PURPOSE AND SCOPE

The purpose of this document is to provide for adoption of CMEN earthing system in the Ergon Energy distribution network. This document provides an interim guideline / methodology for the adoption of CMEN earthing system as part of the network design.

The CMEN system is the preferred method by which to earth Ergon Energy's distribution network, however should only be employed in areas where there is an abundance of low voltage interconnections and a low overall resistance to ground is achievable.

RESPONSIBILITIES

Group Manager Engineering Standards & Technology is the Process Owner responsible for approving this Reference document.

Engineering Manager Distribution Network Standards is responsible for maintaining this Reference document.

Underground & Public Lighting Standards Engineer is the Subject Matter Expert (SME) for the content this Reference document.

DEFINITIONS, ABBREVIATIONS AND ACRONYMS

CMEN Common Multiple Earth Neutral

SWER Single Wire Earth Return

HV High Voltage

LV Low Voltage

MEN Multiple Earthed Neutral

IEC International Electrotechnical Commission

OHEW Overhead Earth Wire

R_{NE} Resistance of network extension

R_E Resistance of existing network

R_t Design Earth Resistance

Design Earthing Resistance the overall resistance required to be obtained / achieved to comply with Curve A1 (refer Electrical Safety Code of Practice 2010 – Works, Clause 3.3.4). The value of this resistance is dependent upon the protection clearing time over the expected range of fault currents at the point of the network extension. Refer to Appendix A1 for a detailed explanation of the fault current range. The Design Earth Resistance is usually a combination of the existing resistance and the resistance of equipment to be connected.

Disconnected Earth Resistance the standalone earth mat resistance value without interconnection to the rest of the network. E.g. disconnected from the neutral, HV cable screens, etc.

REFERENCES

Electricity Act 1994

Electrical Safety Act 2002

Electrical Safety Regulation 2002

Electrical Safety Code of Practice 2010 Works

Distribution Design Manual

Overhead Construction Manual

Public Lighting Construction Manual

Underground Construction Manual

INTRODUCTION

CMEN is a variation of the MEN system whereby the HV earths are bonded to the LV neutral earth system. The system uses the LV system earth resistance obtained by the interconnection of multiple LV substations and faster clearing time to limit the step and touch voltages in the vicinity of earthed structures following the occurrence of a fault.

STATUTORY AND ADVISORY GUIDELINES

The Electrical Safety Code Of Practice 2010 Works (Subordinate to the Queensland Electrical Safety Act and Regulation) sets out recommended earthing practices for Queensland Electricity Distribution systems. This Code Of Practice specifies a maximum earth resistance of 1 ohm for CMEN and prospective touch voltage limits within curve A1 (refer Electrical Safety Code of Practice 2010 – Works, Clause 3.3.4) – refer to Appendix A2.

The specified limits are classified by line voltages (below 66kV and 66kV and above) and by the probability of exposure to the public. Locality classifications are Special, Frequented and Remote as defined below.

- A Special Location is a location within a school's grounds or within a children's playground, or within a public swimming pool area, or at popular beach or water recreation area, or in a public thoroughfare within 100 metres of any of the above locations.
- A Frequented location is any urban area associated with a city or town other than special locations.
- A Remote location is an area not defined as special or frequented.

The curves derived for the special category for voltages below 66 kV are the most onerous and are consistent with IEC recommendations for current which will not result in death for 95% of the population based on worst case for skin resistance, basically that for bare feet on wet concrete. The allowable current and therefore voltage is dependent on the fault clearing time. For clearing times of 0.2 second or less, the allowable voltage rise is 600 volts. For clearing times greater than 2 seconds, the figure is 60 volts with a log linear interpolation between these points.

The more liberal curves for frequented locations are the result of taking into account the reduced probability of members of the public being in the proximity of the asset, the likelihood of footwear being worn and the probability of less than the worst case soil resistivity.

No limits are specified for earthed structures in remote locations.

In calculating the step and touch voltage in the vicinity of an earth structure, allowance can be made for the voltage gradient around the structure to reduce over a distance of several metres. Step and touch voltage differences over a distance of 1 metre are much less than the voltage to remote earth. This gradient effect is dependent on soil resistivity and can reduce the voltage difference accordingly.

