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EP 12 10 00 10 SP

EP 12 10 00 11 SP

Standard

HV Earthing for Substations and Distribution Systems

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Document information

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Document history

Revision	Effective date	Summary of changes
3.00	May 2010	EP 12 10 00 10 SP and EP 12 10 00 11 SP version 3.00 published.
1.00	22/02/2023	First issue as TS 03726. Version number recommenced in line with new designation.

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Preface

This standard supersedes both EP 12 10 00 10 SP and EP 12 10 00 11 SP. This is the first issue of this standard under the designation TS 03726.

Substations and distribution systems are widespread throughout the Transport Network. These assets supply and distribute power from the supply authorities to a wide range of assets. This standard is issued by the Asset Management Branch (AMB) (formerly the Asset Standards Authority (ASA)) to stipulate the minimum earthing requirements for the whole life cycle of HV and LV earthing systems at traction substations, sectioning huts, HV ac switching stations, distribution substations (pole mounted and ground mounted) and systems (aerial lines and cables) for the heavy rail network.

The contents of this standard are developed from the following documents:

- EP 12 10 00 10 SP (v3.0) *System Substation Earthing*
- EP 12 10 00 11 SP (v3.0) *Distribution Substation Earthing*.

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Table of contents

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1 Scope

This document specifies the minimum earthing requirements for the whole life cycle of HV and LV earthing systems at traction substations, sectioning huts, HV ac switching stations, distribution substations (pole mounted and ground mounted) and distribution systems (aerial lines and cables) for the heavy rail network.

This document does not cover the requirements for earthing design risk management. For this process refer to TS 00006.

2 Application

This standard applies to all new HV and LV earthing systems at traction substations, sectioning huts, HV ac switching stations, distribution substations (pole mounted and ground mounted) and systems (aerial lines and cables).

Existing installations may not be consistent with the requirements of this document. Due to the changes in the surrounding environment and the deterioration of earthing systems over time, an earthing installation may no longer perform as originally designed. For these reasons, modification of interfacing systems can lead to challenging considerations for the Technically Assured Organisation (TAO). Where the requirements of this standard cannot be practically met, alternative solutions aligned to the philosophy of this standard may be accepted subject to a request for concession.

3 Referenced documents

The following documents are cited in the text. For dated references, only the cited edition applies. For undated references, the latest edition of the referenced document applies.

International standards

EN 50122-1:2011 *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*

IEEE Standard 80–2020 – *IEEE Guide for Safety in ac Substation Grounding*

Australian standards

AS IEC 61000.6.4 *Electromagnetic compatibility (EMC) Part 6.4: Generic standards – Emission standard for industrial environments*

AS IEC 61000.6.5 *Electromagnetic compatibility (EMC) Part 6.5: Generic standards – Immunity for equipment used in power station and substation environment*

AS 1768 *Lightning protection*

AS 2067 *Substations and high voltage installations exceeding 1 kV a.c.*

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AS 2239 *Galvanic (sacrificial) anodes for cathodic protection*

AS/NZS 3000 *Electrical installations "Wiring Rules"*

Note: Known as the *Australian/New Zealand Wiring Rules.*

AS/NZS 3835.1 *Earth potential rise – Protection of telecommunications network users, personnel and plant – Part 1: Code of practice*

AS/NZS 4853 *Electrical hazards on metallic pipelines*

AS/NZS 7000 *Overhead line design*

AS 7722 *EMC Management*

Note: AS 7722 is an Australian Standard that is published and maintained by RISSB.

AS/NZS ISO 31000 *Risk management – Principles and guidelines*

CJC 5-1997/SAA HB101-1997 *Coordination of power and telecommunications – Low frequency induction (LFI)* (Standards Australia)

Note: Code of practice for the mitigation of hazardous voltages induced into telecommunication lines.

Transport for NSW standards

T HR EL 06001 SP *System Substation Battery and Battery Charger*

T HR EL 10001 ST *HV Aerial Line Standards for Design and Construction*

T HR EL 11001 TI *SCADA Standard I/O Schedule*

T HR EL 11004 ST *Electrical SCADA Interface Requirements*

T HR EL 12002 GU *Electrolysis from Stray DC Current*

T HR EL 12004 ST *Low Voltage Distribution and Installations Earthing*

T HR EL 12005 ST *Bonding for 1500 V DC Traction Systems*

T HR EL 12009 SP *Hybrid Voltage Limiter*

T HR EL 21001 ST *Lightning Protection and Insulation Coordination*

T HR EL 99001 ST *Substation and Sectioning Hut Commissioning Test and Processes*

T HR EL 99002 ST *Substation Minimum Construction Standard*

T HR EL 99004 ST *Substation Fencing*

T HR TE 21003 ST *Telecommunications for Traction Substations and Sectioning Huts*

T MU AM 01001 ST *Life Cycle Costing*

T MU AM 06006 ST *Systems Engineering*

T MU AM 06016 GU *AEO Guide to Verification and Validation*

T MU MD 00006 ST *Engineering Drawings and CAD Requirements*

T MU MD 20001 ST *System Safety Standard for New or Altered Assets*

TS 00006 *HV Earthing Design*

TS 01455 *Configuration Management*

TS 10504 *AEO Guide to Engineering Management*

TS 10507 *AEO Guide to Systems Integration*

Transport for NSW drawings

EL0005630 *Substations and sectioning huts earthing system for fibre glass padmount substation*

EL0008409 *33kV/ 500 – 250V transformer single pole structure operating notice*

EL0000930 *Earthing arrangement substation on timber pole with low voltage earthed*

EL0000931 *Earthing arrangement substation on timber pole with low voltage unearthed*

EL0003147 *Electrolysis isolating joint for underground water pipe*

EL0013170 *Transmission lines conductor spacing-earth wire general arrangements*

EL0013171 *Transmission lines conductor spacing-earth wire general arrangements*

EL0013172 *Transmission lines conductor spacing-earth wire general arrangements*

EL0015788 *Transmission lines pole top earthing earthwire support*

EL0017051 *Eastern suburbs railway H.V. & L.V. equipment earthing arrangement*

EL0017446 *Transmission lines conductor spacing – earth wire ground wire arrangement*

EL0017447 *Transmission lines conductor spacing – earth wire ground wire arrangement*

EL0017448 *Transmission lines conductor spacing – earth wire ground wire arrangement*

EL0024017 *Substations H.V. outdoor equipment typical earthing arrangements*

EL0284008 *General high voltage aerial lines and cables OHEW & UGOH earth electrodes typical installation details*

EL0455388 *RailCorp 11kV/415V Padmount Assembly Minimum Requirements Information Footprint Arrangement*

EL0474177 *General distribution padmount substation 11kV/415V distribution transformer schematic diagram – up 315kVA (distribution only)*

