will result in a low or tolerable risk level i.e. an earthing design is considered acceptable if it meets the safety criteria that have been selected to deliver an outcome of low or tolerable risk.

Table 2. RISK CLASSIFICATION

RISK LEVEL	RISK MANAGEMENT
High or Intolerable risk	Must prevent occurrence regardless of costs
Intermediate or ALARP region (as low as reasonably practical)	Must minimise occurrence unless risk reduction is impractical and costs are grossly disproportionate to safety gained
Low or Tolerable risk	Risk generally acceptable, however, risk treatment may be applied if the cost is low and/or a normally expected practice.

Safety criteria selection starts with the identification of all possible hazards. Then each identified hazard is assigned a safety criterion for risk to an individual (termed individual risk, see Section 6.2.1) and, where applicable, a safety criterion for risk to a group of people (termed societal risk, see Section 6.2.2).

Safety criteria, as applied in earthing design, are generally associated with shock voltages. Shock voltage includes touch, step and hand to hand voltage. Touch voltage has a lower tolerable limit than step voltage and must always be considered in risk assessment. Where there is likelihood of hand to hand contact this must also be considered. Although the tolerable step voltage value is higher compared to the other types it may be the one with the highest contact rate scenario and hence present an overall higher hazard level (in terms of the likelihood of a fatality occurring). Where this is of concern risk assessment shall include step voltage hazard.

**It is a requirement that the identification of hazards and selection of safety criteria, including all assumptions made, be appropriately peer reviewed and approved. Record of this review and approval shall be included in project documentation.**

### 6.2.1 Individual risk safety criteria

Individual risk is risk involving a single person. The safety criterion or shock voltage target limit for individual risk can be derived using the guidelines in ENA EG-0 which describe two methods:

- Standard curves (case matching) method: Aligning the design to be undertaken with a published case and using the specified voltage/time curve (which was probabilistically derived) as the design safety criteria.
- Direct probabilistic method: Directly calculating the contact and fault event coincidence and fibrillation probability to derive a 'design specific' target voltage limit. Alternatively ARGON may be used to work out this limit

Method 1 should be adopted if it is applicable for the given situation. In this method the standard curves in Appendix B – Standard design curves created using ARGON, can be used to select risk target limits for typical locations as found in the distribution network. These curves plot fault duration against voltage limit that will produce an outcome of low or tolerable risk. Table 3 lists the conditions that apply for using these curves.

Table 3. – CONDITIONS FOR USE OF STANDARD TOUCH VOLTAGE LIMIT CURVES

LOCATION CLASSIFICATION	CURVE	COMMENTS	ASSUMPTIONS/CONDITIONS		
			Fault freq./yr	Contact Scenario	Footwear
Aquatic centre	AQ12	Contact with metalwork associated with an aquatic centre that operates 12 months of the year. Note :does not apply to residential type swimming pools	0.1	150 gatherings/yr 7 contacts/person/yr per gathering Contact duration: 2s <43 persons	None
MEN	TDMEN	Contact with MEN connected metalwork ((e.g. household taps) where MEN or soil is affected by distribution assets	0.1	MEN-2000 contacts/yr for 4 sec	Standard

<b>Residential backyard</b>	TDB	Contact with metalwork in a backyard affected by distribution asset. (e.g. metallic fence near a substation)  Note: Does not apply to commercial installations or to direct contact situations involving Evoenergy's distribution asset (e.g. substation). See DU below	0.1	Backyard- 416 contacts/yr for 4 sec	Standard
<b>Urban interface</b>	DU	Contact with distribution asset in urban interface location (e.g. substation)	0.1	135 contacts/yr for 4 sec	Standard
<b>Remote</b>	N/A.	Ensure earthing gives enough current for protection operation	0.1	Less than 60 off (4 sec) contacts for 1 sec fault duration, or less than 75 off (4 sec) contacts for 0.2 sec fault duration	N/A

In situations where the default conditions for method 1 above cannot be satisfied method 2 must be used..

Examples of scenarios where method 1 cannot be used include:

- The default fault rate assumed in a standard curve does not match that experienced at the given location
- Where people could likely gather in the vicinity of an Evoenergy asset such as a substation or a conductive pole
- Construction or development sites exposed to EPR events or transfer voltage hazards.
- Earth fault events involving Zone substations.

Method 2 involves working out the risk target limit manually or by using ARGON.

### 6.2.2 Societal risk safety criteria

Societal risk is the perceived risk of an earth fault event causing multiple simultaneous fatalities at one location.

A convenient method for specifying safety criteria for societal risk is by inspecting 'F-N' curves developed using ARGON. These curves plot the probabilistic frequency, F, of a given number, N, of fatalities for a given shock voltage value, population size, fault rate and contact scenario. The selected safety criterion (i.e. shock

voltage value) will be one that results in a probabilistic frequency of occurrence, F, less than  $1 \times 10^{-6}$  for a single fatality (N=1). See Figure 7.

ARGON requires the following input parameters for developing societal risk safety criteria:

- Population size. A reasonable allowance must be made for population size to reflect future growth, changes to land use etc. (e.g. development of a residential site in the vicinity).
- Contact rate and duration,
- Fault rate and duration
- Footwear
- Surface layer resistivity

### **6.2.3 ARGON – ENA’s safety risk assessment software**

ARGON may be utilised to develop custom curves and select corresponding safety criteria where standard curves cannot be used to select individual risk safety criteria. It can also be used for societal risk assessment and for working out the coincidence of probability, P<sub>coinc</sub>, for a given set of operational and environmental conditions.

For selection of safety criteria for individual risk ARGON requires user input of:

- Annual earth fault rate and average duration per earth fault,
- Annual contact rate and average duration per contact.
- Footwear type
- Surface layer resistivity

ARGON uses default values for footwear type (standard) and soil surface layer resistivity (50Ω.m). These can be over-written to suit site specific conditions.

Values for fault rate and duration are best obtained from system records. Appendix D – 'Evoenergy distribution network fault rate and duration' provides a table of values for Evoenergy’s distribution network.

Examples of risk assessment using ARGON for individual and societal risk are shown in Figures 6 and 7.

### **6.2.4 EPR limits for telecommunications and metallic pipeline services**

In addition to meeting individual and societal risk safety criteria as above the design must also comply with EPR limits for telecommunications and shock voltage limits for metallic pipeline services. Refer to Sections 8.7 and 8.8.



FIGURE 6. – ARGON RISK ASSESSMENT EXAMPLE – INDIVIDUAL RISK

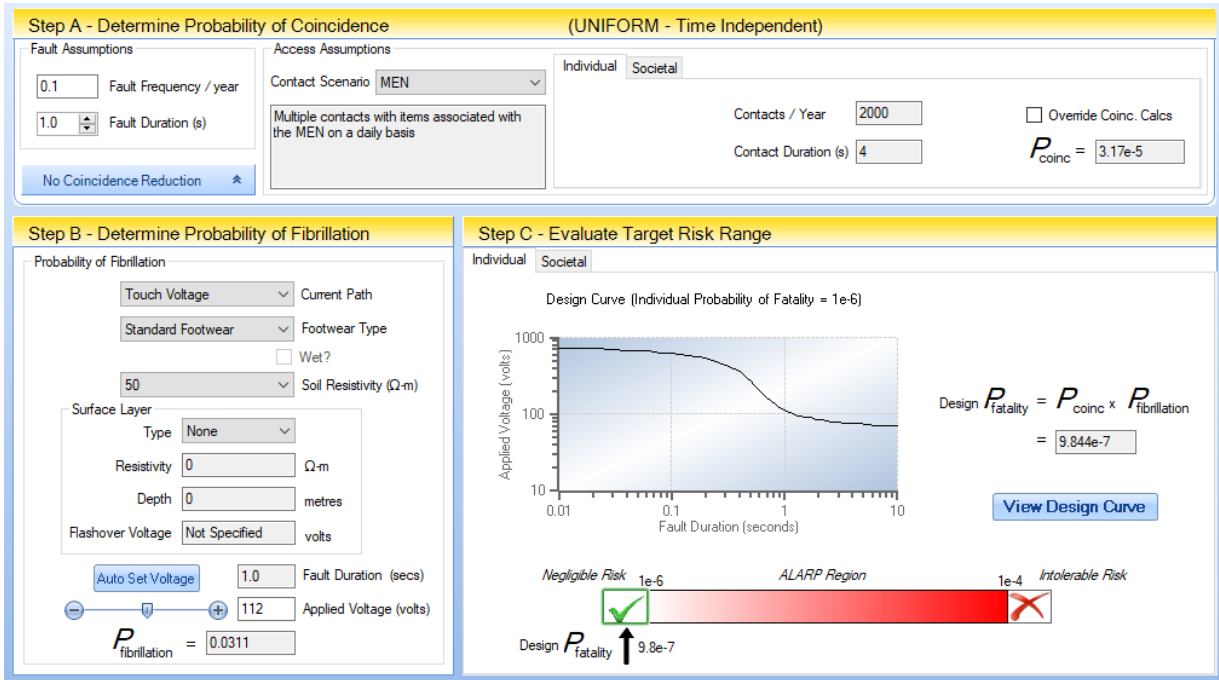
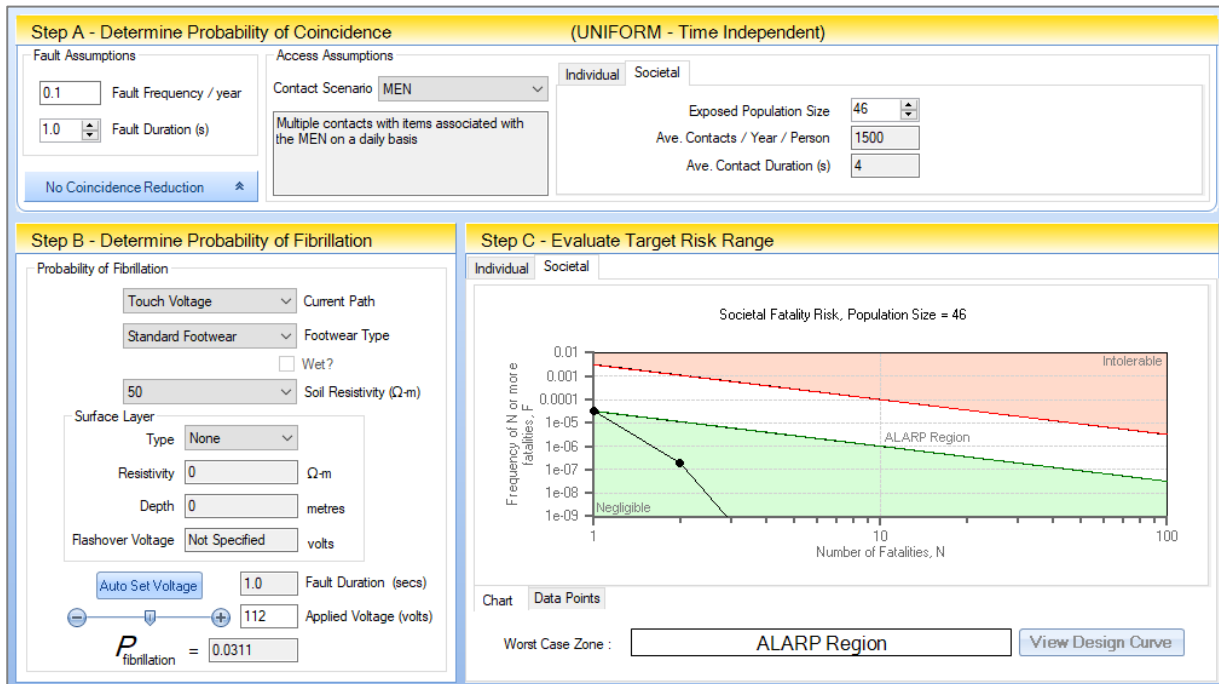


FIGURE 7. – ARGON RISK ASSESSMENT EXAMPLE – SOCIETAL RISK (F-N CURVE)



## 7. DISTRIBUTION EARTHING SYSTEMS

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### 7.1 Low Voltage Multiple Earthed Neutral (MEN) System

The MEN system relies on a large number of low impedance earths on the LV neutral to ensure a low EPR for earth faults. To achieve a low resistance between the neutral and ground, the low voltage neutral in a MEN system is earthed at the following locations:

- the LV neutral terminal of the transformer
- the end of radials (main cables)
- service pillars and pits
- LV only conductive pole.
- switches (link pillars or disconnect links on poles)

Note that there is a neutral bond and an earth stake at each conductive LV pole. Also, inside the customer's installation, the neutral conductor is connected to a local earth at the customer's switchboard (MEN link). Consequently, all metalwork of appliances, tools etc. are also connected to the low voltage neutral. It is therefore essential that the neutral conductor be kept at, or close to earth potential to ensure electrical safety during earth faults.