RISKS ASSOCIATED WITH CMEN SYSTEMS & VOLTAGE RISE IN CUSTOMERS INSTALLATION

The introduction of a CMEN system significantly increases the possibility of voltage rise resulting from a fault on the high voltage system being transferred into consumer's residences. In such situations the voltage rise will occur between the frame of earthed appliances, water pipes, taps, etcetera and ground and this risk must be recognised and managed.

The probability of exposure in a domestic situation would be at least equal to that of a structure in a special location. When a CMEN system is introduced, compliance with the requirements of the special curve is considered necessary in order to limit transferred voltages into consumer earthing installations to safe values.

The Electrical Safety Code Of Practice 2010 – Works requirement for a maximum earth resistance value of 1 ohm for a CMEN system is not necessarily sufficient to ensure that voltage rise under fault conditions remains below recommended levels as defined by Curve A1. In practice a much lower value is required in areas of high to moderate fault levels. To achieve the allowable limit of 600 volts for up to 0.2 second clearing time in an area with a fault current approaching the maximum on the Ergon Energy system (above 15000 amps), an earth resistance of less than 0.04 ohm would be required.

RURAL APPLICATIONS

In rural applications, or situations where an extensive neutral system is not available, continuation of the use of a separate earth system will be necessary, due to the expense of obtaining an earth resistance of 1 ohm or less.

In these situations, consideration needs to be given to the magnitude of step and touch voltages for locations that are considered to be special or frequented when locating earthed structures. In general, most locations would be considered to be remote except for small townships or transformers located in close proximity to a customer’s residence. The possibility of frequented area’s voltage recommendations being exceeded will depend on the fault level, protection clearing time and HV earth resistance. It is unlikely that the limits for special locations would be able to be met at any location on the system.

APPLICATION OF CMEN TO OVERHEAD AND UNDERGROUND RETICULATIONS

Where an area is established as separately earthed and there is no requirement to convert the system to CMEN due to the installation of new equipment, separate earthed system can continue.

In locations which have established CMEN or are selected to be converted to CMEN, the existing equipment on the network shall be converted to CMEN earthing as part of the works. This will involve installing a bond between the HV and LV earth at the transformer. In some instances, it may be necessary to install an earth cable with the HV supply cable in order to tie the installation back to the adjacent overhead neutral system or install missing spans of LV network. Additionally if HV equipment such as free-standing RMU, air-break switches and gas switches are present in the area to be converted, these can also be tied to help reduce the total earth resistance value provided they meet the requirements in the respective Construction Manuals.

What to do when working with different earthing systems

The HV Cable screen is to remain double point bonded, i.e. the screen is to be connected to the HV earth at the separately earthed padmounted substation and the HV/LV earth at the common earthed padmounted substation.

The LV neutral is not to be connected between a separately earthed padmounted substation and a common earthed padmounted substation and / or OH transformers respectively.

What to do when working with the same earthing system

The LV neutral shall be made continuous between padmounted substations / OH transformers with the same earthing arrangements.

SUB-TRANSMISSION LINES

Sub-transmission (33kV, 66 kV & 132kV) conductive pole structures and OHEW’s should be kept separate from the Distribution Earthing system to avoid the possibility of sub-transmission voltages being transferred to the distribution system. On occasions when an LV service is to be attached to a sub-transmission conductive pole, a second level of LV insulation shall be provided. The requirement for use of overhead earthwires of low conductivity should be maintained in order to limit voltage rise on sub-transmission conductive poles.

SWER

The use of CMEN on SWER systems is not permitted due to the nature of the HV earths used on these systems. SWER installations are generally in remote areas where CMEN would not be practical or justified.

ESTABLISHMENT OF CMEN AREA

The following sequential steps should be followed in Establishment of a CMEN area or conversion of an existing area to CMEN earthing system.

Step 1: Define the possible CMEN area

Step 2: Identify the Design Earth Resistance (R_T)

Step 3: Determine the Existing System Earthing Resistance (R_E)

Step 4: Determine the required disconnected resistance for the network extension (R_{NE})

Step 5: Establish the CMEN area

Step 6: Record the new CMEN area in the relevant field in the GIS map- substation table.

These steps are provided in Microsoft Excel spreadsheet form in NA000403R482 Supplementary Reference to NA000403R481 Guideline for Adoption of CMEN Earthing System.