EL0480394 *General RailCorp 11kV/415V padmount assembly minimum requirements information earthing arrangement*

EL0497822 *General HV aerial lines anchors guy – type T14/1 arrangement*

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EL0497823 *General HV aerial lines anchors guy – type T14/2 arrangement*

EL0497824 *General HV aerial lines anchors guy – type T14/3 arrangement*

EL0497825 *General HV aerial lines anchors guy – type T14/4 arrangement*

Legislation

Work Health and Safety Act 2011

Other referenced documents

Energy Networks Australia 2022, *Power System Earthing Guide (EG-0) Part 1: Management Principles*, ENA DOC 025-2022

Energy Networks Australia 2022, *Substation Earthing Guide*, ENA DOC 045-2022 (EG-1)

IEEE 2013, *Guide for Safety in AC Substation Grounding*, IEEE 80

4 Terms, definitions and abbreviations

The following terms, definitions and abbreviations apply in this document:

ac alternating current

ac switching stations these locations contain high voltage ac circuit breakers and there is no 1500 V dc equipment.

AMB Asset Management Branch

clearing time the time taken for the protective devices to identify and isolate the fault current

conductive part a part capable of conducting current, although it may not necessarily be used for carrying service current

> Note: For the purpose of this document conductive parts can include, but are not limited to, elements built from conductive materials, for example, steel fences, steel horizontal safety screens, steel vertical safety screens and steel balustrades.

dc direct current

DCCB direct current circuit breaker

distribution system the electricity power lines and associated equipment and electricity structures used to convey and control the conveyance of electricity to, from and along the rail network electricity system operated by, for or on behalf of Sydney Metro, Sydney Trains, Transport Asset Holding Entity of New South Wales or Transport for NSW (tailored from Electricity Supply Act 1995 No 94 Section 12A)

earth (verb) to make an electric connection between a given point in a system or in an installation or in equipment and local earth

earth fault occurrence of an accidental conductive path between a live conductor and the earth

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earth grid interconnected uninsulated conductors installed in contact with the earth (or an intermediate material) intended for the conduction and dissipation of current and or for the provision of a uniform voltage reference. One part of the earthing system (source ENA DOC 025-2022)

earth potential rise (EPR) a voltage between an earthing system and a remote earth reference

earthing system an arrangement of earth conductors which typically includes but not limited to an earth grid, earth electrodes and additional earth conductors such as overhead earth wires (OHEWs), cable sheaths, earth continuity conductors (ECCs) and parallel earthing conductors

electrolysis an electrochemical reaction involving an electrolyte and metals which are carrying a dc current

fault clearance the amount of time it takes a circuit protection device to clear a fault

GST galvanised steel troughing

HV high voltage, A voltage exceeding 1000 V ac or 1500 V dc

IEEE Institute of Electrical and Electronics Engineers

LPS lightning protection system

LV low voltage, A voltage exceeding 50 V ac or 120 V ripple-free dc but not exceeding 1000 V ac or 1500 V dc

OHEW overhead earth wire

O&M operator and maintainer

PEN protective earthed neutral

PVC polyvinyl chloride

REC rail earth contactor

remote a location where the contact frequency is suitably low that the fault/contact coincidence probability is less than the target fatality probability. It is typically a location with few people around such as a rural area.

remote earth an electric potential outside the zone of influence of the relevant earthing arrangement which is conventionally taken as zero

RISSB Rail Industry Safety and Standards Board

sectioning huts these locations sectionalise the overhead wiring for 1500 V dc protection and voltage regulation. If the Sectioning hut includes any high voltage ac equipment, then the design shall be the same as for a traction substation

SFAIRP so far as is reasonably practicable

soil resistivity specific resistivity of a material is used to define the resistance of a material to current flow and is defined as the electric field strength (V/m) divided by the current density

(A/m^2). Values tabled are normalised to 1 amp flowing into a one metre cube of material yielding units of ohmmeter (Ωm)

step voltage a voltage between two points on the earth's surface that are 1 m distant from each other while a person is making contact with these points by their feet

system substation umbrella term which includes traction substations, sectioning huts, and HV ac switching stations

TAO Technically Assured Organisation (formerly Authorised Engineering Organisation (AEO))

TfNSW Transport for NSW

TMP Technical Maintenance Plan

traction substations these locations supply traction power to the 1500 V dc overhead wire. The incoming HV ac supply is converted to 1500 V dc using rectifiers. Some equipment that may be encountered at traction substations may include HV ac switchgear, 1500 V dc switchgear, HV and LV transformers, traction supply equipment (rectifiers/harmonic filters/reactors), batteries, and Rail Earth Contactors (REC)

touch voltage a voltage between conductive parts when touched simultaneously

> Note: The value of the effective touch voltage may be influenced by the impedance of the person in contact with these conductive parts

UGOH underground to overhead

5 Authorisation requirements

All earthing design, construction and commissioning activities shall be undertaken by a TAO with suitable authorisation in "earthing, bonding, electrolysis and lightning protection" for the applicable life cycle stage.

The following AMB documents provide information and guidance on TfNSW requirements and responsibilities of TAOs who are engaged in the provision of engineering services to TfNSW:

- TS 10504
- T MU AM 06016 GU
- TS 10507
- T MU MD 20001 ST.

6 General requirements

The HV earthing design process is documented in TS 00006. Designers shall take into account the entire life cycle of an asset as well as the whole of life costs when assessing earthing design options as specified in T MU AM 01001 ST.

6.1 Design

Earthing designs are typically documented in three stages to allow for appropriate stakeholder consultation, agreement and endorsement at the concept, detailed and for construction design stages. These stages are aligned with TS 01455 and summarised as follows:

- concept design report (CDR) at Gate 1
- preliminary design report (PDR) at Gate 2
- for construction design (FCD) at Gate 3.

All engineering drawings shall be produced in accordance with T MU MD 00006 ST.

6.1.1 Concept design report (CDR)

The CDR shall contain the following:

- supplied data including proposed substation general arrangement drawings, concrete footing drawings, fencing drawings, Before You Dig Australia (BYDA) and a detailed services search
- description of the proposed earthing ‘functional design’ that complies with TfNSW standards
- site investigation findings
- preliminary hazard log and risk analysis
- for existing earth grids (brownfield sites), current injection testing and fall of potential measurements
- soil resistivity measurement and modelling. This typically includes the following:
    a. at least two soil resistivity test profiles
    b. resistivity test profiles planning based on review of services search
    c. inversion of the resistivity test data using appropriate software
    d. supplied Geotech information
    e. discussion on how the design soil model was chosen
- ac HV earth fault levels with associated primary and backup earth total fault clearance times
- identification of the most onerous fault scenario
- touch, step and transfer voltage safety limits. Limits for touch and step voltage shall be determined for all identified contact scenarios in accordance with TS 00006.