Traditionally generic target resistance values were specified for low voltage earthing. Such values no longer exist and earthing systems shall be designed in compliance with the risk based approach.

### 7.2 Common Multiple Earthed Neutral (CMEN) System

The Common Multiple Earthed Neutral System (CMEN system) is an extension of the MEN system whereby the low voltage neutral conductor (and hence the low voltage earthing system) is considered to be of low enough resistance to remote earth that the high voltage earthing system (transformers, zone substations, poles carrying exposed metalwork etc. capable of being energised at high voltages) is allowed to be connected to it. The CMEN system is sometimes referred to as a 'bonded' or 'common' earthing system as the high voltage and low voltage earthing systems are bonded together. The CMEN system uses the low voltage neutral conductor as the return path for both low and high voltage fault currents. A very low resistance to earth for the neutral is required to ensure HV fault currents do not cause unacceptably high voltages on the LV network.

As a minimum the conditions required for creating a CMEN system are:

- a combined earth grid resistance of less than  $1\Omega$  before connecting to the MEN network

AND

- a **minimum** of three transformers with LV neutral interconnected

The three transformers connected must have a large number of earths (typically more than 100 electrodes including pillars, conductive poles and customer electrodes).

Chamber substations are always configured as CMEN. The implication is that the earthing resistance of a chamber substation must be sufficiently low to meet the safety criteria for all hazard scenarios associated with the substation. Of particular concern are touch voltages at MEN items. The decision to install a chamber substation may be overruled if these risks cannot be managed to acceptable levels. Alternatives such as installing a separately earthed padmount substation should be considered.

CMEN should only be considered in Dense MEN areas. In high load density areas, conditions generally allow a CMEN system. In many cases, the use of CMEN reduces overall EPR and touch voltages to low values. However, there are some situations where the application of CMEN needs to be considered carefully.

CMEN transfers a large proportion of EPR for all events that impact the HV substation to the local MEN. Consequently, metallic objects some distance away from the distribution substation may have hazardous touch voltages present. For example 132kV earth faults at Zone Substations that are downstream bonded to

nearby distribution substations may cause excessive EPR on the LV MEN. Consequently, downstream bonded distribution substations close to Zone Substations may require separate earthing. Overhead areas with Sparse MEN should not be bonded to the Zone substation earth mat. However, where there are a number of distribution substations in Dense MEN areas it is advisable to connect the distribution earth to the Zone substation earth mat using the HV cable screens. In this case, the resistance to earth is low and EPR from 132/66kV fault currents is expected to be low.

This transferred EPR also causes ground voltages to be elevated for extended distances. If telecommunications pits are close by, then it is recommended that CMEN is avoided if substation EPR cannot be limited to below 430V.

CMEN should be avoided in the following situations:

- Sparse MEN areas
- HV earth faults cause higher than allowable EPR for 3rd parties such as telecommunications and metallic pipelines

Evoenergy's 11kV overhead line network does not have a conductor that can be earthed or that provides earthing continuity along the line. Hence it is not possible to interconnect HV earths of distribution substations connected to this overhead line network to drive the overall HV earth resistance to an adequately low value. It is likely that distribution substations supplied by an overhead line feeder will not be suitable candidates for CMEN.

Excluding chamber substations, sites configured as CMEN should be able to be reconfigured to a separate earthing arrangement by only removing the CMEN link. In this arrangement HV earthing must not impact LV earthing assets. This requires insulating the first span of the HV earth conductor.

### **7.3 Separately Earthed System**

In cases where the conditions required for CMEN earthing set out in the previous section cannot be met, the high voltage earth must be kept separate from the LV MEN system. Typically this would occur in sparsely populated areas such as rural areas with low load density and Sparse MEN. Separation is required to ensure high voltage earth faults, lightning impulses or switching surges (e.g. conducted to earth through surge arresters) do not cause excessive EPR on the LV system.

It is important to provide adequate separation between HV and LV earthing systems to prevent coupling a HV EPR through the soil.

Separate earthing may be the preferred, technically acceptable and cost effective option in the following situations:

- Sparse MEN areas; avoid CMEN in sparse areas even if it can be established that it is possible to achieve the required earth resistance with common earthing. This is to provide a safety margin to address instances where a few MEN points may be removed from the system due to a variety of causes.
- Where the assessed touch voltage at an MEN item due to the substation EPR as a result of a remote 132kV Zone Substation fault exceeds AS2067 TDMEN or AQ12 safety criteria; generally at substations upstream bonded to Zone Substations (within 2km)
- Close to swimming pools
- HV earth faults cause higher than allowable EPR for 3rd parties such as telecommunications and metallic pipelines
- Substations connected to a predominantly 11kV overhead line feeder
- HV earth faults or transferred 132kV earth faults cause higher than allowable EPR for 3rd parties such as telecommunications and metallic pipelines.

Separately earthed systems shall be designed to facilitate converting to CMEN with minimal additional work in the future when conditions permit.

## 8. EARTHING DESIGN PARAMETERS

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The following sections discuss parameters used for earthing system design of the distribution network.

### 8.1 Soil Resistivity

A good earthing design which truly reflects actual site conditions and soil parameters will produce results which align with site measured values (provided construction is completed in accordance with design layout drawings and instructions). The EPR profile developed by this design can be relied on to assess the various safety criteria with confidence. Project delays and cost of site rectification work are also avoided if the design work is carried out correctly.

Soil resistivity values are used to develop soil models in earthing system design. It is important to ensure that tests carried out to obtain these values are performed correctly as the soil models derived from these have a significant influence on design outcome.

Existing database records may be used if these are from at least two test sets with similar results and the tests have been conducted within the last 5 years. The most conservative set of soil resistivity test results shall be used for purpose of designing the proposed earthing system.

A soil resistivity test should be requested by the designer if no useful data is available from the existing database. This information should be added to the soil resistivity master database for future reference by other earthing design projects.

Testing after recent rainfall should be avoided. Incorrect readings and inaccurate or erroneous values should be identified and eliminated. Refer to **Earthing Construction Manual**.

### 8.2 Earth Electrodes

Preliminary design is carried out based on Evoenergy standard drawings applicable to the asset. If the target earthing resistance value cannot be achieved with the standard arrangement design revision is required. This includes varying the electrode count, spacing and lengths.

Two types of earth electrodes may be used. These are:

- Vertically driven rods are used where site conditions permit installation and where deep soil penetration is not required to achieve the target earth resistance value. The rods are interconnected with horizontal bonding conductors. The first span of the horizontal bonding conductor is always insulated. Subsequent horizontal spans are of bare conductor unless there is a need to control the EPR zone to minimise its influence on other buried services in the vicinity. Copper clad steel rods used as driven earth electrodes are typically 12.5mm in diameter and 1440mm long. Rods can be extended by coupling the ends if required for deeper soil penetration.
- Drilled earth rods may be considered in situations that do not permit installation of driven electrodes (due to soil condition, availability of space) or design calculations indicate it is more beneficial to probe to greater depths. A drilled electrode constitutes a 70mm<sup>2</sup> hard drawn bare copper conductor installed in a 75mm diameter hole filled with earthing compound

Vertical electrodes should be positioned to optimise their utilization by minimising the proximity effect. It is recommended that the separation between rods be at least one rod length.

Influence of adjacent installed earthing must also be considered when selecting earth electrode location.

The designer must ensure the placement of HV earthing does not allow coupling to LV earthing assets. ENA recommend a minimum 4 m separation between LV and HV earthing infrastructure. The designer must specify a revised value if greater than 4m separation is required between the two earthing systems to avoid coupling. Note that assessment of optimal electrode separation is part of the design process.

### 8.3 MEN Earth Resistance

MEN earths can deliver a significant reduction to the overall earth resistance of the connected asset (substation, pole etc.) when connected in parallel.

In an established suburb one feeder may have 20, 30, 40 or 50 lots connected. It is necessary to have a number of distribution substations paralleled to get low enough resistance to earth for CMEN.

A new greenfield development is not expected to deliver the required MEN resistance reduction due to the limited number of residential lots i.e. interconnected MEN earths. Hence substations installed during the early stages of greenfield development should be configured as separately earthed. These substations must be converted to CMEN when the opportunity presents itself, namely when sufficient lots have been established and connected to the MEN system.

It is recommended that all separately earthed substations that are candidates for future conversion to CMEN by the reasoning outlined above be assessed periodically for conversion to CMEN. Earthing system design must include checking the configuration of upstream and downstream connected substations (to a reasonable extent) and including, if appropriate and justifiable, work to convert separately earthed substations to CMEN.

## 8.4 HV Earth Resistance and cable screening factor

Interconnecting HV earths of several distribution substations by means of HV screen bonding or via dedicated aerial earth conductors (the latter is not standard Evoenergy practice) will contribute to a reduction in the connected substations' HV earth resistance. The extent of reduction depends on the number of interconnected substations, cable length and screen characteristics.

In addition to the reduction in HV earth resistance obtained by interconnecting several HV earths as above further reduction is possible by providing a direct earth connection, via 11kV cable screen bonding or other continuous conductor, between the distribution substation and source zone substation earth. Under this arrangement a portion of the earth fault current will flow back to source through the interconnected earth bond and not contribute to EPR at the local earthing system. The reduction in local earth resistance is substantial with this arrangement as the zone substation earth resistance is very low. See also Section 8.5

Therefore it is reasonable to apply a screening factor to obtain a reduced value for the current actually flowing into the local earth grid where there is cable screen bonding. The screening factor is the proportion of the total earth fault current actually flowing into the distribution substation earthing system, the remainder returning to source through the 11kV cable screens (directly or via other interconnected substations).

Where there is uncertainty in specifying a screening factor a value of 1 should be used (i.e. all fault current is assumed to flow into the local earthing system). Note that this will result in an overly conservative design.

It is important to note that if any part of the interconnected bonding arrangement changes at some stage the assumed screening factor will be affected. Causes for bonding arrangement changes over the lifetime of the installation include:

- Removal of an HV screen interconnected distribution substation
- Changes to the network that affect continuity of the bond e.g. conversion from overhead to underground and vice versa

**Any proposed work (construction, re-development, asset removal or relocation etc.) that involves changes to existing earth bonding infrastructure must consider the impact this will have on the earthing system of the connected assets.**

## 8.5 11kV Cable sheath bonding at 66kV and 132kV Zone Substations

As discussed in Section 8.4 Evoenergy practice is to bond HV cable screens to earth bars at Zone Substations and to earth bars at all distribution substations along the underground cable route in order to reduce system earth resistance as much as possible. The risk of an EPR at the Zone Substation due to a 66kV or 132kV earth fault being transferred to remote earths of connected distribution substations and other assets such as RMUs and U/G-O/Hs must be investigated and managed as part of the design process.

The magnitude of transferred zone substation EPR at any given downstream cable screen bonded asset depends on several factors including the effective resistance of the combined earthing system at the asset end. It follows that all assets with cable screens bonded to the source zone substation earth must undergo a transfer potential risk assessment to ascertain hazard levels (touch, transfer, telecommunications and metallic pipeline services coordination) using the most onerous safety criteria appropriate for the location.

Where a U/G-O/H transition is the first asset installed on an underground feeder that exits from a zone substation the associated HV cable screen shall not be earthed at the U/G-O/H end. This is to avoid transfer of potentially dangerous levels of zone substation EPR onto the U/G-O/H earthing system.

## 8.6 Earth Fault Level and Clearing Time

In general Zone substation primary protection relay clearing time is to be used for fault duration when assessing safety hazard risk. Where it is reasonable an available upstream protection device before the Zone substation relay may be used. This is the case for pole mounted substations with drop-out fuses and for assets supplied through reclosers. Ground mounted substations are not suited to this approach as a line side earth fault (upstream of the fuse) in the enclosure, is more likely to establish direct contact with the substation earth grid via the enclosure body. Zone substation protection relay clearing times must be used for ground mounted substations.

