evoenergy

DISTRIBUTION EARTHING DESIGN MANUAL

MIMIMUM REQUIREMENTS FOR THE SAFE EARTHING OF EVOENERGY DISTRIBUTION NETWORK ASSETS

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

CONTENTS

1. SCOPE

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
- LV service pillars, pits, and POE cubicles

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 PO07477
- Application of Australian standards and guidelines

2. NOT IN SCOPE

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 implementation 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

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

Distribution earthing system should –

- Reduce electrical hazards to staff and public to as low as reasonably practicable during the transfer of earth fault energy and under load imbalance conditions.
- Ensure adequate earth fault current to allow protection equipment to operate satisfactorily under normal HV and LV 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; this includes induced potential hazards on adjacent non-electricity related assets such as fences and pipeline.
- 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

The recommended design standards and guidelines for earthing design of distribution installations are AS2067, AS/NZS7000, AS/NZS3000 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 all credible voltage hazard conditions. This primarily involves assessment of touch voltages. In addition, the likelihood of step voltage and hand to hand voltage hazards occurring will also be investigated and assessed accordingly. (Note: 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 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. Backup clearing time is to be used for sizing of earthing components.

Earthing design 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.

Earthing design shall only be carried out by personnel who have attended and successfully completed Evoenergy training module “Earthing Safety and Fundamentals”

6. OVERVIEW OF THE EARTHING SYSTEM DESIGN AND MANAGEMENT PROCESS

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

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

- The coincidence probability P_{coinc} is negligible (less than 1 in a million) and
- The likelihood of public gathering around the item (societal risk) can be excluded

Details of assumptions made and justification for not carrying out an earthing design shall be included in the project documentation and validated and approved by the Project Team Manager.

Coincidence probability P_{coinc} is the likelihood of a person being in a hazard situation and is defined as the probability that the person is in a situation to receive a shock voltage from an item at the same time that the item is affected by a fault. Figure 2 taken from AS 2067 illustrates the various hazard situations associated with a substation earth fault.

P_{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.

Earthing design is still required to assess risk of damage arising from EPR to equipment.

If an earthing design is required, the process shown in Figure 3 (taken from ENA EG0) shall be followed. This manual covers Step 2 'Power Frequency Design'.

Design is to be based on Evoenergy's standard construction drawings in the first instance. If design targets cannot be met solutions must 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 the Project Team Manager and review and approval workflow records included in the design documentation.

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

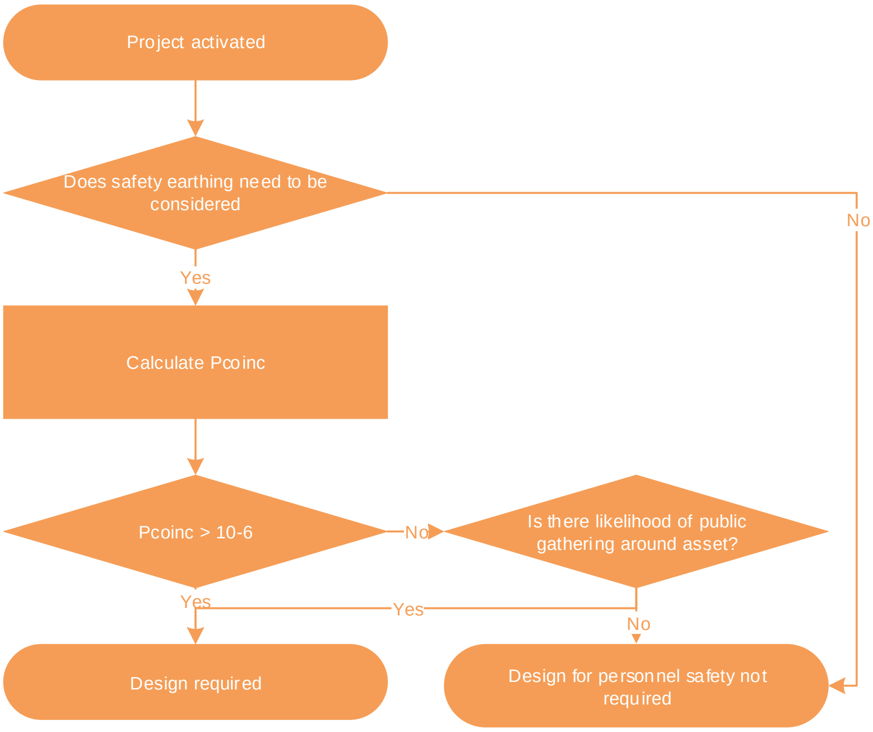


FIGURE 2. HAZARD SITUATIONS ARISING FROM A TYPICAL SUBSTATION EARTH FAULT (SOURCE: AS 2067)

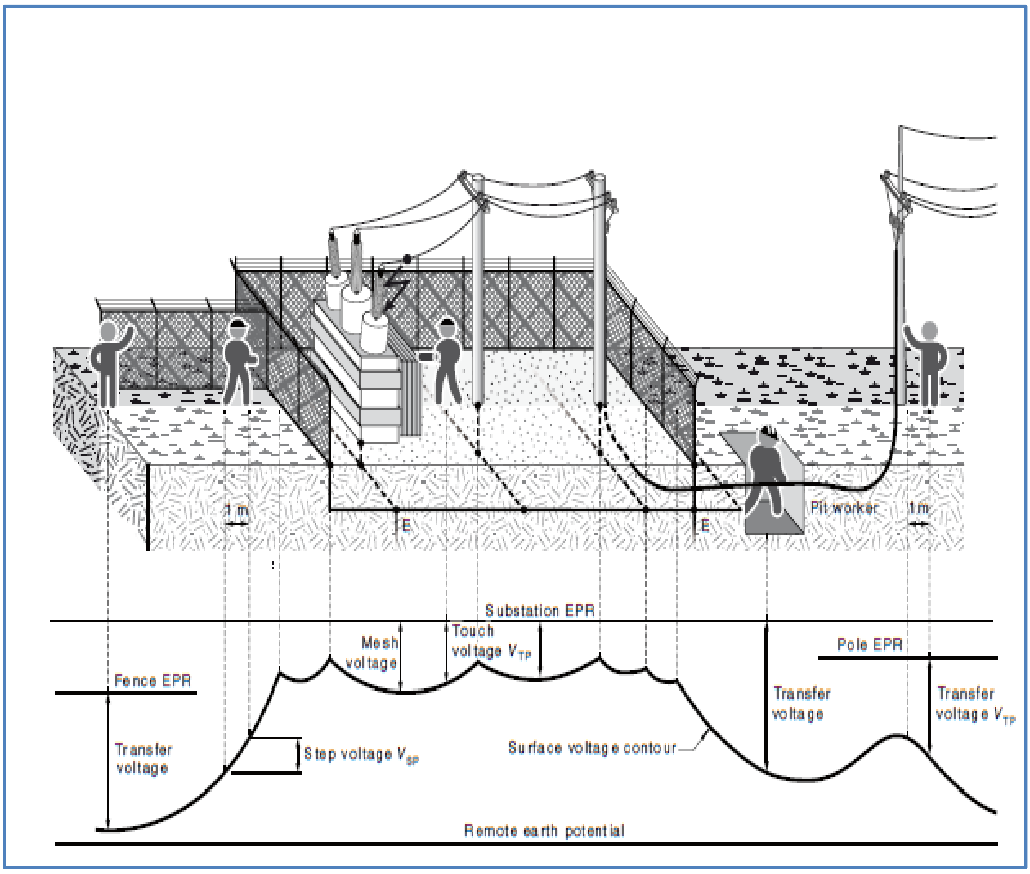


FIGURE 3. DESIGN MANAGEMENT PROCESS OVERVIEW (SOURCE: ENA-EG0)

6.1 Power Frequency Design

Power frequency earthing design deals with earthing of assets to manage hazards associated with fault voltages in the normal operating frequency range (nominal 50Hz). The process for carrying out a power frequency design is outlined in Figures 4 and 5. Table 1 describes the various steps in further detail.