6.1.2 Preliminary design report (PDR)

The PDR shall contain the following:

- hazard log and risk analysis shall be updated, as required, particularly when further hazards and risks are identified in the design process
- using the hierarchy of controls, an assessment shall be provided on which engineering controls be implemented to mitigate, so far as is reasonably practicable, the touch, step and transfer voltage hazards
- fault current distribution calculations
- earthing system impedance and EPR calculation. This includes any calculated transfer voltage hazards
- touch and step voltage calculations
- identify need for transient analysis (if required)
- identify the need for any concessions to standards
- lightning risk assessment in accordance with AS 1768 (if required)
- safety in design documentation
- conductor sizes shall be calculated in accordance with IEEE 80 using maximum future earth fault levels and backup total clearance time.

6.1.3 For construction design (FCD)

The FCD shall contain the following:

- final EPR, earthing system impedance (local & global), current distribution, touch, step and transfer voltage simulation results
- lightning protection design and transient analysis (if required)
- final hazard log and risk analysis
- for construction drawings including the following:
  - earthing system general arrangement
  - earthing system major connections diagram
  - earthing system schematics
  - LPS details (where required)
- safety in construction documentation
- installation test plans

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- commissioning test plan.

6.2 Construction

All earthing systems shall be constructed using the approved equipment, materials and methods identified in this document and reference general arrangement drawings. Equivalent products and methods may be used subject to agreement by the relevant asset steward and the AMB.

All inspection test plans (ITP) shall be provisioned with adequate witness and hold points to facilitate inspection and testing of earthing activities and components such as, but not limited to, the following:

- drilling and excavation
- connection or insulation of reinforcement, earth conductors and buried services
- continuity or insulation resistance testing
- installation of permanent test points.

6.3 Commissioning

All substation earthing systems shall pass commissioning testing in accordance with T HR EL 99001 ST and TS 00006 before being put into service. The designer shall provide the commissioning test plan and the final approval of the commissioning test results to the relevant asset steward and O&M, to certify that the asset is fit for purpose.

A commissioning test report is required to demonstrate that the asset is fit for purpose and all risks have been reduced SFAIRP. The test report shall include details of the test plan, results analysis and calibration certificates of all test equipment used. The test report shall be forwarded to the relevant asset steward and O&M.

6.4 Asset handover

All documentation shall be submitted to TfNSW asset stewards and O&M upon final commissioning in accordance with TS 00006.

6.5 Maintenance

All earthing systems shall be designed and installed with consideration given to RAMS across the whole-of-life cycle. Consideration shall also be given to maintenance activities and TMPs.

Where a claim of similarity cannot be made against an existing TMP then any additional or residual maintenance processes and frequencies shall be documented and agreed with the operator maintainer and submitted as supporting evidence with a request for concession.

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6.6 SFAIRP

AS 2067 was revised in 2016 to align with the SFAIRP and due diligence principles of the *Work Health and Safety Act 2011*.Duty of care (due diligence) is demonstrated when all reasonably practicable precautions have been taken. Refer to TS 00006 for further guidance on the SFAIRP process.

7 Lightning protection

A LPS is required to protect infrastructure and assets from a lightning strike by intercepting the stroke current and safely dissipating the energy to earth. The earthing requirements of LPS systems, both above and below ground, are critical to ensure efficient operation.

7.1 General

General requirements relating to lightning protection and requirements relating to insulation co-ordination can be found in T HR EL 21001 ST.

Compliance with the requirements of this section is required for all new Traction substations and HV ac switching stations. All existing Traction substations and HV ac switching stations shall comply where modifications result in one or more of the following:

- any extension of the building structure
- any modification to incoming HV aerial line terminations
- increasing or modifying the footprint of the substation
- the addition or relocation of outdoor equipment.

7.2 Lightning protection system

A LPS is required for all new traction substations, and HV ac switching stations. A lightning risk assessment in accordance with AS 1768 is required for all other substations to determine the need for dedicated lightning protection (not including padmount substations and critical locations, see Section 7.4). For requirements relating to the lightning protection of aerial lines see Section 9.

> Note: For existing substations, modifications to the existing LPS may be required subject to the extent of the modifications to the substation identified in Section 7.1 or the identification of damage to the substation, see Section 7.3.

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The LPS shall be designed to reduce the risk of overvoltage surges from direct and indirect lighting strikes:

- shielding of the substation building and equipment from direct lightning strikes using an LPS including lightning intercept conductors (for example, air terminals, external protective conductors), down conductors and an earthing system
- protect substation equipment from indirect strikes and system generated overvoltage's using surge protective devices (SPD's)
- installation of overhead earth wire (OHEW) on aerial lines entering or leaving substations, see Section 9.2.

The lighting intercept conductors providing shielding from direct strikes shall be designed using the rolling sphere method and shall meet the requirements for Lightning Protection Level 1 as defined in AS 1768.

Additional guidance for the implementation of LPS against lightning strikes can be found in AS 1768 including the following:

- best practice for the design of LPS (earthing system configurations, conductor types, routes and lengths)
- earth impedance criteria for LPS
- lightning air terminals and external conductors (type, location, height)
- the installation of strike or event counters (required for critical locations)
- installation of external protective conductors.

Refer to T HR EL 21001 ST and AS 1768 for details on lightning strike rate.

7.3 Existing locations

At existing substations with an outdoor yard, the aerial line termination structure is typically used as the lightning intercept conductor for the substation.

Where a lightning strike has resulted in damage to a substation an assessment of the LPS system for the installation shall be conducted. Where the existing LPS does not meet the requirements of Section 7.2 the LPS shall be modified to achieve compliance.

7.4 Critical locations

In addition to locations identified in Section 7.2 a LPS shall be provided at critical locations such as operating centres and major signal locations with a high risk of exposure to lightning. The LPS shall be provided in accordance with Sections 7.1 and 7.2. Typically, segregated HV/LV earthing systems are used at these locations. Where the building at a critical location is

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connected to a combined HV/LV earthing system the LPS shall be interconnected and form part of the HV earthing system.

Due to the high frequency nature of lightning surges an earthing system may not dissipate lightning surges as effectively as system generated earth faults. At critical locations a computer simulated lightning transient analysis (such as CDEGS) shall be done in order to ensure the earthing system surge impedance is adequate to effectively dissipate a lightning strike.