STEP 1: DEFINE THE POSSIBLE CMEN AREA

Use GIS data and / or local knowledge to locate areas where common earthing has been previously established or is proposed.

The locality may be a suburb or area of a large town or a small town supplied from a radial feeder. The proposed CMEN area may be small and contain as few as one distribution substation however in general the more substations that can be interconnected, the easier the required criteria will be to meet, particularly in areas close to zone substations with high fault levels.

There is no upper limit to the size of a CMEN area and it is possible that an entire city such as Rockhampton may become a single CMEN area containing hundreds of substations.

STEP 2: IDENTIFY THE DESIGN EARTH RESISTANCE

Part A: Developer Design and Construct
The Design Earth Resistance will be provided as part of the design parameters.

Part B: Ergon Energy Design
The designer is to request fault currents as defined below from Network Planning. The fault currents returned from Network Planning are to be forwarded to Protection. Protection will provide the designer with the Design Earth Resistance. The designer is to record the fault current and the design earth resistance in the e-folder for the job.

STEP 3: DETERMINE THE EXISTING SYSTEM EARTHING RESISTANCE

It is not considered practical to determine the resistance of a CMEN system by test. In lieu of a practical test methodology the CMEN resistance shall be determined by calculation. A methodology of determination by calculation is shown below. In all cases, the designer and approver shall confirm that the method of calculation and verification is appropriate.

HV and LV system earths

Where possible the disconnected test values for the padmount substations / OH Transformer and MEN earths should be used, however where such data is unavailable the maximum earth resistances of the padmount substation / OH Transformer and MEN earths specified in the Construction Manuals should be used.
Note: For earths in close proximity (spaced less than 2 x depth of the stake) it is prudent to exclude the higher of the two values from the calculation.

Once the HV and LV system earth values are known the total resistance of the system can be calculated using the parallel resistor formula, combining all earthing resistance data to establish the equivalent total resistance for the area defined in step 1.

$$\frac{1}{R_E} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \quad \text{Eq. 1}$$

Where:
R_E .... Resistance of existing network

$R_1, R_2, R_3, \ldots, R_n$ .... Resistance of individual earths that are installed on the network

Note: Where completion of the calculation described above (R_E) demonstrates that the existing CMEN area as defined in Step 1 meets the requirements of Step 2 (R_t), there is no need to proceed with the remaining steps. The Network Extension can be installed with value less than or equal to the maximum as prescribed in the appropriate Construction Manuals.

Customer Earths & Other Earths

Ergon Energy's preference is customer earths and conductive poles (e.g. Streetlight poles) are not included in the calculation for system resistance. Often these earths are of unknown value.

The above may be included in any calculations at the certifying engineer's discretion and subject to Ergon Energy agreement. Customer's earths may only be included in calculations for established properties; no customer's earths shall be included for future properties.

Care must be taken when measuring earth resistance. Driven earth stakes and / or additional bare earth electrodes laid in the ground shall be clearly identified and isolated to limit "double dipping", otherwise false measurements can result.

Check that the LV Neutral System has adequate cross sectional area.

The neutral conductor system must be capable of carrying the fault current both from the consideration of thermal overload and dissipation of the fault current into the LV neutral network such that voltage rise in the neutral does not cause the design CMEN voltage rise to be exceeded.

In general, neutral conductor sizes will be more than adequate to cater for the maximum fault currents likely to be experienced provided that the combined copper equivalent area of all neutrals exiting the substation exceeds 50 sq mm. E.g. two circuits of 7/.080 copper may be marginal.

Additional design checks may be necessary in cases such as the following:

- A location close to a major Zone substation.
- A single customer pole mount or chamber substation that is connected to the LV neutral system via a cable screen or a significant run of single neutral conductor.
- A situation where a feeder exit cable screen is bonded at both ends and will be in the fault current path.

In some cases it may be necessary to upgrade the neutral conductor.

Established CMEN area

If the area defined in step 1 is an established CMEN area and the calculation shows that is does not meet the design earth resistance then:

1. increase the size of the CMEN area defined in step 1 and / or
2. if all interconnected earths have been considered and the earthing resistance still does not comply, then notify the Ergon Energy Regional Asset Manager.