FIGURE 4. POWER FREQUENCY DESIGN PROCEDURE STEPS 1 TO 8

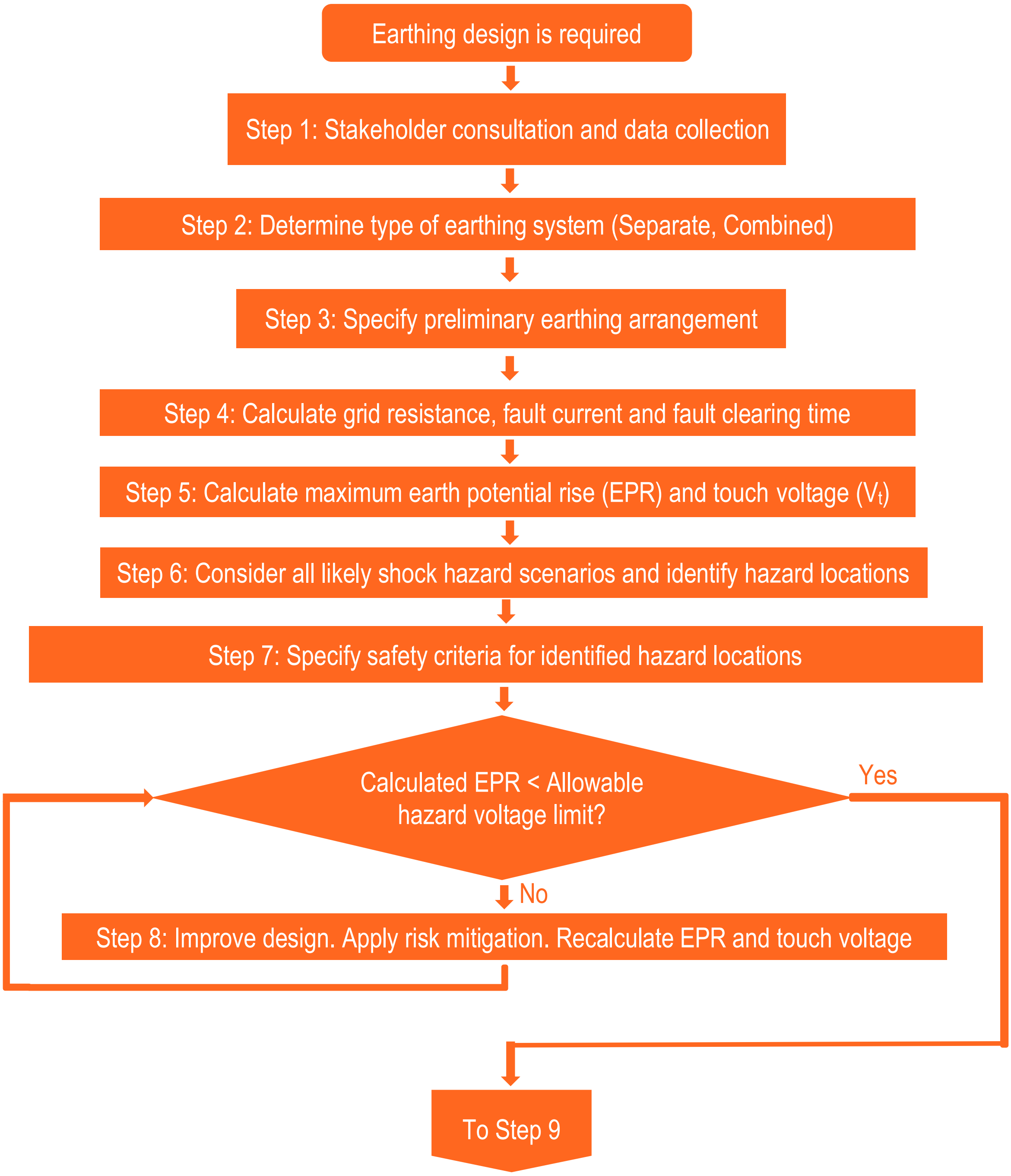


FIGURE 5. POWER FREQUENCY DESIGN PROCEDURE STEPS 9 TO 14

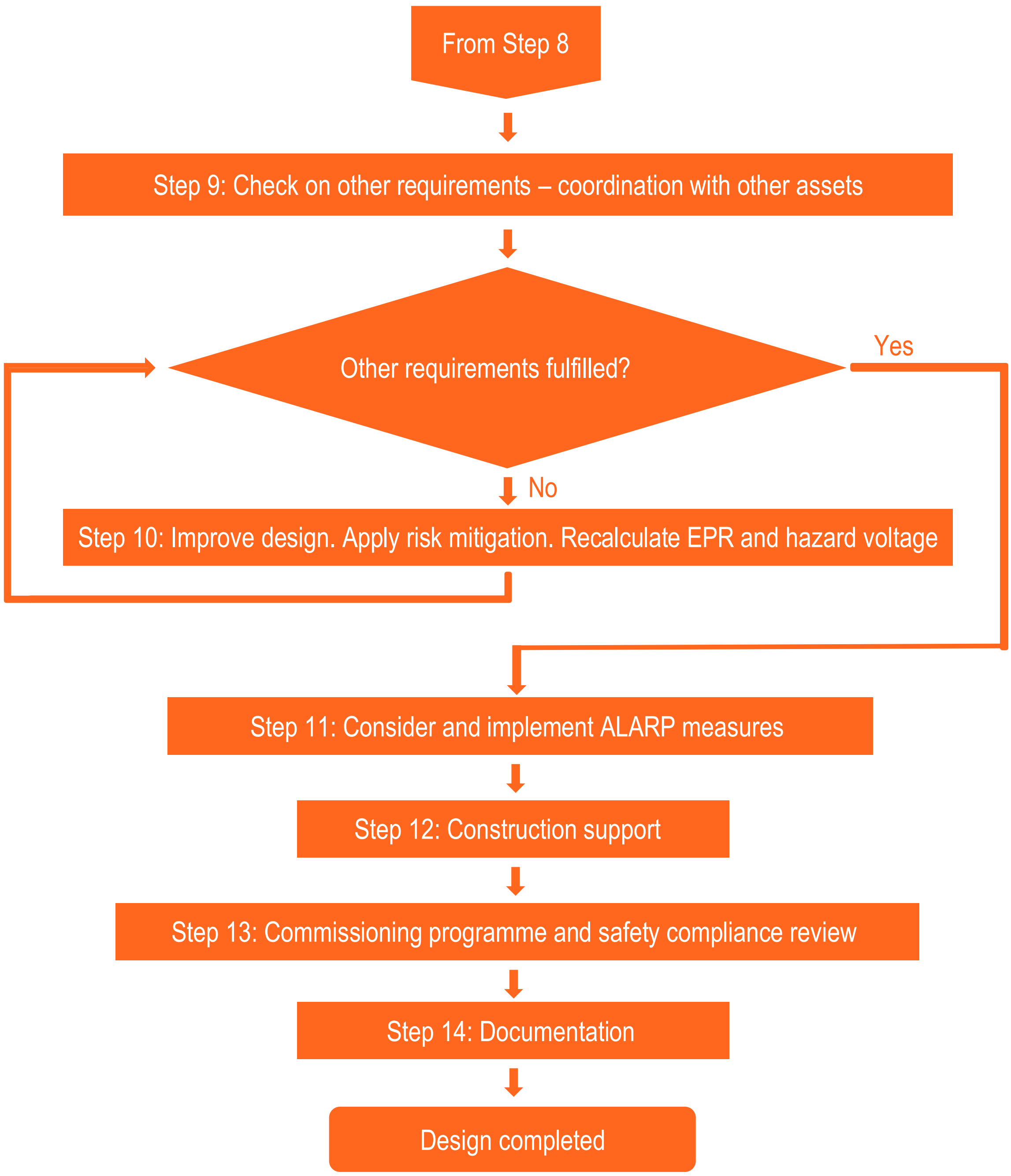


Table 1. POWER FREQUENCY DESIGN PROCEDURE STEPS 1 TO 14

STEP	PROCESS DESCRIPTION
1	**Stakeholder consultation and data collection** 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. Fault current contribution from embedded generation should not be ignored if network configuration supports earth fault current flow from these sources.
2	**Determine type of earthing system required – Separate or Combined (Section 7)** 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.
3	**Specify preliminary earthing arrangement** Distribution substation earthing arrangements are available from Evoenergy standard drawings.
4	**Calculate grid resistance, fault current and fault clearing time (Section 8)** The actual fault current will always be lower than the prospective fault current due to the additional series resistance of the earth grid (often in parallel with 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.
5	**Calculate maximum earth potential rise (EPR) and touch voltage** 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
6	**Consider all likely shock hazard scenarios and identify hazard locations (Section 6.2)** 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 to a remote location).
7	**Specify safety criteria (allowable touch voltage limits) (Section 6.2)** 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.
8	**Improve design. Apply risk mitigation. Recalculate EPR and touch voltage** If compliance to the selected safety criteria is not achieved at all locations implement mitigation measures to improve the design and repeat process starting from Step 2. See Section 14 for typical mitigation techniques.
9	**Check on other requirements – other hazards, coordination with other assets** Telecommunications and pipeline exposure and coordination - see Sections 8.9 and 8.10 Induced voltages on passive non-conducting objects (metallic fences, pipelines) Lightning and other transients – see Section 8.13 Manage any likelihood of interaction of the earthing system with other buried services in the vicinity under normal steady state operating conditions (e.g., corrosion issues)
10	**Improve design. Apply risk mitigation. Recalculate EPR and touch voltage: See Step 8**