7.5 Documentation

For new installations the LPS above ground components are designed as part of the power frequency earthing design and therefore the design process is documented as part of the power frequency earthing design. Where an independent lightning protection assessment or design is required to modify an existing installation, to reflect the detail that would otherwise be captured in the power frequency design documentation the following independent documentation shall be produced:

- design report with all design inputs, hazard logs, assumptions, criteria, calculations, software simulation graphs and plots, compliance and reference to standards. The report shall include all drawings produced for the assessment, design and construction of the LPS in particular connection details to an existing LPS.
- coverage of the lightning intercept conductors can be demonstrated by using a 3D rendered model (such as CDEGS SES shield or equivalent) or plan and elevation drawings with the required sphere radius and shall be to scale identifying as a minimum:
    1. the substation building (outline)
    2. outdoor yard (outline)
    3. all major equipment located outdoors (for example transformers and bays, fences, lighting poles and aerial line structures)
- details and connections shall also be shown on drawings to enable the construction and installation of the LPS. Drawings shall include a detailed parts list and comprehensive construction notes.

All drawings shall comply with T MU MD 00006 ST.

8 Electromagnetic fields

In accordance with the requirements of T MU AM 06006 ST all HV substations shall comply with AS 7722, CJC 5-1997/SAA HB101-1997, AS IEC 61000.6.5, and AS IEC 61000.6.4.

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9 HV aerial lines

This section documents the minimum requirements for earthing and lightning protection of HV aerial lines.

9.1 General

An earthing design shall be done for the HV aerial line installation and associated equipment for each project as part of the earthing design for the overall project.

Connection to earth shall be made to:

- overhead earthwire at each support structure (see Section 9.2.3 for further information)
- cable screens and the base of surge arresters at UGOH arrangements
- cable screens, catenary wire, and the base of surge arresters at the pole for the transition of 11 kV ABC to bare aerial conductors
- 11 kV ABC catenary wire for tension arrangements, such as arrangement 11/48 (drawing number EL 0002979), where an earth down lead is installed
- guy wires and rods below the guy insulators
- steel poles.

Additional requirements relating to the design and construction of OHEW systems for HV aerial lines are documented in TS 00006, T HR EL 10001 ST and AS/NZS 7000.

9.2 Overhead earth wire

OHEW is not typically installed on 11 kV aerial lines but is required on voltages at or above 33 kV. Requirements for the design of OHEW on aerial lines pertaining to type and size of conductors and support arrangements are documented in T HR EL 10001 ST and in AS/NZS 7000.

Refer to T HR EL 21001 ST for requirements related to aerial line outages due to lightning strikes.

9.2.1 Minimum length

Overhead earthwire shall be installed for the full length of the aerial feeder for voltages of 33 kV and above.

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For modifications to existing installations, the extent of overhead earthwire coverage may be reduced with justification by a cost-benefit analysis. The resultant configuration shall provide for the following as a minimum:

- a minimum of 800 m of overhead earthwire adjacent to the termination of an HV aerial line at a system substation
- a minimum of 800 m of overhead earthwire from an UGOH arrangement
- all new poles for aerial lines with a nominal voltage of 33 kV and above shall be designed to be suitable for overhead earthwire installation.

Where the minimum 800 m length cannot be achieved a request for concession shall be submitted to AMB which includes a SFAIRP justification for the reduced length. For significant deviations to the minimum OHEW length (greater than 10% or one transmission line span) a lightning insulation coordination study shall also be provided which includes the following:

- computer simulated travelling wave (lightning attenuation) analysis using commercially available software (for example, ATP, EMTP) which accounts for actual surge and earth impedances and back flashover
- power frequency earth system modelling to determine the impact on the earthing system.

9.2.2 Shielding angles

The shielding angle shall not exceed the following:

- 30° at 0 Pa wind with a conductor temperature of 5°C
- 40° at 500 Pa wind with a conductor temperature of 15°C.

Refer to drawings EL0013170, EL0013171, and EL0013172 for information on typical practices.

9.2.3 Down leads

Overhead earthwires shall be earthed at each support pole, except at locations which present significant stray current or transfer potential risks that cannot be mitigated by design. The earthing design shall list all locations at which the overhead earthwire is not connected to earth, and detail the reasons for such omissions, and the impacts on the electrical infrastructure. All such locations shall be clearly identified on the layout drawings. A cross-reference to the earthing design shall also be provided on the layout drawings.

The earth down lead shall be spaced from the surface of the pole with a nominal distance of 275 mm by pole stand-off supports (as shown in EL0015788). The vertical distance between a pole stand-off support and any crossarm or insulator support shall not be less than 400 mm.

A cable guard shall be provided for the down earth lead up to a minimum height of 2.4 m from ground. Non-conductive cable guards are preferred as they do not require earthing assessment prior to installation. Metallic cables guards may be used (subject to an earthing assessment)

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where there is an increased risk of theft, repeated malicious damage or in fire prone areas (although fire resistant PVC may also be used). Refer to drawing EL0284008 for further detail.

At joint use poles the down earth lead shall be insulated or segregated from other utilities equipment and earthing systems to provide a minimum 2.0 m clearance between exposed earthing systems.

Refer to drawings EL0017446, EL0017447, and EL0017448 for typical arrangements for the down earth lead, and EL0284008 for details of connection to pole earth electrodes.

9.3 UGOH poles

Typical arrangements for the earthing of UGOH poles and aerial OHEW can be found in general arrangement drawing EL0284008.

9.4 Stay poles

General requirements for stay poles are documented in T HR EL 10001 ST. Where practicable, and as required by lightning risk assessment stay poles supporting 33 kV or above aerial lines with OHEW, shall be provided with an earth system equivalent to the feeder pole to which it is connected. Earthing connections to stay poles shall be made below the guy insulator.

Earthing connections are not required for stay poles supporting aerial lines that do not have OHEW installed.

Refer to drawings EL0497822, EL0497823, EL0497824, and EL0497825 for earthing arrangements.

9.5 Steel poles

General requirements for steel poles are documented in T HR EL 10001 ST. Where steel poles supporting an overhead earthwire are installed within the rail corridor, a suitable mitigation of potential corrosion of the steel structure by stray dc current shall be designed and installed. For example, a LV limiter may be inserted between the overhead earthwire and the pole. Any such LV limiter shall be as follows:

- block the passage of stray dc current
- allow the passage of ac fault currents and lightning surges
- be type approved (refer to T HR EL 12009 SP)
- be assessed for its suitability as a mitigation in the specific location.

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10 System substation earthing

Majority of system substations are traction substations with 1500 V dc equipment and require special precautions compared to standard transmission, sub-transmission or zone substations owned by other electricity distributors.

10.1 General

The earthing system at system substations shall be a combined HV and LV earthing arrangement with the combined earth impedance to meet the requirements of TS 00006 but shall not be greater than 5Ω. There may be rare occurrences at system substations that are not considered HV installations such as sectioning huts where a separate HV and LV earthing system may be preferred. Where a separate HV and LV earthing system has been identified as the preferred solution, it shall be agreed with the asset steward (operator/maintainer) and a request for concession shall be submitted to the AMB.