STEP 4: DETERMINE THE REQUIRED DISCONNECTED RESISTANCE FOR THE NETWORK EXTENSION

The disconnected earth resistance for the network extension can be calculated by the method described below.

$R_{NE} = \frac{R_E \times R_t}{R_E - R_t}$ .... Eq. 2

Where:

R_{NE} .... Resistance of network extension

R_E .... Resistance of existing network

R_t .... Design Earth Resistance

The result (R_{NE}) is the combined resistance of all the earths for the network extension. It is recommended that the designer consider calculating disconnect earthmat resistances for individual equipment which forms part of the network extension. Ergon Energy's preference is that LV MENs are considered installed at the maximum value specified in the construction manuals. Consideration should be given if the value calculated can be practically achieved onsite.

<u>Where the designer considers that it is not practical to achieve the disconnect resistance calculated, either separate HV and LV earthing must be used or additional interconnection between network areas added.</u> Another option is to reduce the protection clearing time by installation of a fuse (e.g. Installation of a HV fuse at the cable termination pole to protect a padmount may be an option for some installations), however this option must be carefully considered due to the impact on the overall feeder protection scheme and as such Protection Group must be engaged if this option is to be implemented.

E.g. For a typical subdivision requiring 4 padmount substations with an existing network resistance of 0.16 ohm ($R_E = 0.16\,ohm$), and a design earth resistance of 0.13 ohm ($R_t = 0.13\,ohm$) the required maximum disconnected resistance of the new subdivision would be 0.69 ohm ($R_{NE} = 0.69\,ohm$). The 0.69 ohm will be made up of the combined parallel resistance of the padmount substation's earths plus the MEN earths on the new network extension.

Calculations for the CMEN shall be submitted with the construction plan at the approval stage.

Note: the above methodology is not the only methodology for determining a compliant CMEN system design. If a certifying Engineer has a methodology they would prefer to use, details of the methodology should be submitted for review prior to seeking approval of an earthing design.

STEP 5: ESTABLISH THE CMEN AREA

Transformers considered as part of the CMEN area defined in Step 1 shall be converted to CMEN earthing as part of the works. This will involve installing a bond between the HV and LV earth at the transformer. Standard insulated 35mm^2 copper conductor is satisfactory for this purpose except in close proximity to a major zone substation in which case the bonding conductor should be doubled up.

Existing practice is to bond LV neutrals at adjacent substation boundaries however as this bonding is critical to the safe operation of CMEN systems, a check should be carried out at the time of conversion to ensure that interconnections are in place. In some cases it may be necessary to install missing link spans of LV neutral in order to achieve maximum interconnection.

STEP 6: RECORD THE NEW CMEN AREA

Following conversion to a CMEN system, advice should be forwarded back to the Network Data department to allow for the conversion to be recorded in the GIS.

Note: Measured earth values and dates shall be recorded into the GIS / Asset Register against the equipment.

EXAMPLE

Consider a typical residential subdivision requiring the installation of 2 x 315 kVA distribution padmounted substations.

Step 1: Define the CMEN Area

The new subdivision was preceded by 2 earlier stages with 2 padmounts in each stage (4 padmount substations in total). When the previous stages were constructed they were constructed as separate earthed installations. The disconnected earth grid resistances are available from the commissioning of the padmount substations in the previous stages.

Step 2: Identify the Design Earth Resistance

Ergon Energy Protection Group has provided a Design Earth Resistance (R_t) of 0.29 ohm for the next stage of the subdivision.

Step 3: Determine Existing System Resistance

The existing earth resistance (R_E) would be made up of the parallel combination of the following resistances, as follows:

- All existing Padmount Substations HV earth grid disconnected resistances are 5 ohms each (measured at commissioning as per the dates in step 1)
- MEN earths (LV network of the existing padmounts)– assume 8 earths at 30 ohms each per padmount - Total 3.75 ohms

Calculate the combined resistance for each padmount.

$$\frac{1}{R_{pad}} = \frac{1}{R_{Earthmat}} + \frac{1}{R_{MEN}} = \frac{1}{5} + \frac{1}{3.75} = 0.4666$$

$$R_{pad} = 2.14 \ ohms$$

The existing padmounts have a system resistance of 2.14 Ohms for each padmount. This value will be used for each padmount substation to calculate the resistance of the proposed CMEN system.