11	**Consider and implement ALARP (as low as reasonably practicable) measures** A compliant design is one that delivers a probability of fatality of less than one in a million. Consider further risk reduction options where implementation cost is not prohibitive and justifies the benefit gained. This is not a mandatory requirement but considered good and responsible engineering. The ALARP approach may be considered in some cases to justify acceptance of design which does not deliver compliance to the 'one in a million' criterion. Refer to Appendix E.
12	**Construction support** 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.
13	**Commissioning programme and safety compliance review** 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.
14	**Documentation** Include description of: • physical installation - drawings and sketches showing earthing arrangement • design assumptions, constraints, and justification for decisions • calculated and measured earth resistance • soil resistivity data.

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 practicable)	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.

Further reading on risk categories including definitions and guidelines on incorporating the ALARP process in earthing design is available in Appendix F

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 (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 criterion.
- Direct probabilistic method: Calculating the contact and fault event coincidence and fibrillation probability to derive a 'design specific' target voltage limit. 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
Residential backyard	TDB	Contact with metalwork in a backyard affected by distribution asset. (e.g., metallic fence near a substation)	0.1	Backyard- 416 contacts/yr for 4 sec	Standard

		Note: Does not apply to commercial installations or to direct contact situations involving Evoenergy's distribution asset (e.g., substation). See DU below			
Urban interface	DU	Contact with distribution asset in urban interface location (e.g., substation)	0.1	135 contacts/yr for 4 sec	Standard
Remote	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 of 0.1 per year assumed in a standard curve does not match that experienced at the given location
- Where a group of people could likely gather in the vicinity of an Evoenergy asset such as a substation or a conductive pole (See Section 6.2.2)
- 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 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 $1x10^{-6}$ 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_{coinc}, 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 8.9 and 8.10.

FIGURE 6. – ARGON RISK ASSESSMENT EXAMPLE – INDIVIDUAL RISK

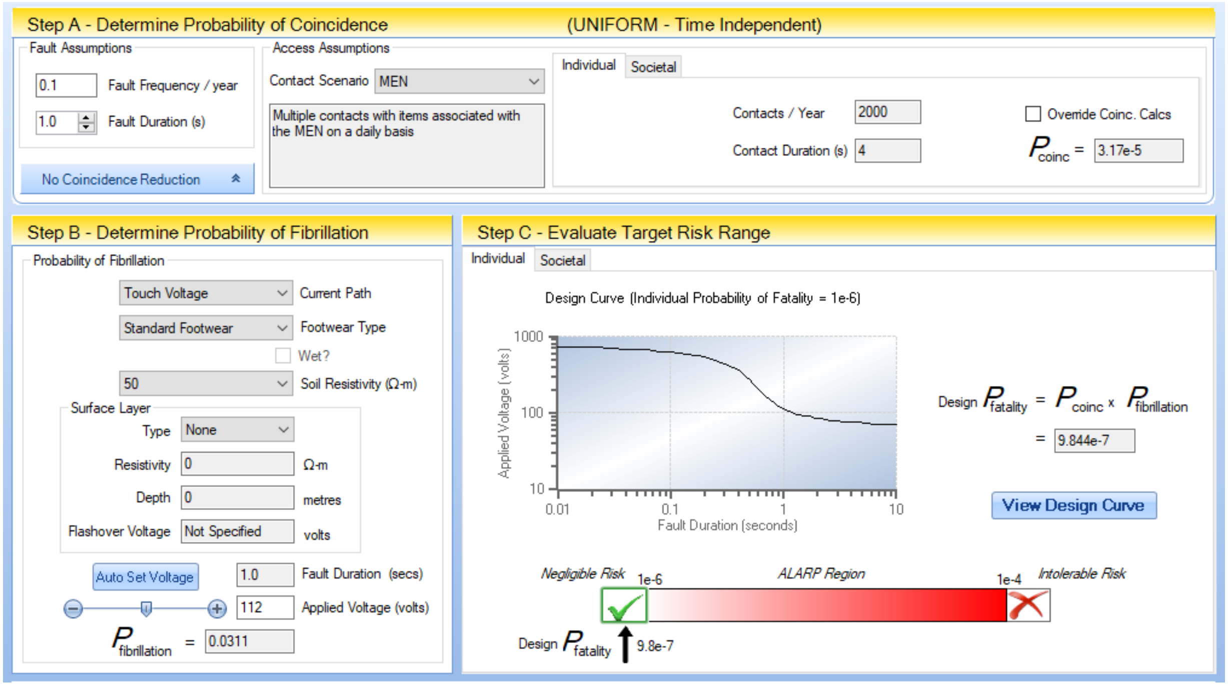
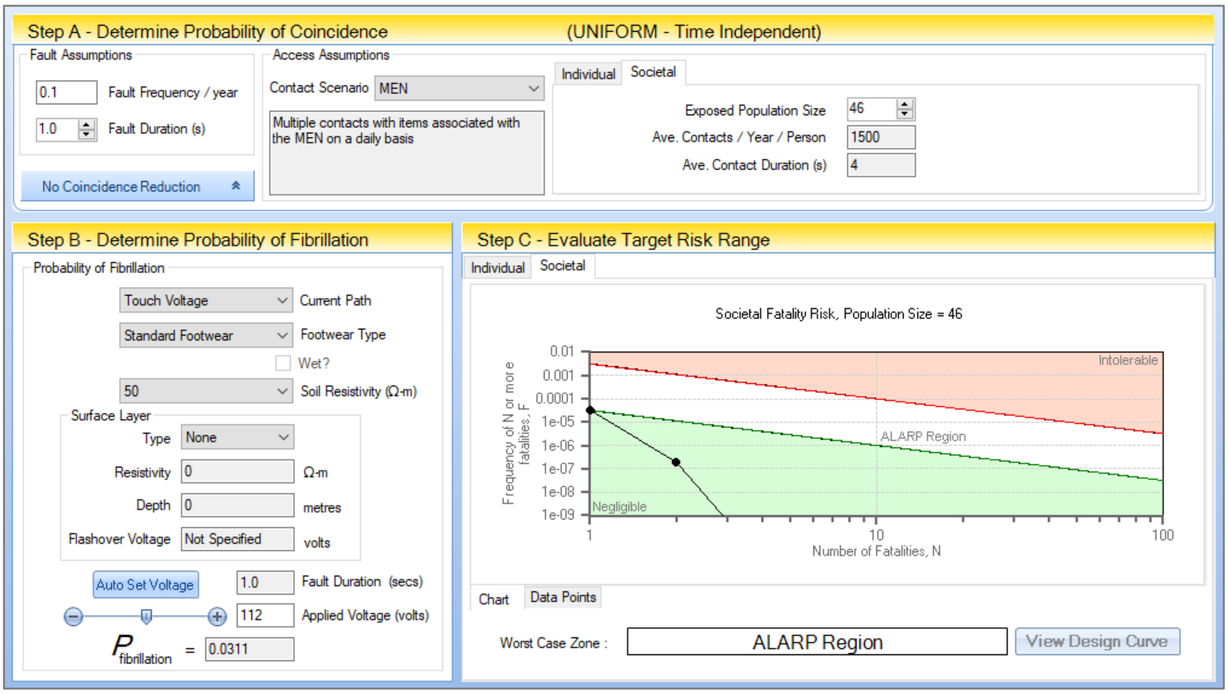