System substations should have the following:

- a high fault level
- a large earth grid that is walked over by substation staff
- a number of items of electrical equipment with electrical protection of various clearing times
- a number of aerial and/or cable feeders
- fences with associated prospective touch voltages for people external to the substation
- other services (for example, water, communications) connected.

10.2 Equipment to be earthed

Equipment or conductive components that are considered to be part of any significant fault path or may pose a touch potential risk shall be connected to the combined HV and LV earthing system. This may include but is not limited to any of the following equipment or components:

- fixed metal items within the substation (for example metal roofs and down pipes)
- all accessible exposed and continuous metal parts containing or supporting HV conductors, (for example, cable trays and ladders)
- metallic substation enclosures of all HV and LV equipment
- exposed metalwork of all HV equipment
- surge protection devices
- cable sheaths/screens/armouring
- metal of all floor and wall reinforcing as required by design

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- metallic fences, both internal and boundary
- metal pipes such as water pipes, within the substation boundary
- transformer LV neutrals.

The following equipment shall not be connected to the combined HV and LV earthing system:

- any part of the 1500 V dc negative return path
- metal battery stands and cabinets
- some existing 220 V ac auxiliary supplies (see Section 13.2)
- 1500 V dc rectifier cubicles, circuit breaker frames, and rectifier auxiliary transformers. In most cases, and any future designs, this equipment shall be connected to earth through a frame leakage relay
- Cable support systems that are not considered part of any significant fault path (for example, non-continuous fixings and fittings secured to the floor to support cables).

10.3 Supplies to nearby loads

LV supplies shall not to be reticulated outside the substation boundary to locations such as depots, camps or private consumers. The connection of a load external to the substation will transfer the substation earth potential which may result in high prospective touch voltages.

> Note: A 33 kV fault can result in earth potential voltages in excess of 10 kV whereas a standard 240/240 V isolating transformer has a design withstand voltage of only 5 kV.

Where an isolating transformer is used in a system substation the case of the transformer shall be connected to the substation earth. This requirement is based on the necessity to earth all metalwork in a substation. It is not an electrical requirement with regard to isolation.

The screen of the isolating transformer shall also be connected to the substation earth grid. The connection shall be sized to carry the maximum fault currents that may flow for the time required for the back-up protective device to operate. The minimum size of the earthing cable shall be 16 mm^2 copper.

11 Distribution substation earthing

The standard distribution substation employs a separate earthing system for the HV and the LV sides of the transformer. This is a significant difference in approach to the standard design of local electricity distributors and is brought about primarily by the proximity of the 1500 V dc system and the presence of a stray current risk.

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11.1 General

Distribution substations are located throughout the network and are often adjacent to the traction system. They have a relatively low fault level compared to system substations and are typically designed in accordance with general arrangements. The general arrangements outline the minimum requirements for distribution substation earthing. Refer to the following drawings for details of the approved padmount substation design:

- EL0455388
- EL0480394
- EL0474177.

A concession shall be submitted to the AMB for any deviation from the minimum requirements.

The distribution substation earthing system shall be a separate HV and LV earthing arrangement. Where it is not practical to utilise a separate earthing system, such as underground locations, a combined HV and LV earthing system may be used subject to compliance with the requirements in Section 11.3. The minimum separation clearances that shall be maintained between the HV and LV systems is at least two metres or as far as required to prevent transfer of noncompliant earth voltage hazards. Refer to T HR EL 12004 ST for further requirements related to the LV supply earthing system.

This separation shall also apply to conductors connected to the electrodes unless the conductors are suitably insulated to at least 0.6/1 kV insulation level or the maximum earth potential (EPR) across the insulation whichever is greater.

Conductors and metallic parts: Unless insulated to at least 0.6/1 kV insulation level or maximum EPR across the insulation whichever is greater; a clearance of not less than 35 mm shall be provided to any conductors or metallic parts which are connected to the HV earthing system.

11.2 Equipment to be earthed

Equipment or conductive components that are considered to be part of any significant HV fault path or may pose a touch potential risk shall be connected to the HV earth. This may include but is not limited to any of the following equipment or components:

- all accessible exposed metal parts containing or supporting HV conductors
- exposed metalwork of all HV equipment
- HV Surge Protection Devices (SPD)
- HV cable sheaths/screens/armouring
- equipotential loop.

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Equipment to be individually connected to the LV earth bar on the first main switchboard (the supply main switchboard) shall be as follows:

- LV earth grid
- transformer LV neutral (connected via LV neutral bar)
- LV SPD's
- exposed metallic objects associated with the LV system
- nearby metallic water pipes which are connected to earth.

11.3 Combined earthing system

Requirements for combined HV and LV earthing systems for distribution substations can be found in the following sections.

11.3.1 General

The primary reasons for not using a combined HV and LV earthing systems for distribution substations are as follows:

- A combined earthing system provides a relatively low earth path for dc stray current. This could permit stray current to flow between the earths and cable screens at the local substation and traction substation and corrode the earthing system leading to a significant safety risk
- The difficulty in obtaining a sufficiently low earth impedance to achieve compliance with safety requirements. The ac system does not have sufficient multiple earth-neutral connections along its reticulated neutral as an MEN system which increases the difficulty in obtains low earth impedances.

For above ground locations a combined HV and LV earthing system may be used subject to a request for a concession to the AMB. Where it can be demonstrated that the SFAIRP solution combines the HV and LV earthing systems then the following shall be addressed:

- the combined earthing system shall not be adversely affected if part of the earthing system is removed including temporary disconnections
- a stray current risk assessment shall be provided in accordance with T HR EL 12005 ST. The installation of a type approved hybrid voltage limiting device (HVLD) or stray current blocking device shall be considered in accordance with T HR EL 12002 GU and T HR EL 12009 SP.

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11.3.2 Underground locations

A combined earthing system shall be used at a distribution substation where it is not reasonably practicable to ensure there are no unintentional connections between the HV and LV earth systems leading to the possibility of dangerous touch, step, and transfer voltages. This situation is typically encountered at underground locations.

Examples of existing substations that are based on this principle are the substations for the City and Eastern Suburbs underground railway stations. Keeping the HV and LV earthing systems separate to minimise traction return leakage current may not be feasible at these locations. The drawing for the earthing arrangement of the Eastern Suburbs Railway, EL0017051 shall be used for maintenance purposes only.

11.4 Other locations supplied from a distribution substation

Where a sectioning hut is supplied from a dedicated distribution substation located outside of the sectioning hut boundary, the secondary of the transformer shall not be earthed at the distribution substation. The only LV earth system shall be the sectioning hut earth grid. The transformer mains active and neutral conductors shall be double insulated all the way into the supply main switchboard of the sectioning hut. The sectioning hut supply main switchboard shall have the neutral bar and the earth bar connected together; this shall be the only earth-neutral connection for the sectioning hut supply. The earth bar of the switchboard shall be directly connected to the sectioning hut’s earth grid.