Checks must also be made to confirm that there is adequate fault current flow with all impedances accounted for in the earth fault loop (including calculated earth system resistance) for protection device pickup.

Note that both magnitude (hence EPR) and duration of fault current contribute to risk. It is possible to have a higher risk with lower fault current magnitude but requiring longer clearing time (duration). Fault levels and protection relay clearing times provided by Secondary Systems typically assume zero earth grid resistance. At distribution substation level earth grid resistance values may be of the same order as source fault impedance values. In this case the actual earth fault current with the earth grid impedance in the loop may be significantly lower than the value initially provided to the designer. For this reason it is important to recalculate the fault current with the substation earth grid resistance in the fault loop and ascertain ensuing fault clearing time for the appropriate fault protection device. These values must be used to derive safety criteria for risk assessment.

Values for earth fault levels and clearing times must be obtained from Secondary Systems Section at the time of design. These values should include an allowance for any anticipated permanent changes to the network configuration, system growth etc.

## 8.7 Accessible Metalwork

The general requirement is to ensure that any accessible metalwork (i.e. conductive surface able to be touched by persons) does not become a touch hazard. Accessible metalwork includes:

- operating handles for air break switches and conductive cable guards on poles
- equipment cabinets including metallic street light boxes and multi-unit point of entry metallic cabinets

## 8.8 Earth Surface Potential at Distance from Earth Electrode

For earthing design it is necessary to know the earth surface potential gradient around a hazard location in order to work out touch and step voltages. The earth surface potential at a distance from the earth electrode or grid is also required to assess risk to other services or objects (such as telecommunications and buried pipeline) and persons touching these objects. These objects may or may not be intentionally connected to the earth electrode.

Earthing system design typically determines voltages at the following conductive objects a distance from the earthing system:-

- Telecommunication's equipment (see Section 8.8)
- Buried metallic pipeline (see Section 8.9)
- Street light or traffic light cabinet
- Car park ticket machine
- Streetlight or traffic light column
- Bus stop

- Rail infrastructure
- Metal fence
- Playground equipment

For electrical safety it is important to maintain adequate separation between electrical installations and close by objects. Drawing 3832-018, Separation and Cover Requirements for Cables and Plant, provides conservative minimum separation distances. This document is useful for planning purposes and as a first pass assessment of required separation. However, more accurate separation distances must be calculated when required, for example, to check that earthing design meets limits for telecommunication assets or buried conductive pipeline .

Simplified empirical formulae may be used to calculate the earth surface potential gradient and touch and step potentials at a given distance from the earth electrode or grid for simple symmetrical earthing arrangements. Non-symmetrical or more complex arrangements generally require computer programs that use advanced finite element earthing analysis algorithm for more rigorous modelling and simulation of earthing system parameters.

Objects electrically bonded to the distribution substation earthing system must be assessed as part of the earthing system. Generally, connecting other metallic objects to the earthing system will reduce the earthing resistance but could also extend the hazard zone, for example grading rings.

It should also be recognised that buried metallic pipelines and fences can transfer the local earth surface potential to locations at the remote end of the pipeline or fence. This can happen even if the object is not directly connected to the earthing system. Hence particular attention must be made to the presence of metallic fencing or buried pipeline in the vicinity and measures taken to prevent transfer potential hazard.

Possibility of interference with cathodic protection systems on buried metallic pipelines and low frequency induction into telecommunications circuits and railway signalling systems should, if applicable, be investigated and accounted for in the design.

## 8.9 Telecommunications EPR Limits

EPR hazard voltage limits for telecommunications personnel and equipment during an earth fault on the power system are specified in AS/NZS 3835.1 'Earth Potential rise – Protection of telecommunications network users, personnel and plant'. AS/NZS 3835.1 provides guidance on allowable EPR at telecommunication assets.

Per AS/NZS 3835.1 the EPR for telecommunications circuits depends on the reliability category of the electricity network and maximum fault clearance time. Compliance to this standard's Category C requirement for an EPR limit of 430V is recommended for all Evoenergy 11kV assets unless it can be confirmed that a clearing time of < 0.5 seconds can be achieved for a fault at the asset considered and it is a ground mounted asset. In this case AS/NZS 3835.1 Category B requirement for an EPR limit of 1000V may be used. .

Note: In some situations telecommunications circuits are exposed to voltage stress from both power system EPR as well as due to induced voltage if the telecommunications circuit and power line follow a parallel path in close proximity. In these cases the allowable EPR will be lower than indicated in Table 9. A separate assessment to account for induced voltage effect is required and the EPR limit adjusted accordingly.

## 8.10 Metallic Pipeline Touch Voltage Limits

AS/NZS 4853 'Electrical hazards on metallic pipelines' provides detailed methodology for risk assessment of electrical hazards for persons in the vicinity of pipelines and pipeline equipment in the field. The hazards covered are those caused by EPR and LFI. Risk associated with EPR is of direct relevance to this earthing design manual though in some instances the effect of LFI on touch voltage needs to be considered also as described in AS/NZS 4835,

AS/NZS 4853 describes three levels of risk assessment for buried metallic pipeline and pipeline equipment. For purposes of assessing safety risk for pipeline and pipeline equipment located in the Evoenergy network level 2 risk assessment as specified in AS/NZS 4853 will be adopted. Level 2 risk assessment involves compliance with pre-determined touch voltage limits for the various contact scenarios at the location. These touch voltage limits are reproduced in Table 5. Touch voltage limits shown in this table assume a fault

frequency of 2 per year and fault duration of 1 second. If these conditions cannot be satisfied for the given scenario and location customised voltage limits have to be developed using ARGON.

Assessment involves identifying the various contact scenarios at the location and checking that the calculated touch voltage is below the applicable limit for each scenario.

Table 4. – METALLIC PIPELINE TOUCH LIMITS (FROM TABLE 4.6 OF AS/NZS 4853-2012)

AFFECTED PERSON	PIPELINE CONTACT SCENARIO	CURRENT PATH	VOLTAGE FOR TOLERABLE RISK (VOLT)
Public	Regulator metallic pit lids	Step	≤ 1700
	Scour or air valve	Touch	≤ 120
	Air valve in playgrounds, sporting fields etc.	Touch	≤ 50
	Houses (as per ENA EG-0 TDMEN)	Touch	≤ 80
Pipeline operators	Gas valve operation	Touch	≤ 70
	Water valve operation	Touch	≤ 58
	CP test point inspection	Touch	≤ 75
Construction Worker	New gas pipeline	Touch	≤ 110
	Tee-off from long exposed pipe	Touch	≤ 110
Maintenance worker	Leak repair on water pipe	Touch	≤ 95
	Leak repair on gas pipe	Touch	N/A (low risk)

## 8.11 Low Voltage Earthing

Local LV faults at the substation mostly result in a direct return of fault current to the transformer neutral without going through the earth medium. Faults in the LV MEN network external to the substation use the low impedance return path provided by the neutral conductor. In both cases it is reasonable to expect the fault current to be adequate for protection to clear a fault within 5 seconds.

Notwithstanding the above an LV earth is required at the substation for connection to the transformer neutral. Evoenergy standard practice is to earth transformer LV neutral direct to earth at the distribution substation using a single electrode as shown in Evoenergy construction drawing.D303-0011.

A minimum LV earth resistance of 15Ω is required.

LV earth shall be separated from HV earth by at least 4 meters. The actual separation required has to be assessed during design to prevent LV earth potential rising to an unacceptable level under the influence of an EPR associated with a HV fault event.

## 8.12 Lightning and Other Transients

Lightning is a source of hazard to people and plant. Lightning over-voltages and currents can travel a long way through overhead lines and affect personnel working on the connected network.

It is impractical to provide adequate protection to personnel in the form of earthing and equipotential bonding during lightning conditions because lightning surges typically have high current magnitude and rate of rise. All personnel should stop handling all conductors including those associated with any earthing system until



the lightning hazard has passed. Guidelines exist regarding managing staff risk to lightning for such circumstances (refer to AS/NZS 1768 flash to bang time limits and personal/group early warning systems are available).

Lightning protection earth may be bonded to the local electricity supply earth (substation earth, MEN earth etc.) that is in close vicinity to create an equipotential bond between the two services. It is a condition that the independent lightning protection earth meets the impedance target in AS/NZS 1768 before connecting to Evoenergy's earth. As required in AS/NZS 1768 the risk of galvanic corrosion to the lightning earth electrode must be considered before connecting to Evoenergy's earth where stray DC current may be present.

Earthing is required for surge arresters to ensure correct operation. Typically a low inductance down lead and an earthing resistance of 30ohms is required for surge arresters. It should also be recognised that faulty surge arresters can allow significant leakage current into earthing systems. Depending on the situation, significant EPR, touch and step voltages can occur. Appropriate operating procedures and protective equipment is required for personnel working in close proximity to surge arresters.

## 9. MATERIALS AND SIZING

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### 9.1 Introduction

The earthing system including all components (e.g. conductors, rods and connectors) shall be capable of safely and reliably conducting backup fault current for the operational life of the distribution asset. The earthing materials shall be chosen to ensure they are adequately thermally rated, mechanically robust and able to withstand the effects of corrosion. All earthing materials shall be Copper, Stainless Steel or Brass. Lugs to be used for earthing shall not be aluminium shear bolt lugs.

### 9.2 Bored Earths

Bored earth electrodes are used in HV and LV earthing systems. Each electrode comprises 70mm<sup>2</sup> hard drawn bare copper installed in a 100mm diameter hole which is back filled with earthing compound. The nominal length of the electrode is 20m. Selection of actual lengths, quantity and disposition of the electrodes to be installed forms part of the earthing design process.

### 9.3 Driven Stakes/Rods

Vertical driven copper clad rods may also be used in certain earthing systems. Typical use of earth stakes in standard construction includes;

- Connection to grading rings of padmount substations and other ground mounted equipment
- Local earthing at conductive inline poles
- Pillars and service pits

Unless otherwise stated driven rods are to be minimum 12.5mm diameter copper clad or plated steel, 2.4m long. Copper cladding\plating to be minimum 250µm thick.

### 9.4 Conductors

Copper is to be used for all earthing conductors. Unless otherwise stated, the minimum size for earthing conductor is 70mm<sup>2</sup> (19/2.14mm) copper. The buried insulated section required to connect onto the top of bored electrodes shall be black insulated minimum 70mm<sup>2</sup> copper.

Table 6 gives ratings for bare and PVC insulated 70mm<sup>2</sup> copper conductor at different fault durations. Where the calculated fault current exceeds the rating shown in this table a larger conductor size is required. This size may be worked out using formulae in AS/NZS3000.

Table 5. CABLE FAULT CURRENT RATINGS

CABLE	2 SECOND CURRENT RATING	1 SECOND CURRENT RATING
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	AMP	AMP
70mm <sup>2</sup> Cu bare	8414	11900
70mm <sup>2</sup> Cu insulated	6731	9520

For bare cable connections to rods and bored electrodes in corrosive soils, the cables should be laid in earthing compound to prolong their service life.

## 9.5 Connectors

The preferred connection method for cable is crimp connectors. U bolts are to be used for connecting cable to earth rods.

## 9.6 Labels

Warning labels are required for all padmount and ground mounted plant (not for poles) earthing cables as below:

- Warning - NOT to be disconnected unless supply is isolated.

The substations shall be labelled with the type of earthing (CMEN or separate) as requested by the designer.

All earth tails entering the padmount substation and the CMEN bond must be labelled at their termination. This includes HV or LV electrode, grading ring, earth mat and CMEN bond.

## 10. DESIGN RECORDS

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Records must be kept of:

- design assumptions and calculations
- results of site tests carried out to verify target values for the earthing system at each site

Ensure layout and dimensional details showing the full extent of the installed earthing system are captured in 'dial before you dig' and as-built drawings. Note that earthing systems generally extend beyond the aboveground footprint of the asset.

Earthing design data should be entered against the specific asset in City Works and ArcFM. Required data includes:

- Substation identification
- Earthing configuration - CMEN or separate earthing
- Soil resistivity test results
- Risk assessment and safety criteria selection; assumptions made
- All earthing parameter and design values (soil resistivity, fault level and clearing time, earth resistance target)
- Measured values of HV and LV earth resistance
- Current injection test results for EPR and touch voltage profiling
- Record of approvals

Such information is required for ongoing condition monitoring, maintenance and future reference.