FIGURE 7. – ARGON RISK ASSESSMENT EXAMPLE – SOCIETAL RISK (F-N CURVE)



7. DISTRIBUTION EARTHING SYSTEMS

Evoenergy's low voltage network is a multiple earthed neutral (MEN) system.

The MEN system relies on a large number of low impedance earths on the LV neutral to obtain 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)

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 apply, and earthing systems shall be designed in accordance with the risk-based approach.

The following methods are used for the safety earthing of Evoenergy's distribution network assets:

- a common earthed, or CMEN, system where the LV MEN system is interconnected with the HV earthing system
- a separately earthed system where the LV MEN system is kept separate from the HV earthing system

7.1 The CMEN System

In the CMEN system the low voltage earthing system is considered to provide a low enough resistance to remote earth allowing the high voltage earthing system 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.

The conditions required for creating a CMEN system are:

- all credible risk scenarios involving touch, step, and transfer potentials and EPR at 3rd party assets that could arise with the earthing systems interconnected have been assessed for compliance

  AND

- a **combined** earth grid resistance of less than 1Ω can be achieved

  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 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 resistance cannot be brought low enough to manage local and transfer voltage hazards. The application of CMEN needs to be considered carefully in such cases.

Distribution substations supplied by cable with screen bonded to Zone substation earth grid are subject to 132kV transfer potential hazard. Of particular concern is that cable screen bonded CMEN substations may experience excessive EPR on the LV MEN during a 132kV fault at the Zone substation. This risk must be assessed before implementing a CMEN solution.

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.

Evoenergy's 11kV overhead line network does not have an overhead earth wire. It is not possible to interconnect HV earths of distribution substations in this overhead line network in order to drive overall HV earth resistance to an adequately low value. Hence It is unlikely that distribution substations supplied by an overhead line feeder will 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. Under this arrangement HV earthing must not impact LV earthing assets. This requires insulating the first span of the HV earth conductor.

7.2 The 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 MEN 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 MEN points may be removed from the system due to a variety of causes.
- Where the assessed touch voltage at a MEN item exceeds AS2067 TDMEN or AQ12 safety criteria if the earthing systems are combined. This is generally the case with cable screen bonded substations close to the Zone substation (within 2km)
- Close to swimming pools
- Substations connected to a predominantly 11kV overhead line feeder
- Transferred HV or 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

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 varies with depth, and it is rare to encounter soil with uniform resistivity to any considerable depth. In practice several layers are present. Using a homogenous soil model to represent this type of soil in design calculations will result in inaccurate results. A two-layer model of the multi-layer soil has been shown to produce results of acceptable accuracy. The two-layer soil model comprises an upper layer to a given depth and a lower layer of infinite depth. The resistivities of the two layers are different. Several methods using algorithms to develop a two-layer model that best fits measured resistivity records are available. These analytical tools are incorporated in most proprietary earthing system design software.

It is important to ensure that tests carried out to obtain soil resistivity 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.

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, layout, and lengths.

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

- Vertically driven rods where site conditions permit this type of 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^2 hard drawn bare copper conductor installed in a 100mm 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 in separately earthed systems. A minimum 4 m separation between LV and HV earthing infrastructure is recommended. 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 an adequately low MEN resistance 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.

Further reduction is possible by providing a direct earth connection to source via 11kV cable screen bonding or another continuous conductor. Under this arrangement a portion of the earth fault current will flow directly back to source via the interconnected earth and hence not contribute to EPR at the local earthing system. The reduction in local EPR is substantial as the fault current return path via the cable screen is of low resistance and negligible reactance due to mutual coupling with the conductor. 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. Screening factor is the proportion of the total earth fault current flowing into earth via the distribution substation earthing system and other cable screen interconnected substations, the remainder returning to source through the bonded11kV cable screen.

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 direct to earth). 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 at Zone Substation and distribution substation ends. The risk of an EPR at the Zone Substation due to a 66kV or 132kV earth fault being transferred to earths of screen bonded 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 cable screen interconnected asset depends on several factors including the effective resistance of the combined earthing system. Assets with cable screens bonded to the source zone substation earth must undergo a transfer potential risk assessment to assess all applicable hazard scenarios (touch, transfer, telecommunications, and metallic pipeline services coordination).

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 upstream protection device before the Zone substation relay may be used, for example a recloser. It is appropriate to use drop-out fuses for pole 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 of magnitude 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. The recalculated 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.

Hazard voltages can also arise from faults in the low voltage network. These are generally limited to 240V but are lower in practice. However, given the contact scenario (domestic, commercial) the allowable touch voltage will be correspondingly lower.

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

The EPR around a hazard location is required to work out touch and step voltages. The EPR 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.

EPR at the following locations is required to assess risk:

- Telecommunication equipment (see Section 8.9)
- Buried metallic pipeline (see Section 8.10)
- Streetlight or traffic light column and cabinet
- Car park ticket machine
- Bus stop
- Rail infrastructure
- Metal fence
- Playground equipment

Simplified empirical formulae may be used to calculate the EPR and touch and step potentials at a given distance from the earth electrode or grid for simple symmetrical earthing arrangements in homogenous soil. Non-symmetrical more complex arrangements or non-homogenous soil conditions generally require computer programs that use advanced finite element earthing analysis algorithm for a 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 earthed metallic objects to the earthing system will reduce its earthing resistance but could also extend the hazard zone.

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. See Section 8.11

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.’

Per AS/NZS 3835.1 the EPR limit 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. If it can be confirmed that a clearing time of < 0.5 seconds can be achieved for a fault at the asset, and it is a ground mounted asset 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. In these cases, the allowable EPR will be lower. 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. The hazards covered are those caused by EPR and LFI.

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 vicinity of 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 4. Touch voltage limits shown in this table assume a fault frequency of 10 per year and fault duration of 1 second. If these conditions do not apply for the given scenario 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)

AFECTED 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 Induced voltages on conductive infrastructure near power lines

Conductive objects such as fences and pipelines located in the vicinity of power lines will experience induced voltages with respect to earth due to a varying magnetic field (at 50Hz) through the object. This magnetic field is created by current flowing through the power line and is present as long as there is current flow. At power frequency the voltage in the conductive object is said to be created through low frequency induction (LFI).