Combined resistance for the 4 padmount substations as defined in step 1 is calculated by

$$\frac{1}{R_E} = \frac{1}{2.14} + \frac{1}{2.14} + \frac{1}{2.14} + \frac{1}{2.14}$$

$$R_E = 0.54 \ ohm$$

Note: The combination of the HV earth mats and MENs for the established sites have an overall system resistance which complies with the requirement of a CMEN system to have a maximum 1 ohm resistance but not the 0.29 ohm required to maintain voltages within safe levels in step 2.

Step 4: Determine the required disconnected resistance for the new network extension

Calculate the required disconnected earth resistance for the network extension

R_t = Design Earth Resistance = 0.29 ohm
R_E = Resistance of existing CMEN System = 0.54 ohm
R_{NE} = Disconnected resistance for new subdivision = ?

$$R_{NE} = \frac{R_E \times R_t}{R_E - R_t}$$

$$R_{NE} = \frac{0.54 \times 0.29}{0.54 - 0.29}$$

$$R_{NE} = 0.63\ ohm$$

The network extension (the two proposed padmount substations) must have a maximum earth resistance reading of 0.63 ohm.

For this example each padmount (and its associated MEN network) must have a maximum disconnected earth resistance of 1.26 ohms.

The determined resistance for the network extension shall be indicated on the design drawings. When specifying earth resistances on drawings consideration should be given to limitations of construction methods and proximity to other utilities assets e.g. Telstra, NBN, Gas, etc.

Earth test shall be conducted on the disconnected padmount earth mats and MEN points to determine if the installed earth system is below the maximum determined value as part of the design.

Step 6: Establish the CMEN Area

The design shall indicate that the existing transformers are to be converted to CMEN earthing by the installation of a bond between the HV earth and the LV earth. In this example the 4 existing padmount substations will require a bond to be installed between the LV Earth Bar and the tank earth.

Step 7: Record the new CMEN Area

The earth resistivity reading shall be recorded on the Field Data Collection Form or Earthing Resistance Tests (RSC08) as appropriate. This information shall be transferred into the Asset Register.

APPENDIX A1 – FAULT LEVELS FOR DESIGN EARTH RESISTANCE CALCULATION

Overview

Fault studies are carried out to determine the minimum and maximum fault currents that are anticipated to occur on a power system. The minimum and maximum fault currents are the upper and lower limits for which the system is expected to operate. It is essential when developing or augmenting a network, the system conditions that will result in these two extremities are identified. This anticipated range of fault currents is used in conjunction with the calculated protection clearing times to determine the worst case compliance with A1 curve. The Design Earth Resistance is then calculated based upon this worst case combination of fault levels and protection clearing time. Fault currents outside this range are not expected to occur. Fault currents provided to Protection shall be considerate of the longevity of the design to which they are being applied.

Maximum Fault Current

The maximum fault current will be produced when the source impedance is at its lowest anticipated value. This is expected to occur on the power system when all sources of supply are in service and all parallel paths are closed.

Normally open points used to mitigate high fault level issues shall be kept open for the purpose of the study. This is in agreement with AS3851 which states 'Normally open points which are only closed to maintain supply during rearrangement of the system shall be assumed to be open'. Normally open points that are open at the discretion of the business shall be closed for this study.

When identifying the maximum fault level, the sub transient fault impedance shall be used as the source impedance. This source impedance value is published by the Subtransmission Planning Group. The source impedance relating to the highest forecast fault level shall be used for this study.

For systems with nominal voltage above 650V, the maximum fault level shall be calculated with a 'c' voltage factor of 1.1. This equates to a 1.1pu driving voltage behind the Thevenin equivalent impedance. For systems with nominal voltage below 650V, the 'c' voltage factor shall be 1.06.

Due to the longevity of the design, fault levels for earthing systems shall be based on the network switching condition that produces the highest fault current at the site. This may mean that the distribution feeder is not in its normal configuration and may even be connected to an adjacent zone substation.

The network configuration studied to determine the maximum fault level shall be recorded and maintained.

Minimum Fault Current

The minimum fault current will be produced when the system source impedance is at its maximum anticipated value. This is expected to occur on the power system when the minimum amount of plant capable of sustaining load is in service. For example in substations that have n-1 capability, this will typically occur when a transformer is out of service or the bus section circuit breaker is open. The minimum fault current is calculated using the synchronous impedance of the generating plant in series with the impedance of the minimum plant as described above.