## 11. REQUIREMENTS FOR SPECIFIC OVERHEAD INSTALLATIONS

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### 11.1 Introduction

This section provides earthing requirements for specific overhead installations. Minimum separation from nearby objects to earthing systems shall be as per drawing 3832-018, unless a detailed design indicates closer separation is compliant.

For pole mounted HV equipment that may be operated from the ground, the following electrical safety limit curves apply:

- AQ12 safety limit curve in special locations near water recreation areas
- TDMEN safety limit curve in special locations not near water recreation areas
- TDB safety limit curve in all other locations.

The design effort should always consider options to implement a CMEN solution. It is recommended that CMEN earthing arrangement be adopted for conductive poles with combined use plant (HV and LV) where possible. CMEN must not be installed if the combined earth resistance cannot be brought sufficiently low to meet applicable safety criteria.

### 11.2 Separately Earthed Pole Mounted Transformer

Two separate and distinct earthing systems shall be provided if the requirements for CMEN cannot be met.

The high voltage earthing system consists of bonding the following:-

- transformer tank and high voltage surge arresters
- conductive pole (e.g. concrete or steel)
- any metalwork associated with the HV system
- metallic cable guard
- HV earthing electrode/s.
- grading ring (if installed)

The low voltage earthing system consists of bonding the following:-

- low voltage neutral of the transformer
- low voltage neutral cables
- low voltage surge arresters

The low voltage earthing system is insulated from conductive poles (e.g. concrete, steel) and must be kept separated from the HV earthing system. Minimum requirement is double insulated cable enclosed in UV resistant PVC conduit.

The LV earth lead to the top of the bored LV earth electrode shall be PVC insulated (or similar) and the high voltage and low voltage earthing electrodes shall be separated by a minimum of 4m. Minimum depth of cover over earthing electrodes is 450mm.

### 11.3 CMEN Pole Mounted Transformer

For a CMEN pole mounted transformer, the earthing system shall have the following connected to it:-

- transformer tank and any high voltage surge arresters
- low voltage neutral and any low voltage surge arresters
- conductive pole (e.g. concrete or steel)
- any metal work such as cable sheaths

- local earthing electrode system
- grading ring (if installed)

### **11.4 Pole Mounted Recloser**

For a pole mounted recloser, the earthing system shall have the following connected to it:-

- recloser tank and any high voltage surge arresters
- control cubicle
- conductive pole (e.g. concrete or steel)
- any metal work
- local earthing electrode system
- equipotential mat (if installed)

Earthing design must comply with requirements for HV conductive in-line poles.

### **11.5 Pole Mounted Gas Switch**

For a pole mounted gas switch, the earthing system shall have the following connected to it:-

- switch tank and any high voltage surge arresters
- control cubicle
- conductive pole (e.g. concrete or steel)
- any metal work, cable sheaths and metallic cable guards
- local earthing electrode system
- grading ring (if installed)

Earthing design must comply with requirements for HV conductive in-line poles.

### **11.6 HV U/G-O/H Pole**

For pole mounted underground-overhead terminations, the local earthing system shall have the following connected to it:

- Surge arresters
- Conductive pole (e.g. concrete or steel)
- Any metal work (UGOH bracket etc) and metallic cable guards
- A local bored earthing electrode system.
- grading ring (if installed)
- HV cable screens and earth continuity conductors, subject to checks to confirm that EPR around the pole is below the tolerable limit under a credible worst case fault scenario (usually due to transferred potential from a 132kV fault at the zone substation). In any case the cable screen shall not be connected to the local earth at the first U/G-O/H on a feeder out of a zone substation without any intermediate cable screen earth points. An example is a U/G—O/H on a feeder out of the zone substation without an intervening distribution. See Section 8.5).

Earthing design must comply with requirements for HV conductive in-line poles.

### **11.7 Pole Mounted HV Voltage Regulator**

For a pole mounted regulator, the earthing system shall have the following connected to it:-

- regulator tank and any high voltage surge arresters
- conductive pole (e.g. concrete or steel)
- any metal work
- local earthing electrode system
- equipotential mat (if installed)

Earthing design must comply with requirements for HV conductive in-line poles.

### **11.8 Pole Mounted Air Break Switch**

For a pole mounted ABS, the earthing system shall have the following connected to it:-

- conductive pole (e.g. concrete or steel)
- any metal work and conductive operating handles
- local earthing electrode system
- grading ring (if installed)

Earthing design must comply with requirements for HV conductive in-line poles..

### **11.9 LV Conductive In-Line Pole**

Conductive LV in-line poles must have a bond installed between the neutral conductor and the structure with the pole bonded to an installed earth stake. In special locations the touch voltage has to be controlled to less than the safety criteria applicable to the location. If the standard curves cannot be used a dedicated assessment must be carried out using ARGON. For non-backyard locations DU safety criteria may be used.

Refer to Section 13.2 for a risk assessment of LV conductive poles.

### **11.10 HV Conductive In-Line Poles**

For conductive HV in-line poles in urban interface locations, additional earthing is not required. (Refer to Section 13.3) In special locations the touch voltage has to be controlled to less than the safety criteria applicable to the location. If the standard curves cannot be used a dedicated assessment must be carried out using ARGON.

In any case pole earthing shall be adequate to ensure minimum earth resistance for fault clearance.

## **12. REQUIREMENTS FOR SPECIFIC UNDERGROUND INSTALLATIONS**

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### **12.1 Introduction**

This section provides earthing requirements for specific underground and free standing ground mounted installations. Minimum separation from nearby objects to earthing systems shall be as per drawing 3832-018, unless a detailed design indicates closer separation is compliant.

### **12.2 Separately Earthed Padmount Transformer**

Separate and distinct earthing systems shall be provided for the low voltage and high voltage systems if the requirements for CMEN cannot be met.

The high voltage earthing system consists of the following connected to the HV earth bar:-

- transformer tank
- padmount enclosure
- HV cable screens and earthl continuity conductors

- grading ring
- HV earthing electrode/s.

The low voltage earthing system consists of the following connected to the LV earth bar:-

- low voltage neutral of the transformer
- low voltage neutral cables
- LV earthing electrode/s.

The LV earth lead to the top of the bored LV earth electrode shall be double insulated PVC (or similar) and the high voltage and low voltage earthing electrodes shall be separated horizontally by a minimum of 4m. A minimum of 150mm separation between HV and LV earthing conductors is required at cross over points. Minimum depth of cover over earthing electrodes is 450mm.

### **12.3 CMEN Earthed Padmount Transformer**

For a CMEN padmount transformer, the combined earthing system shall have the following connected to it:

- transformer tank and padmount enclosure
- HV cable screens and earth continuity conductors
- grading ring
- low voltage neutral of the transformer
- low voltage neutral cables
- a local bored earthing electrode system

The substation earthing design and installed assets should allow the substation to be converted to a separately earthed system by just removing the CMEN link in the substation.

### **12.4 Free Standing HV Equipment**

This section is for free-standing HV equipment such as RMUs (ring main units) and ground-mounted switches with exposed metal work that can be touched by the general public, e.g. where located on or adjacent to the footpath or in a park. All HV equipment shall be connected to the local HV earth, as the equipment is capable of being energised by the 11kV conductors in the event of a fault.

Free standing HV equipment must be assessed and designed in compliance with this manual. Free standing HV equipment includes switching stations, ground mounted switches, and ground mounted voltage regulators. Touch voltages must be assessed as compliant to the required safety criteria for general public and workers operating the equipment.

Grading rings may be installed to minimise touch voltage hazards.

Circuits supplying auxiliary power to the HV equipment from external LV mains shall be provided with standalone isolating transformers installed and earthed in accordance with manufacturer's instructions. Separation requirements for Telecommunication assets also apply to these isolating transformers.

### **12.5 Requirements for Chamber Substations**

The CMEN system of earthing shall be used for chamber distribution substations (i.e. indoor substations). Separate earthing is not practical as Evoenergy's HV equipment is on the same concrete slab as the customer's LV equipment. A minimum of three distribution transformer neutral circuits (approximately 100 earth rods) shall be interconnected. Interconnection to other areas may be by LV neutral, lead sheath of HV cable or 70mm<sup>2</sup> copper earthing continuity cable, earthed at 100m intervals.

At the chamber substation, the CMEN system of earthing shall have the following connected to it:

- transformer tank
- all equipment cabinets/frames

- low voltage neutral
- cable sheaths
- building structural steelwork
- a local earthing system
- any metal work such as entry doors and louvres

If the substation is not on the level directly above ground, then two 120mm<sup>2</sup> copper insulated riser cables shall be provided on separate routes from the basement/ground floor earth grid to the remote substation enclosure. The earth grid is to be located directly under the substation foot print where practicable, even when substations are located on upper levels of buildings. It is desirable that there is one common earthing system with the substation earth connected to the customer switchboard neutral, lightning protection system and communications earth.

## 13. RISK ASSESSMENT OF CONDUCTIVE POLES

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### 13.1 Introduction

The following provides an earthing risk assessment of HV and LV conductive poles.

### 13.2 LV Only Conductive Poles Risk

The scenario considered is for individual and societal electric shock risk for a conductive LV only pole with an earth fault.

There is an obvious risk if a fault is not cleared on a conductive LV pole. For example a high resistance earth fault (such as a phase conductor in direct contact with pole structure) may lead to a situation where there is insufficient fault current for effective operation of the LV circuit protection device. In this case even though the corresponding hazard voltages at and around the pole base are within safety limits the faulted condition will remain uncleared indefinitely. It is not practical to address this type of scenario.

The following assumptions have been made to estimate the risk for conductive LV poles:-

#### Individual risk:

- 150 faults/100km-yr (per ENA EG0) and an average span of 50m giving a fault rate of 0.075/year
- 2 second clearing time (conservative upper limit for average fault clearing time per ENA EG0)
- 416 contacts of 4 sec duration per year (“Backyard” assumption from EG-0)
- Surface soil resistivity 5  $\Omega$ m
- Wet bare feet

#### Societal risk:

- 150 faults/100km-yr (per ENA EG0) and an average span of 50m giving a fault rate of 0.075/year
- 2 second clearing time (conservative upper limit for average fault clearing time per ENA EG0)
- 312 contacts per person of 4 sec duration per year (“Distribution Backyard” assumption from ENA EG-0)
- Surface soil resistivity 5  $\Omega$ m
- Wet bare feet
- Assumed maximum population size 42

Using ARGON the touch voltage should not exceed 78V to obtain an acceptable level of risk based on the assumptions listed above.

Expected touch voltage at pole:

- EPR at the pole is assumed to be 80% of the supply voltage to account for earth fault circuit loop impedance. For homogeneous soil, touch voltage can be reasonably assumed to be 65% of the pole EPR. Consequently, expected touch voltage at pole is 125V (240V x 0.8 x 0.65). This is significantly above the allowable touch voltage limit of 78V and would indicate mitigation measures are required. Before considering mitigation measures it would be prudent to review the risk assessment using a more realistic fault current distribution allowing for the effect of fault current return paths through the connected neutral and other MEN points.

Note that LV conductive poles in a CMEN network may be subjected to higher touch voltages. For this reason (and several others) a CMEN earthing arrangement must not be implemented if the pre-requisite conditions specified in Section 7.2 cannot be met.

Mitigation options include:-

- Non-conductive LV poles (e.g. fibreglass)
- Insulating the base of conductive poles
- Grading rings
- Surface insulating layer on the ground around the pole

Grading rings are not recommended as they will not reduce the touch voltage enough and it is not practical to install them in many locations. Similarly, it is not practical to install surface insulating layers in most locations.

In conclusion, conductive LV poles should not be installed in backyard locations. Due to lower occupancy of people, LV conductive poles will have a lower risk in remote locations than in frequented or backyard locations.

If the pole has equipment which is operated from the ground (e.g. LV switch) by maintenance personnel then it should be considered a frequented location, even if it is located in a remote location, and risk assessed accordingly.