Voltages caused by LFI may lead to a hazardous condition for people who come in contact with the object. The voltage induced in the object depends on:

- Distance of object from the power line – decreases with distance
- Length and alignment of object with the power line – increases with length; greatest when it runs parallel to the power line

- Magnitude of unbalanced current through the power line – since the unbalance is greatest under fault conditions the induced voltage is significantly higher during a line to earth fault compared to under normal operating conditions; the shielding on 11kV cables reduces the external magnetic field to very low levels even under fault conditions and hence LFI is generally not a concern with 11kV cables.
- Soil resistivity – increases with resistivity; is influenced more by the deeper layer

The risk of LFI on metallic fences and pipeline located close to power lines must be assessed for tolerable touch voltage limits during a power line earth fault. The risk scenario used (TDU, TDB, TDMEN etc) will depend on the location and expected activity.

Typically, for a soil resistivity of 800Ωm a 500m long isolated (i.e., not earthed at any point) fence running parallel to the power line with 10m horizontal separation from the line will have an induced voltage of 500V when an earth fault current of 3000A flows through the power line. The touch voltage limit for a fault duration of 0.3s (conservative estimate for a 3kA fault current) is 650V using the TDB contact scenario. In this case the risk due LFI voltage is low. For lower fault levels the fault duration will increase with corresponding decrease in allowable touch voltage limit. However, the induced voltage will also be lower due to the lower fault current. This illustrates the need to carry out a detailed risk assessment for long conductive objects, such as fences and pipelines located in the vicinity of power lines. In general objects longer than 400m will require assessment for LFI voltage hazard.

Another hazard arising from proximity to power lines is caused by capacitive coupling with a nearby non-earthed or poorly earthed metal object, such as a fence. An electric field is always present around an energised line even without current flow. Non-earthed objects (conductive ones in particular) are charged by this electric field. The magnitude of the electric field increases with voltage This is a low-risk hazard as far as fences near 11kV power lines are concerned. It is also not a concern for buried metal pipeline in contact with earth.

8.12 Low Voltage Earthing

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. It is possible however that the fault duration may exceed this or even remain uncleared. A risk assessment taking into account conditions specific to the situation creating this type of hazard is required if this is of concern.

A 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.

LV earth resistance should not exceed 15Ω.

LV earth shall be separated from HV earth by at least 4 meters. The actual separation required must 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.

8.13 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. 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 for information on flash to bang time limits and personal/group early warning systems).

Lightning protection earth may be bonded to any 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.

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 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

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 70mm2 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 70mm2 (19/2.14mm) copper. The buried insulated section required to connect onto the top of bored electrodes shall be black insulated minimum 70mm2 copper.

Table 6 gives ratings for bare and PVC insulated 70mm2 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 AMP	1 SECOND CURRENT RATING AMP
70mm^2 Cu bare	8414	11900
70mm^2 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. Labels

Warning labels are required for all removable earthing connections as below:

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

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

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

11.1 Introduction

This section provides earthing requirements for specific overhead installations.

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 works
- 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. 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 metalwork
- 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 poles

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 must 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.

11.9.1 Accessible metalwork and streetlights on LV conductive poles

Accessible conductive items such as metallic cabinets that could become live due to contact with the pole or be inadvertently energised in a fault situation must be bonded to the LV neutral and pole earth.

Streetlight brackets must be bonded to the pole earth ferrule via an earth strap.

11.10 HV conductive poles

Conductive HV in-line poles must be connected to earth via a bond between the pole earth ferrule and an earth stake. Additional earthing is not required. (Refer to Section 13.3). In special locations the touch voltage must be controlled to less than the safety criteria applicable to the location. If standard curves cannot be used a dedicated assessment must be carried out using ARGON.

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

11.10.1 Accessible metalwork on HV conductive poles

Conductive HV pole mounted equipment taking LV supply from an external separately earthed substation must be earthed separate from the HV pole earth using double insulated earth cable. The LV cabinet support must provide insulation from the pole structure to at least 3kV.

Metal cabinets with LV supply from a CMEN substation must be bonded to the pole earth via a direct connection to the pole earth ferrule. Other accessible metalwork including cabinets not associated with any external service must also be bonded to the pole earth.

12. REQUIREMENTS FOR SPECIFIC UNDERGROUND INSTALLATIONS

12.1 Introduction

This section provides earthing requirements for specific underground and free-standing ground mounted installations.

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 earth continuity conductors
- grading ring
- HV earthing electrode/s
- LV switchboard frame

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

- low voltage neutral of the transformer (via LV switchboard neutral to earth link)
- LV earthing electrode/s.

The neutral and earth bars in the LV switchboard must be mounted on post insulators to maintain adequate separation from the switchboard frame. Refer to drawing D303-0009 for details.

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 (via LV switchboard neutral to earth link)
- 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 a footpath or in a park.

All HV equipment shall be connected to the local HV earth.

Touch voltages must be assessed for compliance with 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 70mm2 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 (via LV switchboard neutral to earth link)
- cable sheaths
- building structural steelwork
- a local earthing system
- embedded chamber equipotential frame
- any metal work such as entry doors and louvres

If the substation is not on the level directly above ground, then two 120mm2 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 footprint 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

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 assess 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
- 10 second clearing time (risk level does not rise significantly after this duration)
- 416 contacts of 4 sec duration per year (“Distribution Backyard” assumption from EG-0)
- Surface soil resistivity 5 Ωm
- 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
- 10 second clearing time (risk level does not rise significantly after this duration)
- 312 contacts per person of 4 sec duration per year (“Distribution Backyard” assumption from ENA EG-0)
- Surface soil resistivity 5 Ωm
- Wet bare feet
- Assumed maximum population size 42

Using ARGON, the touch voltage should not exceed 57V 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 (240Vx 0.8 x 0.65). This is significantly above the allowable touch voltage limit of 57V 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 and considering the influence of the soil material on touch voltage. The contact scenario assumed in this assessment is also very conservative and may be reviewed to better reflect site specific conditions.

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 7.1 cannot be met.

Mitigation options include:

- Non-conductive LV poles (e.g., fibreglass)
- Insulating the base of conductive poles

- Grading rings (the efficacy of this option requires further investigation)
- Surface insulating layer on the ground around the pole

Grading rings are not recommended as they will not reduce the touch voltage sufficiently 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.

13.3 HV 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 remains uncleared on a conductive HV pole. To ensure protection eventually 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^{-5} x 2 x 80)
- 10 second fault duration (conservative value to represent extended fault clearing times
- 55 contacts of 4 sec duration per year; assumes that a pole experiencing an extended fault clearing time would be located some distance down the feeder)
- 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
- 10 second fault duration (conservative value to represent extended fault clearing times)
- 55 contacts per person of 4 sec duration per year
- Standard footwear
- Assumed maximum population size 25

Using ARGON, the touch voltage should not exceed 5000V for acceptable individual risk based on the assumptions listed above. The allowable limit is higher for societal risk. A reasonable estimate of touch voltage under unfavourable soil conditions is 1200V. This puts the risk in the acceptable range.

Where the boundary conditions specified above cannot be satisfied (e.g., at a special location) the risk must be assessed using the applicable conditions including estimates of fault level and duration. Risk levels above the negligible limit will require mitigation – see Section 14.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 x 10-6 indicating an overall negligible risk level for this hazard scenario.

13.4 Combined HV and LV poles risk

13.4.1 Risk for HV equipment mounted on conductive poles

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 regulators on 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 only conductive poles. However, HV conductive 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}.

14. MITIGATION

14.1 Introduction

When designing earthing systems, the following risk treatment methods should be considered to manage risk associated with step, touch and transferred voltage hazards if elimination of the risk (e.g., by relocating the asset) is not practical:

- 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 series in the fault loop. Typically, earth grid impedance must approach source impedance value before EPR starts decreasing significantly.

Several options are available to reduce earth resistance such as increasing the electrode count; revising electrode length and arrangement to optimise on the soil model; and interconnecting to other earthing systems. This will affect the EPR contour and impact the hazard zone around the asset. In some circumstances, extension of the EPR contours and a corresponding increase in the hazard zone may be significant compared to a small gain in EPR reduction. Whether this is a desirable outcome will depend on the particular situation.