In the situation where a sectioning hut is not supplied from a dedicated distribution substation, that is, other loads are connected to the same distribution substation as the Sectioning Hut, then the Sectioning hut shall be supplied through an isolating transformer located within the boundary of the sectioning hut. If the HV supply to the distribution substation is greater than 11 kV, then a detailed design shall be carried out to ensure the withstand voltage of the isolating transformer is rated for all possible fault conditions. The screen of the isolating transformer shall also be connected to the sectioning hut earth grid. The connection shall be sized to carry the maximum fault currents that may flow for the time required for the back-up protective device to operate. The minimum size of the earthing cable shall be 16 mm^2 copper.

If the supplying distribution substation is owned by a local distributor, then refer to T HR EL 12004 ST for additional guidelines.

12 Earthing grid

Earth impedance shall be designed to achieve compliance with TS 00006 but not be greater than the earth system impedance requirements specified in this standard.

12.1 Standard electrode

The standard earth electrode shall be a minimum bare 2.4 m x 70 mm^2 stranded copper conductor or equivalent solid copper rod. Copper clad rods shall not be used due to the presence of stray current risk. Copper plated electrodes may be considered subject to provision of a stray current risk assessment in accordance with T HR EL 12005 ST.

For alkaline and acidic soils or in other situations where corrosion is likely, it may be necessary to oversize the electrodes or to apply other measures to give a reasonable lifetime.

The current rating of the earthing electrode is 5 kA for one second when tested in free air with an ambient of 25°C without exceeding a temperature rise of 380°C. A limit of 250°C (absolute) is relevant for bolted connections since extreme thermal cycling can lead to loosening over time. Conductor ratings may be modelled or calculated in accordance with IEEE 80.

12.2 Electrode spacing

The requirements for the number and depth of electrodes is dependent on the local conditions and the detailed design. At distribution substations a minimum of two electrodes shall be installed for each separate HV and LV earthing system and a minimum of four electrodes installed at system substations, even if the resistance of one electrode is sufficiently low. This shall provide a factor of safety against failure.

At system substations, the minimum of four electrodes shall be installed around the perimeter of the substation. If more electrodes are required, then the final number and location of each electrode shall be subject to detail design.

Electrodes which are connected to form an earthing grid shall be positioned with consideration given to mutual coupling as a result of the proximity of other connected electrodes. The efficiency of the current dissipation diminishes exponentially the closer the electrodes are to each other. Space permitting, it is ideal for the electrode spacing to be equal to or greater than their length.

12.3 Installation of electrodes

The electrodes shall be installed using boreholes (minimum 50 mm diameter) back filled with a conducting medium mixture such as bentonite, gypsum and sodium sulphate (50%, 45% and 5% by weight respectively) mixed to AS 2239. The top of each electrode shall finish 200 mm below ground level. The hand driven method may also be used for short lengths up to 2.4 m.

Earth electrodes shall be installed in suitable pits in accordance with EL0284008. Where the electrode is installed within the rail corridor, consideration should be given to the accessibility of the electrode pit. Installation of an electrode pit within a ballast area is non-ideal.

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Although deep insulated earth electrodes have been installed across the heavy rail network, they carry a residual risk associated with the maintenance of the insulation integrity. Where a deep insulated earth electrode is required to mitigate hazards relating to EPR, a concession shall be submitted to AMB. The concession shall demonstrate a SFAIRP argument, TMP process and agreement from the asset steward and O&M.

12.4 Test electrode

All system substations shall have a test electrode installed. The test electrode shall be easily disconnected from the earth grid without effecting performance, this is to allow resistance testing and check for presence of corrosion.

The test electrode shall be placed where it is easily accessible and can be withdrawn without the need to isolate equipment in service. The test electrode shall be identified with the word “Test” marked on the lid.

12.5 Earth mesh

All system substations shall have buried bare horizontal conductors placed under the surface to provide voltage gradient control in effect reducing the prospective step and touch voltages for personnel during a fault. The mesh configuration will also reduce the earth grid resistance. The size and spacing of conductors shall be calculated as part of the design process. A depth of 0.5 m is required for all direct buried earth mesh. Where concrete reinforcement is used as the earth mesh a minimum 50 mm concrete cover is required. Refer to TS 00006 for temperature limits applicable to the use of reinforcement in slabs as earth mesh.

12.6 Earthing connections

All buried connections shall use an exothermic welding process such as a Cadweld. The exothermic weld is preferable to a clamp because of the higher fault tolerance and the electrolysis risk associated within the rail environment. Alternative equivalent connections such as radial swage may also be used subject to type approval. ’C’ clamp connections may be used on above ground joints that are visible for inspection. Typical connection diagrams are shown in drawing EL0024017.

12.6.1 Copper tube electrode connections

Copper tube electrodes have been used in the past where overhead space requirements restrict the use of long solid rods. The 70 mm² copper earth conductor connecting to the copper tube shall have 75 mm of insulation removed and inserted inside the copper tube electrode and crimped. Either of the following crimp methods may be used:

- hydraulic crimp: two crimps with a 70 mm² die over the 75 mm of insert

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- hand crimp: five crimps over the 75 mm of insert.

12.7 HV earth conductors

The size of the HV earthing conductors that form the earthing system shall be determined by the earth fault level but shall not be smaller than 70 mm^2 copper.

12.8 LV earth conductors

The main LV earthing conductor is between the LV earth electrodes and the supply main switchboard earth bar. The size of the main LV earthing conductors shall be in accordance with AS/NZS 3000 and not less than 25 mm^2 copper.

The main LV earthing conductor shall be insulated green/yellow (with 0.6/1 kV rating or to EPR across the insulation, whichever is greater) until connection of the first LV electrode. The LV earthing conductor between electrodes shall be bare copper conductor to minimise earth impedance. Insulated conductors may be used where a stray current risk has been identified. Refer to T HR EL 12005 ST and T HR EL 12002 GU for further information regarding stray current risk.

13 Equipment earthing

Equipment earthing connections noted in Sections 10.2 and 11.2 that are expected to carry HV earth fault current shall be suitably rated for the maximum fault level at that location but shall not be less than 70 mm^2 copper. Considerations shall also be given to thermal effects, conductor annealing, insulation integrity, and conductor sag.

A redundancy level of N-1 shall be provided for earthing connections from the main earth grid to primary equipment such as switchgear, current/voltage transformers, power transformers and so on. Connections to the same infrastructure for the purpose of redundancy shall be made at diverse locations, that is, on opposite sides of the structure. For further information regarding redundancy see ENA DOC 045-2022 (EG-1).