### 13.3HV Only Conductive Poles Risk

The scenario considered is individual and societal risk for a conductive HV only pole with an earth fault in an urban interface location (within 100m of houses)

There is an obvious risk if a fault is not cleared on a conductive HV pole. To ensure protection clears the fault it is recommended that the total earth loop resistance, including pole earth resistance, be limited to 20Ω to ensure at least 300amps fault current at 11kV.

The following assumptions have been made to estimate the risk for conductive HV poles in an urban interface location:-

#### Individual risk

- 40 faults/100km-yr (per ENA EG0) and an average fault exposure line length of 2 x 80m ( two spans) giving a fault rate of 0.064/year (40 x 10<sup>-5</sup> x 2 x 80)
- 1 second clearing time (conservative upper limit for average fault clearing time per ENA-EG0)
- 135 contacts of 4 sec duration per year (“Distribution Urban” assumption from ENA EG-0)
- Standard footwear

#### Societal risk:

- 40 faults/100km-yr (per ENA EG0) and an average line length of 2 x 80m (to allow for contribution from a pole on either side) giving a fault rate of 0.064/year
- 1 second clearing time (conservative upper limit for average fault clearing time per ENA EG0)
- 75 contacts per person of 10 sec duration per year (“Distribution Urban” assumption from EG-0)
- Standard footwear



- Assumed maximum population size 25

Using ARGON the touch voltage should not exceed 6900V to obtain an acceptable level of risk based on the assumptions listed above. In practice this limit is unlikely to be exceeded given a source voltage of 6350V.

A copy of the ARGON assessment report is available in Appendix E – 'ARGON safety assessment report for HV only conductive pole'

The coincidence probability for an electrical person working at the pole works out to less than  $1 \times 10^{-6}$  indicating an overall negligible risk level for this hazard scenario.

## 13.4 Combined HV and LV Poles Risk

### 13.4.1 General

### 13.4.2 Risk for HV Equipment Mounted on Conductive Poles General

The scenario considered is individual risk for a combined use pole mounted equipment and an earth fault.

For SF6 switches, reclosers, U/G-O/H and voltage regulator HV conductive poles, as long as the fault rate is less than 0.1/year, the standard curves can be used to derive safety limits. This will result in the same conclusions as for HV conductive poles. However, conductive HV poles with pole mounted equipment installed in frequented locations will more than likely require mitigation. Refer to the following section for mitigation options.

If the pole mounted equipment is operable from ground level (e.g. ABS) by maintenance personnel then it should be considered a frequented location, even if it is located in a remote location. It should be designed to curve TDB.

For HV conductive poles with transformers, the risk is to be managed to less than  $10^{-6}$  using standard curves and templates.

## 14. MITIGATION

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### 14.1 Introduction

When designing earthing systems, the following risk treatment methods should be considered to manage the risk associated with step, touch and transferred voltage hazards:-

- reduction of the impedance of the earthing system;
- reduction of earth fault current;
- reduction of the fault clearing times;
- low impedance conductors to other sites;
- separation of HV and LV earth electrodes;
- installation of gradient control conductors (grading rings, equipotential mats)
- surface insulating layer;
- insulation and isolation

Often a combination of risk treatments will be required to control EPR hazards. The above methods are detailed in the following sections.

### 14.2 Reduced Local Earthing Resistance

In general reducing the impedance of an earthing system reduces EPR hazards. However, earth fault current increases with reduced grid impedance. Hence the effectiveness of the reduction depends on the impedance of the earth grid relative to the total earth fault circuit impedance. For the reduction to be effective, the resulting impedance needs to be low compared to other impedances in the faulted circuit.

Typically, earth grid impedance must approach source impedance value before the EPR starts decreasing significantly.

If the earthing system earth impedance is reduced by enlarging the earthing system, then even though the EPR on the earthing system will reduce, 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. As a result, the size of any transferred EPR hazard zones will increase. Whether this is a desirable outcome will depend on the particular situation. For distribution substations mounted on poles or in padmounts on foot paths there is very limited space so local earthing system size is also limited.

### **14.3 Fault Current Limitation**

Earth fault current flowing through earthing systems may be reduced by the installation of neutral earthing impedances (NEI) such as neutral earthing resistors or reactors (NER) and neutral earthing transformers (NET). Alternatively, resonant earthing systems comprising Petersen Coils, Arc Suppression Coils and Earth Fault Neutralisers may be very effective.

NETs are used in the Evoenergy distribution network to provide a return path for earth fault current in the delta connected 11kV network. The impedance of the NET is selected to limit this earth fault current to a practical value.

The effect on protection clearing must be investigated when considering NEIs at Zone Substations with long rural feeders where the earth fault level is very low towards the end of the feeder. In the event of an earth fault the NEIs could further reduce earth fault current preventing the fault from being cleared by the protection device.

NEIs may be an effective way of reducing the EPR at faulted sites and thereby controlling step, touch and transferred voltages especially in urban areas where distribution system earth electrodes are bonded to a significant MEN system. However, the reduction in EPR may not always be significant if the impedance of the earthing system is relatively high.

NEIs can also be very effective in reducing induction into parallel services such as telecommunication circuits or pipelines.

### **14.4 Reduced Fault Clearing Times**

EPR hazards can be mitigated by the reduction of the fault clearing time. If it is practical to implement, then it may be very effective.

Reduction of the fault clearing time may require significant protection review and upgrade, and may prove impracticable. The need for adequate protection grading may also limit the effectiveness of this measure.

### **14.5 Low Impedance Conductors to Other Sites**

If the earthing system earth impedance is reduced by bonding remote earths to it, then the resultant reduced EPR is also spread to the remote earths. This also introduces new transferred EPRs onto the earthing system when there are earth faults at any of these remote earths. Examples of this include bonding the earthing system to extensive LV network systems. This risk treatment measure can be very effective in significant urban areas where an extensive earthing system can be obtained by bonding together MEN conductors from adjacent LV networks.

Methods of bonding remote earths include the following:-

- Bonded cable screens
- Buried electrical continuity conductor
- Shield wires on overhead lines

Bonded cable screens provide galvanic and inductive return paths for fault current for both cable faults and destination substation faults.

Bonding of cable screens to the earthing systems at both ends is advantageous in most situations. However, the transfer of EPR hazards through the cable screens to remote sites should be considered as part of the earthing safety design. This is particularly relevant for supply bonded distribution substations.

The bonding of single core cables at both ends may affect the rating of the cables, depending on the cable configuration (due to induced currents in the screens and sheaths). Care should be taken to ensure the rating of the cable is adequate for the application.

The rating of the cable screens should be adequate for the expected earth fault current and fault current duration, and for the current induced in the screen during normal operation.

Electrical continuity conductors may be used to connect the earthing systems of adjacent substations where cable screens or shield wires are not practical. The minimum requirement is 70mm<sup>2</sup> bare copper conductor with a bonded 2.4m earth stake every 100m.

Shield wires can be either overhead earthwires or underslung earthwires. Overhead shield wires are typically used on transmission lines at or above 33 kV but may be installed on lower voltage lines where high reliability is required in high lightning areas. Shield wires may be installed on the whole line or only over a short section of line out from the substation (typically 900m to 2.5km).

While the primary purpose of the shield wires is to provide lightning shielding for the line, bonding of the shield wires to the substation earth grid can significantly reduce earth fault currents flowing through the earth grid into the soil for faults at the station or at conductive poles or towers bonded to the shield wires.

Inductive coupling between the shield wire(s) and the faulted phase conductor can significantly reduce the earth return current during fault conditions at conductive poles or towers bonded to the shield wire(s). Fault current returns to the source via the shield wire(s) rather than the ground. This, in turn, reduces the EPR levels at both the substation and at the conductive pole or tower. However the incidence of (transferred) EPR events at the conductive poles or towers will become more frequent since each station EPR will be transferred to the nearby towers/poles.

For a bus earth fault at a substation, the shield wires can divert significant current away from the substation earth grid. The net effect of the shield wires is to reduce the earth return current thereby reducing the EPR.

Consideration must be given to the shield wire size (fault rating), particularly for the first few spans from the substation.

Shield wires also provide shielding from low frequency induction into nearby services such as telecommunication lines and metallic pipelines.

## **14.6 Separation between HV & LV Earth Electrodes**

For an earth fault on the HV side of a distribution transformer, the EPR on the HV earth electrode is transferred to the LV system via the soil for separately earthed systems. By separating the HV and LV electrodes, the transfer of EPR from the HV system to the LV system can be controlled.

The minimum separation distance required between the HV and LV earthing systems is dependent on:

- size of the HV earthing system
- maximum EPR on the HV earthing system
- distances to the earths bonded to the LV system

A minimum separation distance of 4 m is suggested between the HV and LV earthing systems. In some instances the required separation may be much larger (i.e. low/high resistivity layering and a LV network with limited number of customers).

If there is insufficient space for 4m horizontal separation then vertical separation can be provided by burying the top of the earth electrode up to 4m and using double insulated conductor to connect it to surface equipment.

The integrity of the separated HV and LV earthing systems may be difficult to maintain into the future since other earthed structures may be installed at later stages within the physical separation distance.

Separated HV and LV earthing systems may not be effective in controlling hazardous step and touch voltages in the event of a HV line to LV line contact at the distribution transformer, or on a conjoint HV/LV line section. The following options may be considered for protecting against HV to LV contacts:

- Ensuring the configuration of LV lines at the distribution transformer poles is such that a HV line to LV line contact is unlikely.

- Replacing the LV lines over conjoint HV/LV spans with:
- LV buried cable,
- LV lines on a separate poles, or
- LV aerial bundled conductor cable that is insulated to withstand the full HV conductor voltage.

The transformer should be rated to withstand the maximum EPR on the HV earthing system, without breaking down to the LV side of the transformer (e.g. via HV/LV winding breakdown, or transformer tank to LV winding breakdown).

When the LV earthing system is segregated from the HV earthing system at a distribution substation, the total earth impedance of the LV earthing system plus associated MEN earths, must be sufficiently low to ensure the HV feeder protection will operate in the event of a HV winding to LV winding fault.

## 14.7 Grading Rings

Gradient control conductors can be used to lower touch voltages on distribution substations and equipment. In locations with high EPR a correctly installed grading ring could, depending on soil characteristics, produce a significant reduction to the touch voltage.

Correct installation of grading rings – depth and placement – is critical to the grading ring performing to effectively reduce touch voltage at the desired location. Incorrect installation will result in reduced efficacy of the grading ring. For optimal results the grading ring should be 1m from the conductive structure and buried to a depth of 300mm. The grading ring around the perimeter of the plant item shall be connected directly to the HV earth bar in the enclosure or to an earthing ferule on a pole.

The presence of a grading ring alters the EPR profile and may exacerbate touch and transfer potential concerns for other underground assets in the vicinity. In particular touch voltage hazards need to be assessed at nearby metal objects such as 'Colorbond' fencing and metallic pipeline as these may appear to be adequately separated from the main earth grid but could be influenced by the altered EPR profile due to the grading ring.

Grading rings do not add any value in locations that already have an equipotential plane. An example is a padmount substation installed on a concrete floor extending beyond the profile of the proposed grading ring.

Step voltages can also be controlled with the use of gradient control conductors. One or more gradient control conductors may be positioned in a concentric configuration at increasing distances from the structure i.e. 1 m, 2 m, etc., and the buried depth of each gradient control conductor is increased as the distance increases. As noted above, this measure will push the EPR contours further out from the structure and the resulting effects on third party equipment should be considered.

## 14.8 Surface Insulating Layers

To limit the current flowing through a person contacting a temporarily energised earthed structure, a thin layer of high resistivity material, such as crushed rock or asphalt, may be installed on top of the ground surface. This thin layer of surface material helps in limiting the body current by adding resistance to touch and step voltage circuits.

Crushed rock is used mainly, but not exclusively, in Zone Substations and Transmission Substations for the following reasons:

to increase tolerable levels of touch and step voltages during a power system earth fault

to provide a weed-free, self-draining surface

Asphalt may also be used in Zone Substations and Transmission Substations but is likely to be more expensive than crushed rock. Asphalt has the advantage of providing easy vehicle access. Vehicle access over crushed rock may sometime be problematic especially if the base course is not prepared correctly.

Asphalt and crushed rock can also be used to control touch and step voltages around towers and poles.