14.3 Fault current limitation

Earth fault current flowing through earthing systems may be reduced by the installation of neutral earthing impedances 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 and low value.

The effect on protection clearing must be investigated when considering impedance earthing 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 reduced fault current could prevent the fault from being cleared by the protection device.

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.

Earth bonding of a single core cable at both ends will affect the thermal rating of the cable due to induced currents in the screen and sheath. Care should be taken to ensure the rating of the cable is adequate for the application.

The cable screen should be adequately rated for the expected earth fault current and fault current duration, and for current induced in the screen during normal operation.

Electrical continuity conductors may be used to connect the earthing systems of adjacent substations where use of cable screens is not practical. The minimum requirement is 70mm2 bare copper conductor with a bonded 2.4m earth stake every 100m.

Shield wires, either overhead or underslung, may also be used for electrical continuity of the earth fault loop. 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.

Overhead or underslung earth wires across several spans of HV conductive poles earthed at both ends and several intermittent locations may be a solution to lower the earth resistance of the connected asset.

Inductive coupling between the shield wire(s) and the faulted phase conductor can significantly reduce the proportion of fault current flowing directly to earth via the earth grid. This, in turn, reduces the EPR levels at both the substation and at the conductive pole or tower. However, the fault rate at any connected asset will increase.

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 and type of soil
- 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 on high resistivity soil 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 pole, 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 Ωm and a minimum thickness of 100 mm should be used for crushed rock.
- a resistivity of 10,000 Ωm 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

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—

1. to eliminate risks to health and safety, so far as is reasonably practicable; and
2. 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 AC

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

- Evoenergy Distribution Transformer Fuse Application Guide
- Distribution Earthing Testing Manual
- Soil Resistivity Survey Form
- 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 Practicable
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 rises 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, Prospective and Loaded	A prospective touch voltage is the open-circuit voltage that appears between any point of contact to conductive surface above ground and any point on the surface of the ground at a horizontal distance of 1m away from the vertical projection of the point of contact. A loaded touch voltage is the actual voltage that appears across the human body resistance for the above-described situation.
UG	Underground construction
Zone Substation	An electrical installation transforming from 132kV or 66kV to 22kV or 11kV.

VERSION CONTROL

VERSION	DETAILS	APPROVED
1.0	1st 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
6.1	ALARP approach added in Appendix F & G; B. Bramanathan; M. Horsley	N. Azizi; W. Cleland 02/02/2022 Asset Standards and Acceptance Manager
6.2	Minor Update and template updated	N. Azizi; 20/11/2023

DOCUMENT CONTROL

DOCUMENT OWNER	DOCUMENT CUSTODIAN	PUBLISH DATE	REVIEW DATE
Group Manager Strategy and Operations	Principal Engineer Standards and Specifications	27/11/2023	27/11/2025

APPENDIX A – EVOENERGY DISTRIBUTION SYSTEM

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.

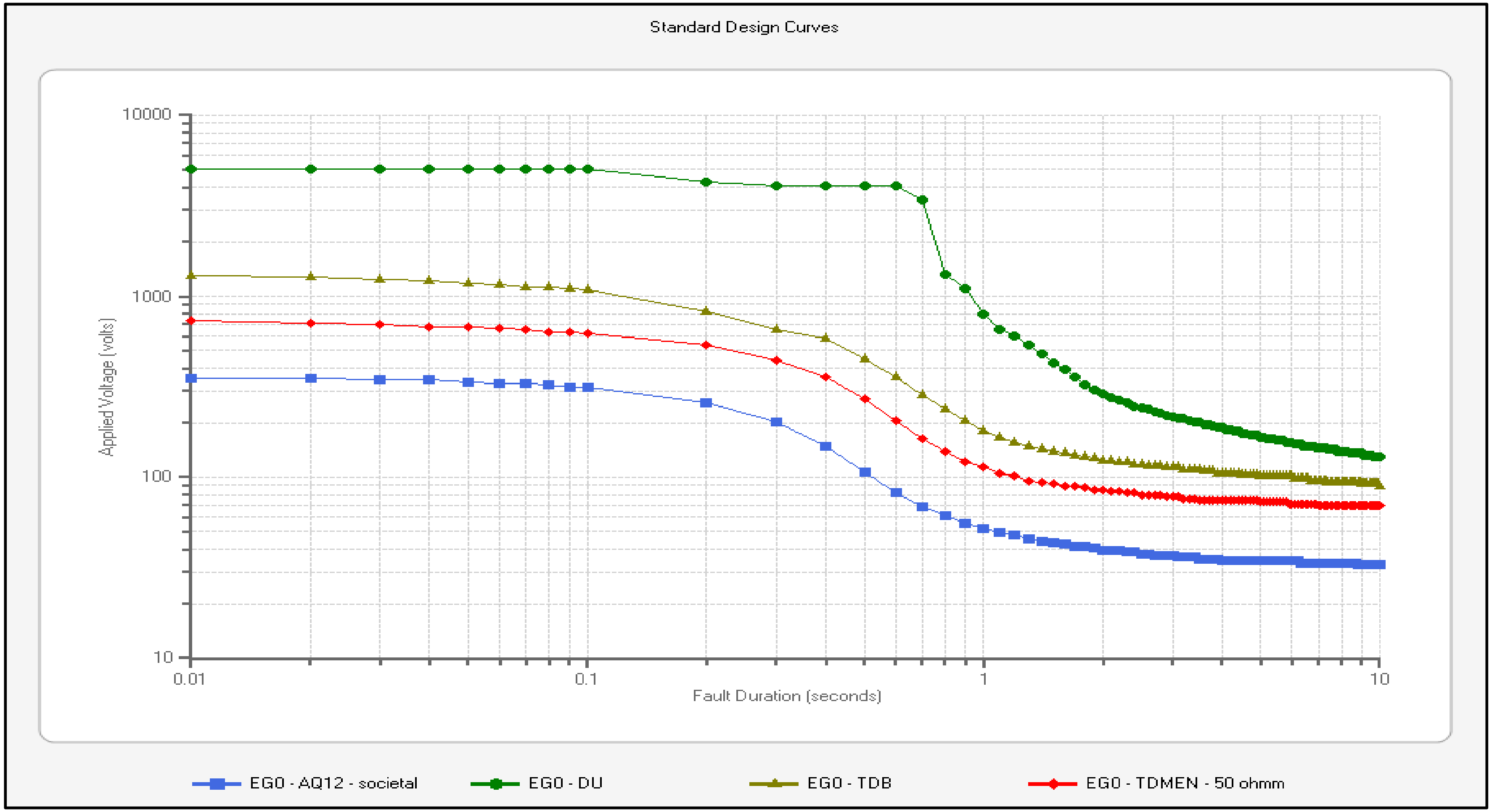
There is no SWER in the Evoenergy network.

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.