Earthing for equipment that is not expected to carry HV earth fault current (for example, battery charger, fire inspection panel) may only carry a minor percentage of fault current compared to main earth fault current carrying earths. Redundancy is not required for earthing connections to support structures and infrastructure that is not likely to represent a primary conductive path. Minimum requirements for earthing conductors which are provided to create an equipotential zone within the substation environment shall be determined by design but shall not be less than 16 mm^2 copper.

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13.1 Surge arresters

The connection between the earth side of the HV arrester and the earth side of the equipment being protected, such as a transformer tank, shall be as short as possible (the same applies to the live side of the surge arrester).

If a LV arrester is installed at a substation, the earth side shall be connected to the LV neutral. This is because the leads of the arrester should be kept as short as practicable and the nearest LV earth is at the supply main switchboard.

Under no circumstances shall the LV arrester earth side be connected to the transformer tank (HV earth) otherwise failure of the HV interturn insulation may occur if there is a lightning strike on the HV. This can arise when a strike on the HV causes the tank potential to rise above earth, the LV arrester may then operate and discharge surge current through the LV winding to the LV earth. This can cause very high voltages to be induced in the HV winding causing its insulation to fail between turns. A failure of the LV arrester could also result in the tank being livened at 240 V.

13.2 Cable sheath and armour

All HV cable sheaths and armouring shall be connected to the HV earth. In Distribution Substations the connection is made at the HV earth bar and at the common earth bar in the case of combined HV and LV earthing. In system substations the connection is generally made within the HV switchgear. In cases where dc stray current blocking mechanisms are implemented; the earthing connection may be external to the switchgear.

For bonding of all 1500 V dc cables at 1500 V dc structures, refer to T HR EL 12005 ST.

13.3 Auxiliary supplies

The auxiliary services in a system substation can include lighting, LV power, dc power supplies (not dc traction loads), hot water, ventilation and compressed air. The auxiliary services are nominally three phase 415 V ac or single phase 240 V ac. A number of locations have existing three phase 220 V supplies which are unearthed. Typically there is a back-up auxiliary supply from a second source.

The usual practice shall be to supply the auxiliary services in a substation from a transformer (designated auxiliary transformer) whose primary winding is supplied from one of the secondary windings of the 1500 V dc rectifier transformer. The case of the Auxiliary transformer shall be connected directly to the earth grid with a 70 mm^2 copper conductor. Refer to T HR EL 99002 ST for additional requirements.

In some situations, the auxiliary supply originates from a supply external to the substation, for example, a back-up emergency supply in a single rectifier substation. In these circumstances if

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the external supply is from the local distributor then the external supply shall be connected via an isolating transformer. Refer to T HR EL 12004 ST for relevant guidelines.

Irrespective of the supply source, the neutral bar and the earth bar shall be connected together in the ac auxiliary supply switchboard. This shall be the only neutral earth connection in the system substation auxiliary supply. The size of the connecting conductor shall be based on the size of the active conductors from the auxiliary transformer. The earth bar shall be connected directly to the substation earth grid with 70 mm^2 copper conductor.

In the past, several variations of the auxiliary supply design have been used. Some of these variations are still in existence, but they should not be used in any new designs. In one variant used in traction substations the earth-neutral connection is made at the auxiliary transformer. This is undesirable as it can result in circulating currents at two rectifier locations where there are two earth-neutral connections, one at each transformer. An older method used in traction substations and sectioning huts used a floating three phase 220 V ac system with C phase connected to earth via a spark gap and an earthed screen in the auxiliary transformers.

13.4 LV final sub circuits

All LV sub-circuits shall contain an earthing conductor in accordance with AS/NZS 3000. Class II equipment as defined in AS/NZS 3000 does not require the installation of an earthing conductor.

13.5 Batteries

All system substations require a set of batteries and battery charger to supply power for the control circuits of circuit breakers and supervisory control and data acquisition (SCADA) equipment. The dc battery system shall not be earthed. For further information relating to battery chargers refer to T HR EL 06001 SP and T HR EL 99002 ST.

13.6 Telecommunications equipment

For telecommunications equipment requirements refer to T HR TE 21003 ST and AS/NZS 3835.1.

13.7 Metallic pipes

All underground metallic pipes, such as water and compressed air pipes, entering a system substation shall be electrically isolated by the permanent installation of an approved isolating joint 1 m outside the substation boundary as shown on drawing EL0003147.

An approved sign, as also shown on drawing EL0003147, shall be secured to the fence directly above the pipe.

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Any metallic pipes within the substation boundary shall be bonded to the substation earth grid by a 70 mm^2 copper conductor.

Nearby buried metallic pipes and services shall be assessed for compliance with AS/NZS 4853.

13.8 Neutral earth resistors

Neutral earth resistors are employed at some system substations to reduce the earth potential rise under fault conditions. The neutral earth resistor shall be connected to the system substation earth through a neutral leakage relay through a current transformer. Neutral earth resistors may be used subject to agreement with AMB and the asset steward. The size of the neutral earth resistor shall be determined by design and agreed by the asset steward and the AMB.

13.9 1500 V Link area (voltmeter rail)

A short length of rail shall be installed in the 1500 V dc link area to facilitate the connection of a voltmeter to test dead the 1500 V dc feeders. The rail shall be connected to the track side of the negative reactor in a traction substation and to the negative of the REC in a sectioning hut. The rail should be placed 1 m clear of any other metalwork, if this is not possible a warning sign shall be erected on the fence of the link area opposite the voltmeter rail stating: WARNING VOLTMETER RAIL IS CONNECTED TO TRACTION NEGATIVE DO NOT BRIDGE TO EARTH.

13.10 Voltage limiting device (VLD)

A VLD, also known as a REC or Auto REC, shall be installed at all traction substations and sectioning huts. The REC and Auto REC are VLD O/F devices. All REC's are normally an open latched contactor connected between rail and earth that is designed to close when its voltage sensing circuit detects an excessive voltage between rail and earth.

- a REC shall remain closed until manually reset on-site and typically has a SCADA indication for the status only
- an Auto REC is a smart device that has the ability to auto reset, automatic lockouts and has a SCADA indication for status and SCADA control for remote operation. For a full list of I/O for the REC refer to T HR EL 11001 TI. The SCADA I/O shall conform to T HR EL 11004 ST.

13.10.1 Rail earth contactor

The standard settings for the REC to operate are as follows:

- 100 V for 0.5 seconds
- 400 V instantaneously.

Certain locations have custom REC settings (up to 120 V with time delay) to address nuisance operations of the REC. The any proposed REC settings that vary from this standard.

The REC and its associated SCADA alarms are required to be commissioned prior to the substation being connected to the 1500 V dc traction system.