Limited data is available on the flashover withstand of asphalt which may be as low as 4 kV for a 50 mm thick sample in relatively poor condition. Therefore, where asphalt is used for mitigation, touch voltage should typically not exceed 3 kV and step voltage should not exceed 6 kV. For applications where these

limits are exceeded, the withstand voltage should be determined based on the type of asphalt that is being considered.

The electrical performance of asphalt can be compromised by cracks and excessive water penetration. Consequently, ongoing maintenance is required to ensure integrity of the asphalt layer.

For design purposes the following criteria for crushed rock applies:

- a resistivity of 3,000  $\Omega\text{m}$  and a minimum thickness of 100 mm should be used for crushed rock;
- a resistivity of 10,000  $\Omega\text{m}$  and a minimum thickness of 50 mm should be used for asphalt.

The resistivity of the crushed rock should be measured prior to laying at site to confirm that the design requirements are met and for the records.

The insulating property of crushed rock can be easily compromised by contamination (e.g. with soil). Therefore, regular inspection and maintenance of a crushed rock layer is required to ensure that the layer stays clean and maintains its minimum required thickness.

Close attention is required to the preparation of the ground prior to the application of crushed rock or asphalt. Suitable base course shall be prepared before laying the crushed rock or asphalt.

Chip seal, or scoria (i.e. light porous volcanic rock), should not be used since the resistivity of the chip seal surface is not typically very high and its breakdown voltage is usually low.

Concrete should not be used to control touch and step potentials due to its low resistivity. However, providing the reinforcing steel is bonded, concrete may be used to provide an equipotential zone. A layer of asphalt 1m out from the edge of a concrete slab can be used to reduce step potential risk.

## 14.9 Insulation & Isolation

Access to structures where hazardous touch voltages may be present can be restricted by the installation of safety barriers or fences. These barriers or fences would typically be non-conductive such as wood, plastic or rubber. For example, a pole could be surrounded by a wooden fence to restrict access to the pole base, or insulating material applied around the base of a steel, or concrete pole. Fibreglass cubicles can be used rather than metal cabinets for padmount equipment. The installation of isolation barriers usually requires ongoing maintenance but can be very effective in reducing the risk.

Third party conductive fences should be kept away from earthing systems to limit touch and step potentials on the fence. Non-conductive sections of fence may also be required at additional locations along third party fences to control low frequency induction.

Mitigation of step and touch voltages of metallic pipelines e.g. water pipes connected to a HV or LV network earthing system can be effectively achieved by the installation of plastic pipes.

## 15. LEGISLATION AND COMPLIANCE

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### 15.1 Health & Safety Legislation

The National Health and Safety legislation in Australia is based on Duty of Care. In the ACT there is the Work Health and Safety Act, 2011, which includes the following:-

A duty imposed on a person to ensure health and safety requires the person—

- a. to eliminate risks to health and safety, so far as is reasonably practicable; and
- b. if it is not reasonably practicable to eliminate risks to health and safety, to minimise those risks so far as is reasonably practicable.

The following outlines a legal perspective of electrical safety with respect to earthing of HV equipment.

The owner of an electrical asset is obliged to take reasonable care that the exercise or failure to exercise its powers does not create a foreseeable risk of harm to persons that may come into contact with electrical equipment (e.g. public, customers of electricity, workers and contractors). Where the state of the electrical power grid or reticulation service, whether from design, construction, works or repair, poses a risk to

persons, then, to discharge its duty of care, the owner (with power to remedy the risk) is obliged to take reasonable steps by the exercise of its powers within a reasonable time to address the risk. If the risk is unknown to the owner, or latent and only discoverable by inspection, then to discharge its duty of care the owner (having power to inspect) is obliged to take reasonable steps to ascertain the existence of latent dangers which might reasonably be suspected to exist.

The response by the owner calls for a consideration of various matters; in particular, the magnitude of the risk and the degree of probability that it will occur, the expense, difficulty and inconvenience in taking the steps described above to alleviate the danger, and any other competing or conflicting responsibility or commitments of the owner. For a utility, the duty does not extend to ensuring the safety of consumers of electricity in all circumstances.

The cost and practicality of any alternative and safer design or construction, if one is available, may be weighed against the funds available to the construction authority. It may also be that although a power line is in a dangerous condition, the authority will have discharged its duty of care by taking reasonable steps to minimise any danger, or to prevent it arising.

This legal perspective must be turned into an engineering approach for design. First, there is an obligation to consider foreseeable risk of harm to persons. In the context of HV earthing this means that the possible ways that persons may receive an electrical shock from HV equipment must be considered. A range of mitigation measures for each contact scenario must then be considered.

ALARP (As Low As Reasonably Practical) involves assessing the expense, difficulty, inconvenience, “utility of conduct” on the one side balanced against the magnitude of risk, probability of occurrence and severity of harm on the other side. “Utility of conduct” means that the outcome must stand up to scrutiny by the courts. In particular, it must be sensitive to the community expectation that there is a duty of care by the utility to ensure electrical infrastructure is safe.

The evaluation is not a strict minimum cost economic exercise. Options of higher cost but more effective must be considered. It implies an overall consideration of spending money to best effect. The ALARP principle recognises that the cost of control measures to eliminate all hazards is prohibitive. An example of the court’s interpretation by Chief Justice Sir Harry Gibbs of the High Court of Australia in 1982 is, “Where it is possible to guard against a foreseeable risk, which, though perhaps not great, nevertheless cannot be called remote or fanciful, by adopting a means, which involves little difficulty or expense, the failure to adopt such means will in general be negligent.” It should also be recognised that a risk assessment is not required in situations that are covered by current standards, guidelines, or where hazards and risks are well known and there are universally accepted control measures. This last category is generally described as accepted industry “good practice”.

## 15.2 Technical Code

Under the Utilities (Management of Electricity Network Assets Code) Determination in August 2013, Section G lists the following standards, codes and guides relating to earthing:-

- AS/NZS 7000 Overhead line design
- ENA EG1 Substation Earthing Guide
- ENA EG0 Power System Earthing Guide
- AS/NZS 3000 Electrical installations
- IEEE 80 IEEE Guide for safety in ac substation grounding
- AS 2067 Substations and high voltage installations exceeding 1 kV a.c.

It also indicates these may be amended and that they do not necessarily represent all the standards that may need to be consulted in meeting the requirements of the Code.

## 16. RELATED DOCUMENTS

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- Evoenergy Distribution Transformer Fuse Application Guide
- Distribution Earthing Testing

- Soil Resistivity Survey
- SWMS 05 001 – SWMS for soil resistivity and earth mat testing
- Work Instruction BEL8.1P39 W20 Earth Grid Test
- NSW 107 – Earthing of Streetlight Columns

## 17. REFERENCES

- Distribution Transformer Fuse Application Guide.
- AS/NZS 7000, Overhead line design
- ENA EG-0 Power System Earthing Guide, Part 1: Management Principles by ENA, August 2010.
- AS/NZS 3835.1, Earth Potential rise – Protection of telecommunications network users, personnel and plant.
- AS/NZS 4853, Electrical Hazards on Metallic Pipelines.
- Work Health & Safety Act, 2011.
- Work Health & Safety Regulation, 2011.
- ENA EG1-2006, Substation Earthing Guide.
- AS 2067, Substations and high voltage installations greater than 1000Volt AC.
- ANSI/IEEE Std 80 – 2000, IEEE Guide for Safety in AC Substation Grounding.
- AS/NZS 1768 Lightning Protection

## 18. DEFINITIONS AND ABBREVIATIONS

TERM	DEFINITION
ABS	Air Break Switch
ALARP	As Low As Reasonably Practical
Approved person	Person having appropriate organisation endorsement in writing for this function, normally the team leader or manager.
CMEN	Common Multiple Earthed Neutral. Earthing system at distribution substations where the HV earthing system is bonded in a deliberate and permanent way to the local MEN via the local LV earthing system at the substation.
DS	Distribution substation.
Dense MEN	Where the distribution substation will have sufficient MEN connections to provide a low enough earthing resistance to allow for CMEN. E.g. there are numerous MEN connections to surrounding substations and they extend more than 100m from the substation. Typically this involves at least three HV screen bonded substations each having a large number of earths (more than 100 electrodes including pillars, conductive poles and customer electrodes).

Distribution Substation	An electrical installation with HV and LV.
ECC	Earthing Continuity Conductor. An electrical earthing conductor providing low conductivity connection between two points.
EPR	Earth Potential Rise. Voltage rise due to injected current.
Frequented Location	Urban residential area.
HV	High Voltage. Greater than 1000V AC. For purposes of this document refers to 11kV AC
LFI	Low frequency induction – voltage induced on telecommunication line by power lines running parallel to and in close proximity to the telecommunication line
Lot	Block or parcel of land with an LV service
LV	Low Voltage. Exceeding 50 V AC but not exceeding 1000 V AC
MEN	Multiple Earthed Neutral. LV system with multiple earths on the neutral to provide a low impedance to earth.
OH	Overhead construction
OHEW	Overhead Earthwire
Remote Location	An isolated location (e.g. rural area) that is not frequented by persons.
Sparse MEN	Where the distribution substation will have insufficient MEN connections to provide and sustain an ongoing low enough earthing resistance for CMEN. E.g. substation only supplies one lot/building or a limited number of customers (i.e. rural development, isolated pocket of residences or electrical loads such as pump, workshop or shed.).
Special Location	A location that is frequented by persons (e.g. public thoroughfare, school, playground) or adjacent to a water recreation area (e.g. swimming pool or beach). Includes sites within 100m of these locations.
Step Voltage	A voltage that may appear between any two points on the surface of the ground spaced 1m apart.
Touch Voltage	A voltage that may appear between any point of contact to conductive surface above ground and any point on the surface of the ground a horizontal distance of 1m away from the vertical projection of the point of contact.
UG	Underground construction
Zone Substation	An electrical installation transforming from 132kV or 66kV to 22kV or 11kV.



## VERSION CONTROL

VERSION	DETAILS	APPROVED
1.0	1 <sup>st</sup> draft version 2	29/04/2014
2.0	Version 3	27/06/2014
3.0	Formatting of the whole document / Minor changes to clauses 5.8 and 9.3	14/09/2015
4.0	Minor amendments	21/12/2017
5.0	Document updated for Rebranding to 'Evoenergy'	06/02/2018
6.0	General review; risk based design concept expanded	Draft for review

## DOCUMENT CONTROL

DOCUMENT OWNER	PUBLISH DATE	REVIEW DATE
Asset Standards and Acceptance Manager		24/01/2022

## APPENDIX A – EVOENERGY DISTRIBUTION SYSTEM

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Operating voltages – Most of the HV network is 11kV but there is also a small amount of 22kV. 22kV is in rural areas and is predominantly overhead. There are some isolated loads at 3.3kV and 2.75kV (e.g. Captain Cook fountain and the Canberra Hospital). LV is 415V three phase, four wire with MEN/CMEN system of earthing.

Up until the mid-1980s the network was substantially overhead with separately earthed distribution transformers. Since the mid-1980s, predominantly underground network has been installed. Approximately two thirds of the urban area is now overhead, excluding high density commercial areas. New commercial and residential areas are underground. Currently, approximately 50 pad mount substations are installed per year with around 12 of these CMEN and the remainder having separate earths. The network is predominantly separately earthed.

Majority of underground system is separately earthed.

Majority of overhead system is separately earthed.

All chamber substations are CMEN.

All Zone Substations are 132kV to 11kV, except for Fyshwick which is 66kV to 11kV. The 132kV side of the transformers are star with neutral point solidly earthed. The 11kV side of the 132kV/11kV transformers is a delta with earthing transformer which provides a return path for 11kV earth faults and limits earth fault current to 3kA. Fyshwick has a delta on the 66kV and a solidly earthed star point on the 11kV side which has an earth fault level of 7kA for one transformer.

At Woden Zone Substation, with 132kV/11kV, there is a step up transformer to 22kV with no earth fault limiter.

The 11kV secondary of Zone Substation transformers are paralleled for short periods almost every day to allow maintenance. Note that there is increased earth fault level when transformer secondaries are paralleled. When paralleled at the Zone Substation earth fault current increases to a maximum of 6kA near the Zone Substation but increase in earth fault level is insignificant some distance away in the field,. Due to the very small time (a few minutes) that transformers are paralleled, the probability of an earth fault while paralleled is small. Consequently, maximum earth fault for earthing design at 11kV (from zone substations) is 7KA for Fyshwick zone substation and 3kA for others.