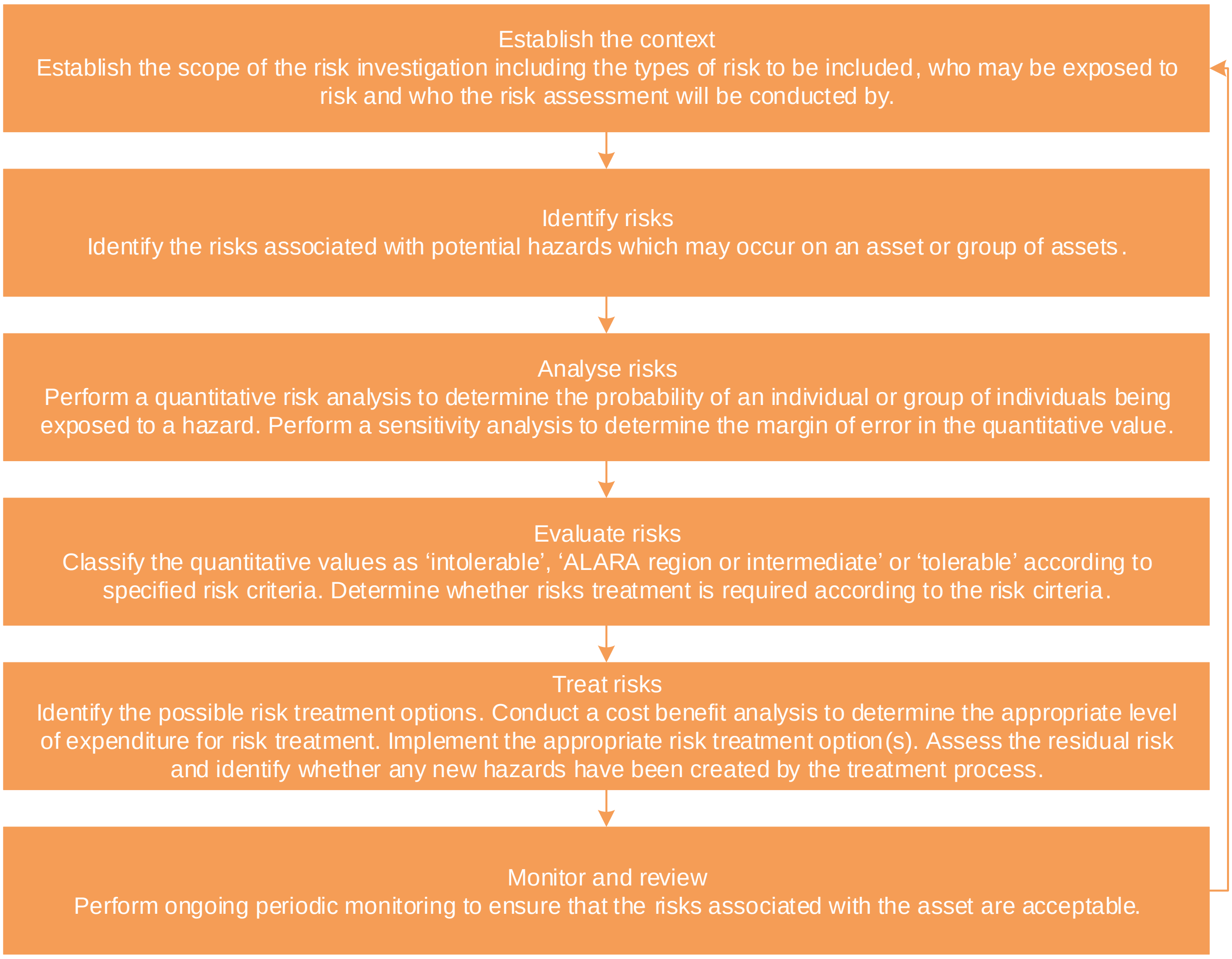
Table 6. **DISTRIBUTION FEEDER AND SUBSTATION STATITICS**

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)
MINIMUM	0.756	3	0.044	2.121	2	0.133
MAXIMUM	13.984	41	0.632	7.985	21	2.114
AVERAGE	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)	33
Annual 11kV feeder fault rate	0.066

Notes:

3. Network feeder length calculated from **Evoenergy Electrical Data Manual** feeder data.
4. Fault data obtained from real time systems records (ADMS).
5. Typical fault rate per ENA EG-0 Table A2 is 10-40 faults/100km/year for 11kV
6. Assuming a 0.2km fault exposure length at any given location: [33 x 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**

Total distribution substations in Evoenergy network	**5709**[1]
Total distribution substation 11kV faults over 3-year period	1215[2]
Average annual distribution substation fault rate	0.07

Notes:

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

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

APPENDIX F – INCORPORATING THE ALARP PROCESS IN EARTHING DESIGN

It is possible in general to obtain a compliant design (i.e. one that delivers a risk level of less than 1×10^{-6} probability of fatality) using current practice and resources. By exercising due care and diligence cost-effective and practical solutions can always be arrived at.

The process described below can be used to decide if a contemplated solution can be justified on a cost-benefit rationale for designs that fail to meet standard compliance criteria.

Context

The Earthing Strategy (PO07141) identified a need to change earthing risk decision processes and introduce risk value-based investments in the ALARP region of the risk tolerability triangle. This is captured in Figure 1.

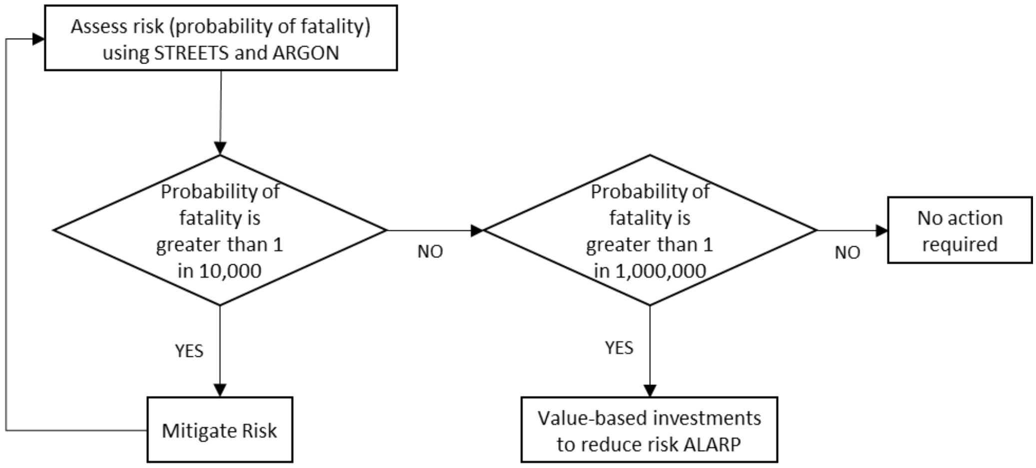


FIGURE 1 EARTHING DESIGN RISK DECISION CHART

Quantifying risk and benefits

Probability of fatality

Earthing systems are required to manage the transfer of fault energy to limit the risk to people, equipment, and system operation. The primary consequence considered when designing an earthing system is a fatality resulting from the proximity of a person to an asset whilst there are dangerous fault energies present. This considers a number of factors which include:

- Level of traffic in the area
- Frequency and type of faults
- Fault levels and clearing times
- Other nearby assets (belonging to Evoenergy or third parties) that may modify the hazard profile
- Soil properties
- Type of land use
- Earthing electrode configuration

Evoenergy utilises two software systems to assist in the calculation of likelihood of fatality: STREETS and ARGON. Designers input combinations of these factors and earthing designs (some of which may exist in pre-defined 'scenarios') to perform the calculation.

Monetised risk

Evoenergy's Asset Risk Value Framework (PO0713) is an artefact that provides a generalised approach to quantifying the monetised risk associated with assets to use as inputs to economic cost benefit analysis.

The Asset Risk Value Framework defines the value of statistical life (*VoSL*) as a value which varies over time (in part tied to the ABS Wage Price Index), for which we can initially use:

$$VoSL = \$4.9M \tag{1}$$

The risk associated with an asset is the sum of monetised risk across the categories of:

- safety
- reliability
- environment and
- financial

In a target state of maturity, earthing risk would be assessed against all of these factors. However, in initial implementation we will consider only the safety risk associated with fatalities with an assumption that this is the dominant risk, and the dominant risk that changes when designs change. This simplification is likely to underestimate the magnitude of risk, as well as the magnitude of change in risk (usually considered from a benefit perspective) from differing designs.