For systems with nominal voltage above 650V, the minimum fault level utilised shall be calculated with a 'c' voltage factor of 1.0. This equates to a 1.0pu driving voltage behind the Thevenin equivalent impedance. This is expected to be the lowest operating voltage at a zone substation. In substations where the voltage is regulated to a value below the nominal voltage, the 'c' voltage factor shall be calculated by dividing the system operating voltage into the substation nominal voltage.

As per AS3851-1991 for systems with a nominal voltage less than 650V, the ‘c’ voltage factor shall be 0.94.

The minimum fault current for an earthing study shall include a 1Ω resistance to accommodate the maximum connected earth impedance allowable for CMEN systems.

The network configuration studied to determine the minimum fault level shall be recorded and maintained.

APPENDIX A2 – CURVES AND CRITERIA FROM THE CODE OF PRACTICE

3.3.4 The Common Multiple Earthed Neutral (CMEN) system

If an electricity entity uses a CMEN system, the low voltage neutral conductor, and the low voltage earthing system, should be connected to the high voltage earthing system. This requirement includes the earthing system of transformer stations, zone substations and at poles carrying exposed conductive parts associated with high voltages.

The CMEN system should only to be used for distribution voltages up to and including 33 kV and where the design limits prospective touch voltages – including within any part of the associated LV installations – to within curve A1 of Figure 2.

The resistance to ground of the LV neutral at any location should be no greater than 1.0 ohm.

3.5 Prospective touch and step voltages

3.5.1 Prospective touch voltages – special locations

Lines operating at voltages less than or equal to 66kV should comply with the requirements of curve A1 of Figure 2. Lines operating at voltages greater than 66kV should comply with the requirements of curve A2 of Figure 2.

3.5.2 Prospective touch voltages – frequented locations

Lines operating at voltages less than or equal to 66kV should comply with the requirements of curve B1of Figure 2.

Lines operating at voltages greater than 66 kV should comply with the requirements of curve B2 of Figure 2.

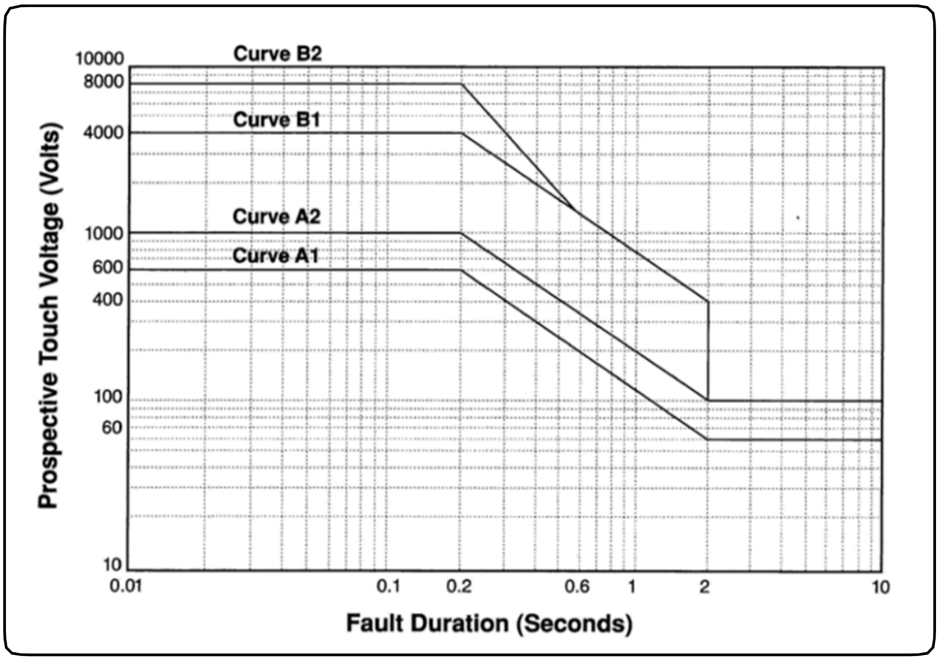

Figure 2: Touch Voltage versus Fault Duration