Remote line end earth fault clearing time is 0.5sec for both 132kV and 66kV networks faults at far end of the feeder as there is no signalling.

Protection on 11kV at Zone Substations is inverse time earth fault and sensitive earth fault. Settings vary widely. However, conservative 11kV values to be used for earthing design of distribution substations are:

- 0.5sec clearing at 4.5kA for Fyshwick zone substation and
- 0.5sec clearing at for 2.5kA and 1 sec at for 300A for other zone substations

Note that the maximum a 3kA earth fault (3kA or 7kA) only occurs for faults at the Zone Substation. As soon as there is some circuit and fault impedance, the earth fault level reduces. Sensitive earth fault rarely operates but is typically set at 5sec for 6amps.

Distribution substations have HV fuses. For more details on fuses refer to document **Evoenergy's Distribution Transformer Fuse Application Guide**.

Some newer chamber substations have protection relays on HV.

Almost all distribution transformers are Dyn1 with star point on LV side solidly earthed.

Distribution substations close to the Zone Substations in underground areas may have the HV earthing system connected by underground cable screens to the Zone Substation earthing system. These are known as downstream bonded zone substations (DBZS) and supply bonded distribution substations (SBDS).

As 11kV overhead does not have an OHEW, the HV earthing system of distribution substations in overhead areas are not connected to the Zone Substation earthing system. Consequently, in overhead areas, Zone Substations are not downstream bonded zone substations and distribution substations are not supply bonded distribution substations.

In underground areas, distribution substations have the HV earthing systems connected by the cable screen. They are known as bonded distribution substations.

As 11kV overhead does not have an OHEW, the HV earthing system of adjacent distribution substations are not connected. Consequently, in overhead areas distribution substations are not bonded distribution substations.

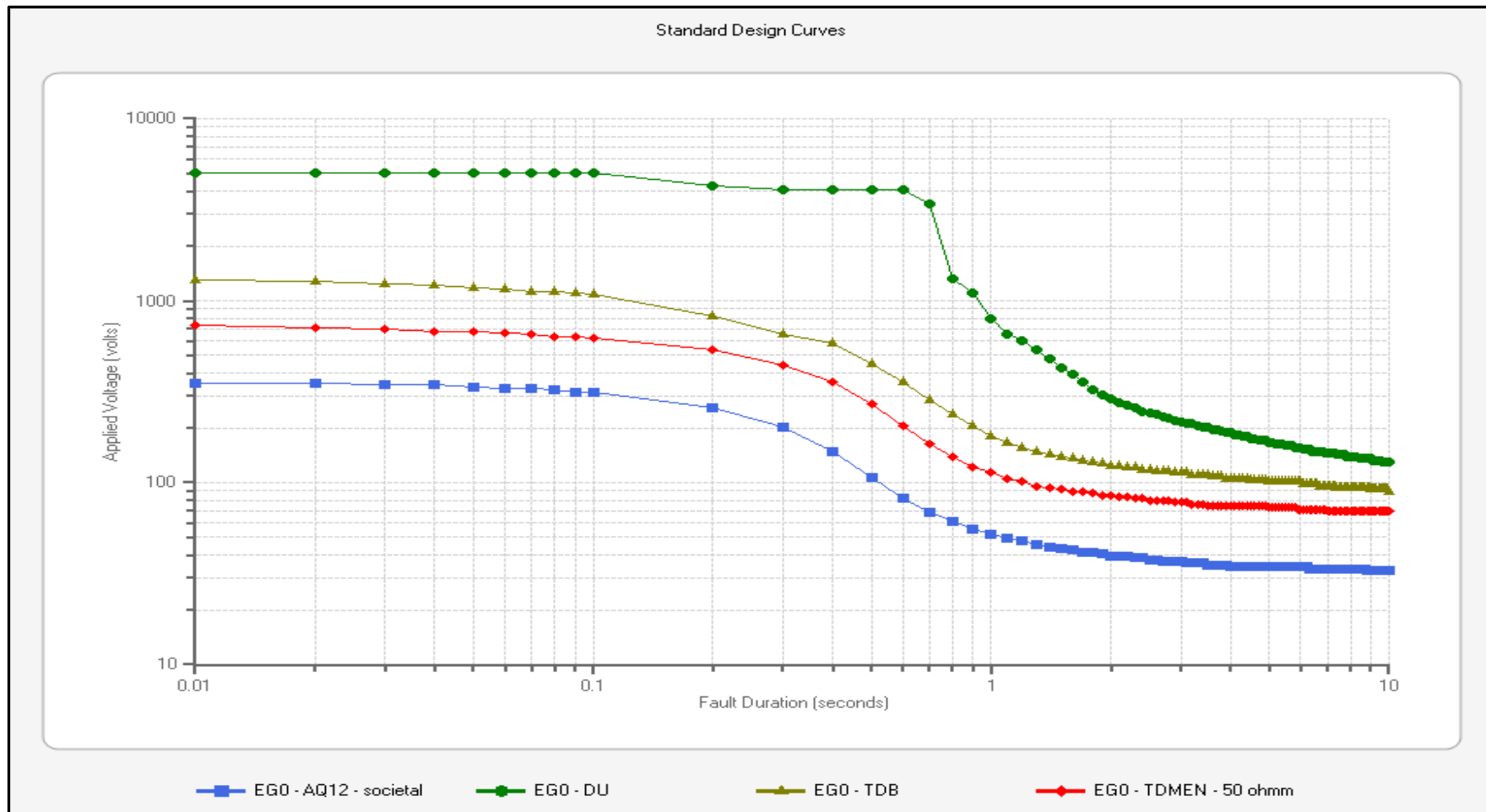
There is no SWER in the Evoenergy network.

The average length of a sample of underground 11kV feeders for residential and commercial areas is given in Table A.1. (Sample size was 10 to 12 feeders.) This table also provides the average number of distribution substations per feeder, 19 for residential and 6 for commercial. The average distance between distribution substations is 314m for residential and 789m for commercial areas.

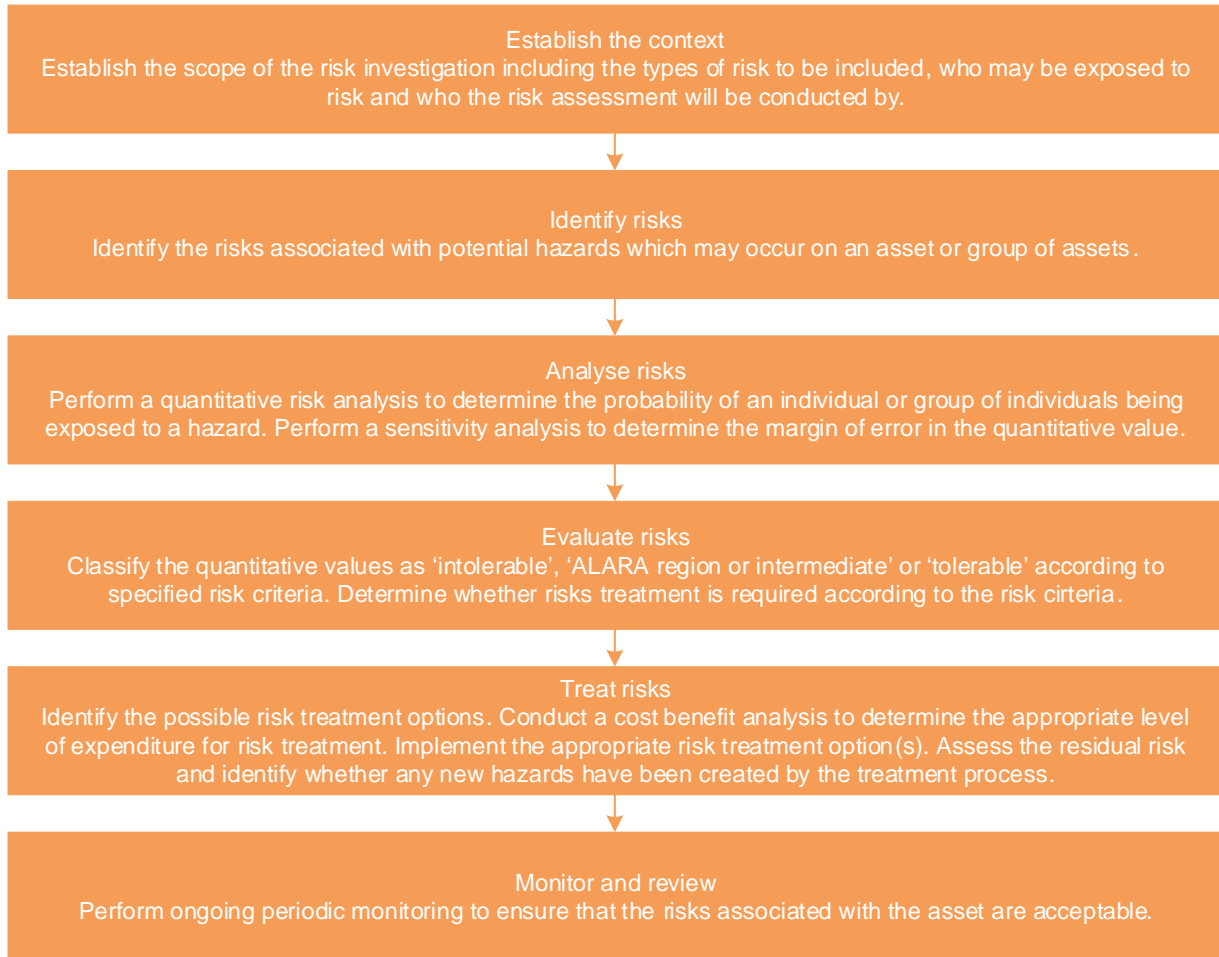
**Table 6.** DISTRIBUTION FEEDER AND SUBSTATION STATISTICS

Parameter	Residential Feeders			Commercial Feeders		
	11kV Feeder Length (km)	No of sub	Length per sub (km)	11kV Feeder Length (km)	No of sub	Length per sub (km)
<b>Minimum</b>	0.756	3	0.044	2.121	2	0.133
<b>Maximum</b>	13.984	41	0.632	7.985	21	2.114
<b>Average</b>	5.369	19	0.314	3.528	6	0.789

## APPENDIX B – STANDARD DESIGN CURVES



## APPENDIX C –RISK MANAGEMENT PROCESS



## APPENDIX D – EVOENERGY DISTRIBUTION NETWORK FAULT RATE

Following values are recommended for use in the ARGON risk assessment tool. Tables 7 and 8 show basis and assumptions used in deriving these figures.

Table 7. TABLE D.1: RECOMMENDED 11KV NETWORK FAULT RATES

Annual 11kV feeder fault rate	0.1
Annual distribution substation fault rate	0.1

Table 8. TABLE D.2: CALCULATED 11KV DISTRIBUTION NETWORK FAULT RATE

Total 11kV overhead feeder length (km)	11101
Total 11kV overhead feeder faults over 3 year period	10992
Average 11kV overhead feeder fault rate (per 100km per year)	333
Annual 11kV feeder fault rate	0.074

Notes:

- Network feeder length calculated from **Evoenergy Electrical Data Manual** feeder data.
- Fault data obtained from real time systems records (ADMS).
- Typical fault rate per ENA EG-0 Table A2 is 10-40 faults/100km/year for 11kV
- Assuming a 0.2km fault exposure length at any given location:  $[33 \times 0.2/100 = 0.066]$ . This value can be used for both overhead and underground feeders. It is a conservative value, particularly when used for underground feeders.

Table 9. CALCULATED DISTRIBUTION SUBSTATION 11KV FAULT RATE

<b>TOTAL DISTRIBUTION SUBSTATIONS IN EVOENERGY NETWORK</b>	5709 <sup>1</sup>
Total distribution substation 11kV faults over 3 year period	1215 <sup>2</sup>
Average annual distribution substation fault rate	0.07

Notes:

- Includes pole mounted, ground mounted and chamber substations. Value obtained from Evoenergy 'Annual Planning Report December 2017'.
- Fault data obtained from real time systems records (ADMS).