Bringing together the above discussion points, we will calculate the monetised risk of an earthing asset/design with a given probability of fatality ($P_{fatality}$) as:

$$Risk\ (\$) = VoSL * \ P_{fatality} \tag{2}$$

Disproportion factor

For some types of risk, Evoenergy has an appetite to spend more than the calculated value of a risk to reduce that risk. This is typically the case for safety risks, for which the Asset Risk Value Framework assigns a range of disproportion factor (*DF*) values that scale with level of severity. A fatality is classified as a Severe safety event, with a disproportion factor of:

$$DF_{Safety\ Severe} = 10 \tag{3}$$

And the modified risk becomes

$$\begin{aligned} Risk'\ (\$) &= DF_{Safety\ Severe} * Risk\ (\$) \\ &= DF_{Safety\ Severe} * \ VoSL * P_{fatality} \end{aligned} \tag{4}$$

Benefit

Benefits are measured as the reduction in risk between one option (including the 'do nothing' option) and another. A naïve approach to the benefit can be calculated as:

$$\begin{aligned} Benefit_{naive} &= \ \Delta Risk'(\$) \\ &= DF_{Safety\ Severe} * \ VoSL * \Delta P_{fatality} \end{aligned} \tag{5}$$

By assessing benefit against the modified risk (rather than original risk) we are able to incorporate the organisation's appetite to pay over and above the original calculated value for this type of risk. However, this approach does not account for the time-based risk benefit provided over the remaining life of the asset.

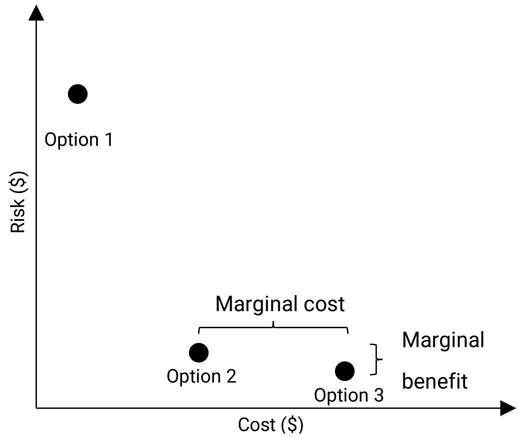
A present value approach can refine the naïve approach to account for these future risk benefits. If we assume that the risk stays constant over the remaining asset life, then the present value of the benefit becomes:

$$
\begin{aligned}
Benefit_{PV} &= PV(D, N, \Delta Risk'(\$)_t) \\
&= \Delta Risk'(\$) * PV(D, N, 1) \\
&= \Delta Risk'(\$) \sum_{t=1}^{N} \frac{1}{(1+D)^t} \\
&= DF_{Safety\ Severe} * VoSL * \Delta P_{fatality} * \sum_{t=1}^{N} \frac{1}{(1+D)^t} \qquad (6)
\end{aligned}
$$

$$
\begin{aligned}
where\ N &= number\ of\ years\ [for\ which\ the\ asset\ will\ remain\ hazardous] \\
D &= discount\ rate\ [WACC\ or\ similar]
\end{aligned}
$$

Investment value and marginal benefit

The value of an investment is the difference between its cost and benefit. When evaluating the merits of an option, its benefits should be assessed on a marginal basis. That is, what is the additional cost of reducing risk by this additional amount relative to other options?



Evaluating investment options

Overview

The general principle when evaluating earthing investment options with risk in the ALARP region is to select the design option with lowest probability of fatality that also satisfies a positive marginal value condition (i.e., the marginal benefit is greater than the marginal cost).

A preferred option is selected by iterative refinement of the total list of options with the following steps:

- Develop a set of options
  - Options should include a base case where no investment is made
  - Probability of fatality should be calculated in an appropriate earthing risk software such as STREETS or ARGON
  - Costs should be estimated to at least a rough order of magnitude level
- Eliminate options with intolerable risk (risk higher than the ALARP region)
  - Any options with probability of fatality greater than 1 in 10,000 cannot be selected as the preferred choice
- Eliminate options with negative marginal investment value
  - For each option (other than the 'do nothing' option), find its appropriate comparison option. Calculate the marginal benefit (Eq. 6) and marginal cost against all other design options. The appropriate comparison marginal value is the one with lowest positive ratio between marginal benefit and marginal cost (to avoid spurious comparisons to inferior options).

- With respect to this selected comparison option, eliminate any option that has marginal cost higher than marginal benefit. Given that this should occur on an NPV basis with disproportion factors applied, these eliminated options have costs that are grossly disproportionate to the benefits.
- Note that these options may be reconsidered if no other options are outside of the intolerable risk region.

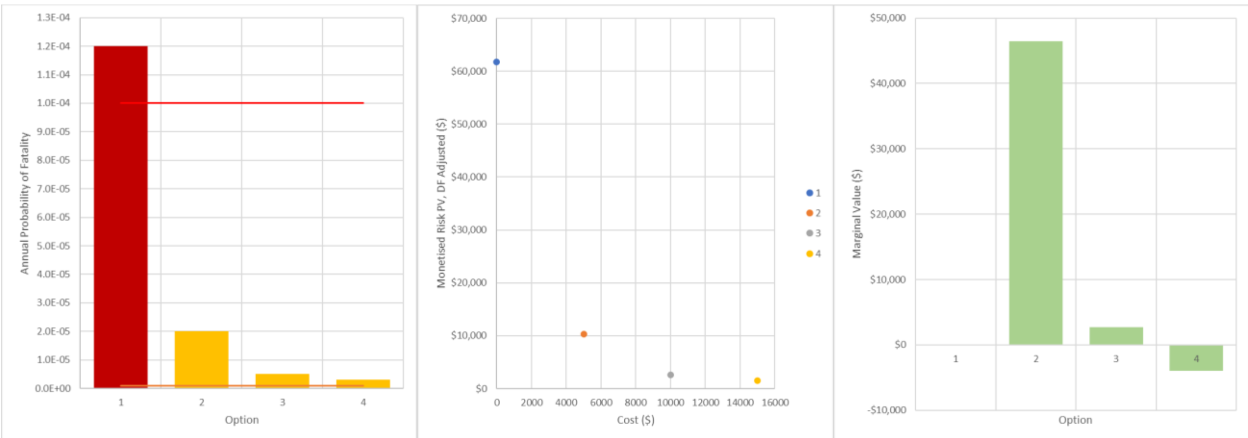
- Of the remaining shortlist, the preferred option is the one with lowest risk

This logic is implemented in an accompanying investment evaluation spreadsheet that can be used for decision-making in practice (Appendix G)

Example

Consider an asset where the risk and cost of four Options has been calculated[1]:

Option	Annual fatality risk	Cost	Marginal Value	Preferred option?
1	1.20E-04	$0	$0	FALSE
2	2.00E-05	$5,000	$46,477	FALSE
3	5.00E-06	$10,000	$2,722	TRUE
4	3.00E-06	$15,000	-$3,970	FALSE



Option 3 is selected as the preferred option as follows:

- Option 1 is eliminated due to its unacceptable risk (>10-4)
- Option 4 is eliminated due to its negative marginal value (the marginal risk reduction benefit is grossly disproportionate to its additional cost when compared against Option 3).
- Options 3 preferred as it has lower risk than Option 2.

Future Opportunities

- Equation 3 states that a disproportion factor of 10 should be used in line with the Asset Risk Value Framework. Because the Framework has had limited utilisation within Evoenergy, there is likely to be a period of time where testing and adjustment of this value is needed to ensure that decisions are well calibrated to the corporate risk appetite. In the meantime, this value of 10 should be considered a guide rather than a mandate, with difference in the earthing context potentially tolerated as long as

[1] Assumptions: VoSL = $5M; N = 40y; D = 5%; DF = 6

it is explicitly acknowledged where used and communicated to the Principal Engineer Asset Optimisation & Network Reliability.

When this ALARP demonstration process and tool have had time to become regularly used in design work, the types of assumptions needed to perform the evaluation in practice will become apparent. These should be collated into a standard assumptions reference list to ensure consistency in application between users.

APPENDIX G – ALARP RCBA TOOL