## APPENDIX E – ARGON SAFETY ASSESSMENT REPORT FOR HV ONLY CONDUCTIVE POLE

### ARGON - SAFETY ASSESSMENT REPORT

Report Generated On : 16 May 2019

Report Generated By : B Bramanathan

from : Evoenergy

Design Location : HV only conductive pole

#### INTRODUCTION

##### Individual Probability of Fatality

This report outlines the results of a risk-based safety criteria assessment study for the above location. The analysis is based on the fact that a fatality due to contact with an external voltage can only occur if both a person is present when a fault occurs and the touch (or step) voltage generated is sufficient to allow a large enough current to pass through the body for sufficient time to cause fibrillation of the heart muscle. The probability that an individual will be present and in contact with an item at the same time that the item is affected by a fault is defined as the Probability of Coincidence ( $P_{coinc}$ ). The probability that the heart will enter ventricular fibrillation due to contact with an external voltage is the Probability of Fibrillation ( $P_{fibrillation}$ ). This situation can be described by the following simple equation:

$$P_{fatality} = P_{coinc} * P_{fibrillation}$$

The probability of coincidence has been calculated using contact and fault data as detailed in this report. The probability of fibrillation has been calculated using the impedance and applied voltage / clearing time information as detailed in this report.

The calculation of the probability of fatality allows the design to be classified according to risk targets ( $1e-6$  to  $1e-4$ ) as either negligible risk, intermediate risk or intolerable risk.

##### Societal Probability of Fatality

For situations where more than one person may feasibly be present at any time, the individual process outlined above is modified slightly to allow for an altered societal probability of coincidence and hence probability of fatality to be calculated in accordance with accepted F-N curves. For societal probability of fatality, the targets are altered from the individual targets based on the frequency of occurrence of N or more deaths. This allows sliding scales to be defined which classifies the negligible, intermediate and intolerable risk zones for a given population size. A design curve can be defined over a range of clearing times which corresponds to the highest applied voltage in the negligible region for each clearing time.

##### Design Compliance

Designs with a negligible risk determination are accepted and the attached design curve(s) may be used at locations with similar contact, fault and series impedance characteristics. Designs which are determined as high risk are not acceptable and there is no valid design curve available until mitigation results in a compliant design. Designs placed in the intermediate risk range may be considered compliant provided the ALARP (As Low As Reasonably Practicable) principle is applied. For designs of this type, documentation is supplied at the end of this report outlining the justification.

The following information outlines the design assumptions and classifies the compliance of the design.

## COINCIDENCE PROBABILITY

### Access / Fault Assumptions

**Scenario Name** User Defined Assumptions  
**Description** Conductive pole in urban interface location including fault at adjacent poles

		<i>Individual</i>		<i>Societal (popn = 25)</i>	
<b>Fault Frequency</b>	0.064	<i>per year</i>	<b>Contact Frequency</b>	135	<i>per Year</i>
<b>Fault Duration</b>	1	<i>seconds</i>	<b>Contact Duration</b>	4	<i>seconds</i>
				75	<i>ave / Year / Person</i>
				10	<i>seconds</i>

### Coincidence Reduction

**Coincidence Reduction Method** None  
**Coincidence Reduction Factor** 1

Individual Coincidence Probability = 1.37e-6

## FIBRILLATION PROBABILITY

### Assumptions

<b>Current Path</b>	Touch Voltage	
<b>Footwear</b>	Standard Footwear	
<b>Wet / Dry ?</b>	Dry	
<b>Soil Resistivity</b>	50	$\Omega\text{-m}$
<b>Applied Voltage</b>	6887	<i>volts</i>
<b>Fault Duration</b>	1	<i>seconds</i>

### Surface Layer

<b>Type</b>	None	
<b>Resistivity</b>	0	$\Omega\text{-m}$
<b>Depth</b>	0	<i>metres</i>
<b>Flashover Voltage</b>	Not Specified	<i>volts</i>

Fibrillation Probability = 0.7304



## RISK DETERMINATION

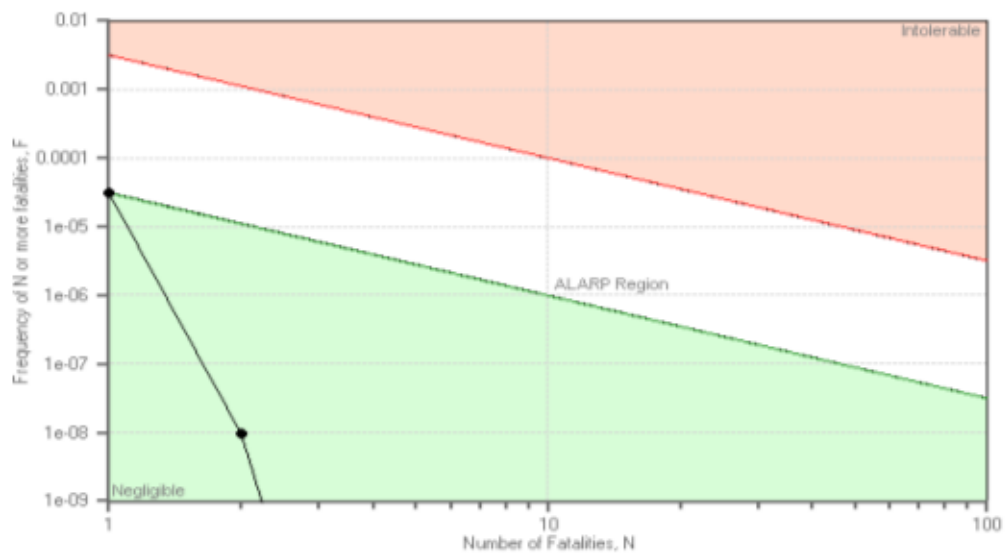
### Individual

Risk Zone : Negligible

Probability of Fatality =  $9.998 \times 10^{-7}$

### Societal

Societal Fatality Risk, Population Size = 25



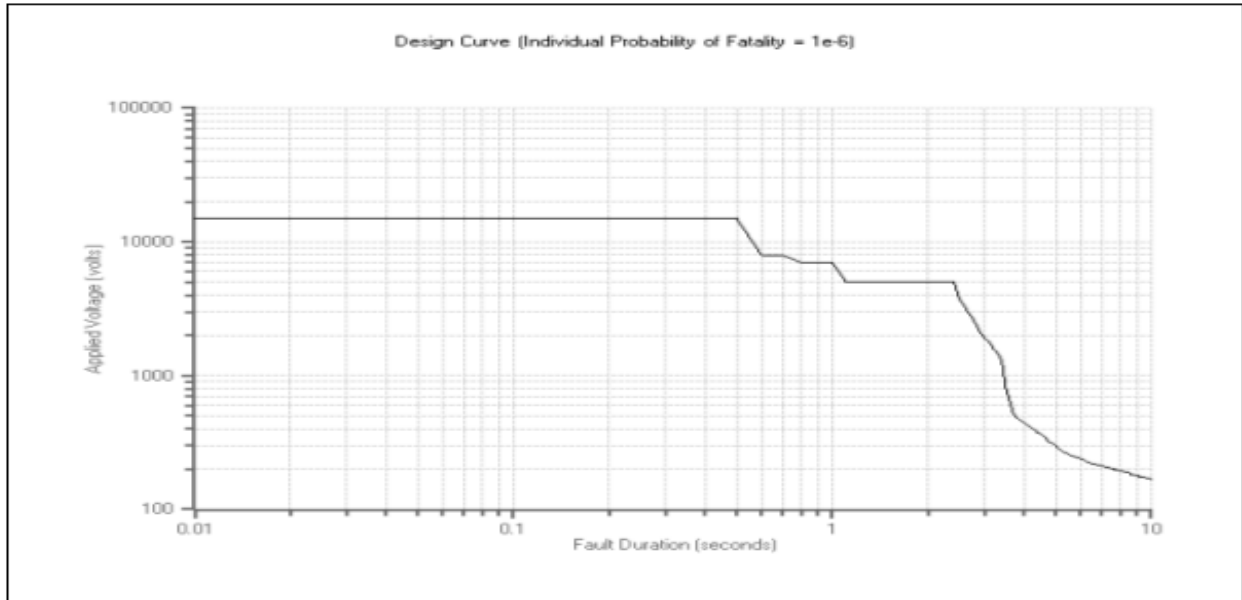
### Worst Case Risk Zone

Risk Zone : Negligible

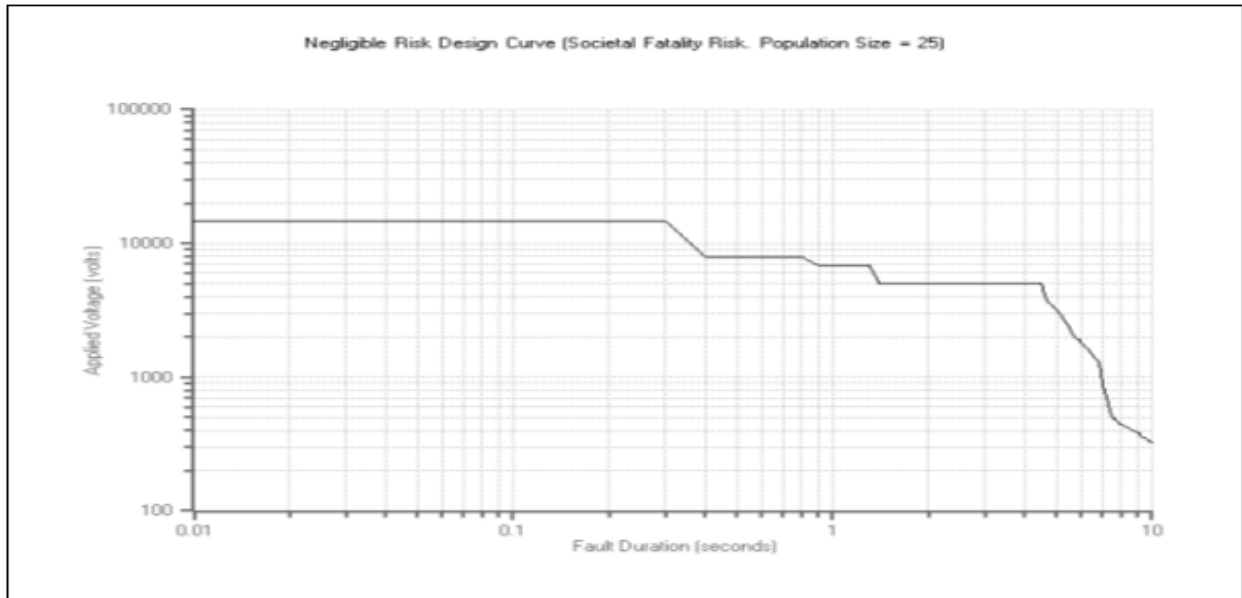
## DESIGN CURVE

These curves are valid for designs which have contact, fault, and series resistance characteristics similar to those outlined in this report. Fault duration need not remain the same. Designs must be compliant with the most stringent requirements from the curves.

### Individual



### Societal



## RISK MITIGATION COMMENTS

Fault frequency of 0.064 derived from :  
11kV overhead line fault rate of 40/100 km/yr and a line length of 0.16 km (2 x 80m span to allow for fault on adjacent poles) =  $(40/100) \times 0.16 = 0.064$  faults per year

## SUMMARY

Based on the information supplied in this report, the design is considered to be **COMPLIANT**

## APPLICATION NOTES

### Surface Soil Resistivity

Surface soil resistivity has a significant effect on the current that can pass through a body. The effect of soil resistivity is linear with the effect on the body and results can be interpolated linearly between two resistivities to provide the effect at the required resistivity when undertaking Argon based analysis.

### Footwear

Appropriate footwear can significantly reduce the current that can pass through a body. Under dry conditions any enclosed leather or non-conductive rubber or plastic footwear in good condition is as effective as electrical safety boots in reducing the risk. Without such footwear the risk is equivalent to bare feet.

Appropriate gum boots are those which pass the following test to ensure that material from which they are made is adequately insulating:

Fill the boot to approximately 90% of its height with salt water and place it in a container of salt water that reaches the same water level. The resistance between electrodes inserted in the water inside the boot and outside of the boot should be determined with a high voltage resistance tester. The resistance should not be less than 1 mega ohm.

Gum boots should be maintained in good condition and replaced if any splits or cracks appear.