For REC details refer to the following drawings:

- EL0153860 for schematic diagram
- EL0491274 to EL0491281 for connection diagram
- EL0491274 to EL0491281 for panel arrangement.

13.10.2 Auto rail earth contactor

The Auto REC shall minimise the presence of stray currents by automatically opening the short-circuiting device when the applied overvoltage is removed and for this reason it has become the preferred REC.

The Auto REC has built in voltage-time characteristic curves which comply with EN 50122. The settings of the Auto REC shall comply with Table 6 of EN 50122-1:2011 D.C (see Table 1).

Table 1 – U_{te} max long-term, U_{te} max short-term

Time (t) sec	U_{te} max long term (V)	U_{te} max short term (V)
>300	120	Nil
300	150	Nil
1	160	Nil
0.9	165	Nil
0.8	170	Nil
0.7	175	Nil
<0.7	Nil	350
0.6	Nil	360
0.5	Nil	385
0.4	Nil	420
0.3	Nil	460
0.2	Nil	520
0.1	Nil	625
0.05	Nil	735
0.02	Nil	870

For Auto REC details refer to the following drawings:

- EL0782611 *Rating plate*
- EL0782612 *Overview diagram*
- EL0782613-22 *Schematic diagram*
- EL0782624-27 *Parts list*
- EL0782628-33 *General arrangement*
- EL0782634-37 *Terminal block arrangement*

VDLs used outside of substations have different requirements and are required to comply with T HR EL 12005 ST.

13.11 Frame leakage protection

1500 V dc equipment such as the rectifier cubicles, rectifier auxiliary transformers and 1500 V dc circuit breaker frames in traction substations and the 1500 V dc circuit breaker frames in sectioning huts shall not be connected directly to earth but shall be connected to earth through a frame leakage relay. An earth conductor is connected from the DCCB frame leakage bar to each DCCB frame in turn. If a breakdown occurs between frame and earth on any one DCCB causing a current to flow, the frame leakage relay will open a set of contacts disconnecting supply for the 125 V dc controls to all DCCB's. For further detail on implementation of frame leakage circuits refer to T HR EL 99002 ST.

14 Substation metal fences

Substation fences shall be constructed in accordance with T HR EL 99004 ST.

14.1 Clearance to other earthed equipment

A 2 m clearance shall be maintained between the substation boundary fence and any metallic object that may connect to remote earth to reduce the risk of a prospective touch voltage. Such examples may include continuous fence lines, pipes, and GST. Where the 2 m clearance cannot be obtained, a suitable approved method such as installing isolating breaks/joints 2 m apart in the continuous metal structure shall be used.

14.2 Bonding of gates

Bonding conductors shall be used where there are any breaks in continuity in the fence, such as for gates. The size of this conductor is dependent on the fault level at the substation, but in any case, shall be a minimum of 70 mm^2 copper.

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14.3 Grading ring

At system substations grading conductors shall be placed around the fence to reduce prospective touch potentials. Typically, one bare 70 mm^2 copper conductor is installed 1 m outside the fence at a depth of not more than 0.5 m. The grading conductor shall be regularly bonded to the fence at intervals. This grading ring is included as part of the overall earth grid design and shall be included in the earth grid impedance calculations.

At distribution substations, grading conductors are typically installed around the substation footprint and are not typically connected to a fence. See Section 11.1 for general arrangements.

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Appendix A Substation on timber pole

A new general arrangement for pole top substations is under development. The requirements shown in Section A.1 through to Section A.14 are for existing pole top substations and are not for future construction.

A.1 General

For details of general earthing arrangements refer to the following drawings:

- EL0000930
- EL0000931.

A.2 Air break switch frame

The air break switch frame is only required to be connected to earth when there is equipment mounted at the top of the pole, for example, transformer or surge arrestor.

The earth connection point on the air break switch frame is the connecting point for the earth conductors for the surge arrester, earthing switch, transformer tank and also connects to the main earthing conductor where a main earth conductor runs down the pole from an overhead earth wire. Where no overhead earth wire exists the earthing conductor from the air break switch frame becomes the main HV earth conductor.

A.3 Air break switch handle

The air break switch handle are connected to the main HV earth conductor by a flexible copper braid such as ALM-Dulmison catalogue number RA 40300 or a connector with equivalent current carrying capacity and equivalent mechanical strength and flexibility.

The air break switch operating handle shall also be connected to an equipotential mat or buried loop located directly below the handle.

A.4 Equipotential mat or loop

An equipotential mat or buried loop shall be placed directly below the operating handle of an air break switch such that the operator shall stand on the mat or within the loop to effectively operate the equipment. This will reduce the risk of an operator suffering an electric shock in the case of a fault current flowing through the operating linkage and causing a voltage difference between the operating handle and the ground whilst an operator is in a critical position.

An equipotential mat consists of a non-slip galvanised mesh or steel plate securely fixed above the level of the ground to ensure that it is not inadvertently covered by the surface material. Although the effectiveness of the mat will not be affected by a layer of dirt, it shall still be visible to the operator to ensure it is in good condition. Where the ground level is sloping the operators mat may be installed by concreting legs, permanently attached at each corner of the mat, to a depth required to effect a permanent stable support (a minimum depth of 300 mm will be necessary).

Alternatively, a buried equipotential loop can be made from a minimum bare 70 mm² copper conductor but shall not be formed from the main earthing conductor. The loop is placed around the pole so that an operator will stand within the loop when operating the air break switch handle. The conductor is typically buried between 100 mm and 150 mm below ground level with a diameter of 2500 mm. Where existing equipotential loops are required to be replaced these shall be buried 500 mm below ground.

The equipotential mat or buried loop shall be connected to the air break switch operating handle.

A.5 Air break switch operating rod

All air break switch-operating mechanisms shall be fitted with an insulated section such that the top of the insulating section should be a minimum of 2400 mm above the operating handle. One of the three following options for insulating materials shall be used:

- Oregon or Tallow wood 50 mm x 50 mm dressed with chamfered ends, 1200 mm (minimum) long for voltages up to and including 33 kV or 2400 mm (minimum) long for voltages exceeding 33 kV
- An ultraviolet inhibited fibreglass rod of equal mechanical strength and length to the wood
- A post type insulator of the same phase to earth voltage rating as the air break switch. The top of the insulator should be a minimum of 2400 mm above the operating handle.

A.6 Earthing switch

An earthing switch is used to earth both sides of a HV fuse to increase the safety for an operator when replacing a fuse.

The following are the two types of earthing switches that are used:

- operating rod

  Transformer locations connected to the 11 kV system have an earthing operating rod part way up the ladder. It shall be positioned so that the operator cannot easily proceed past the point without earthing the HV supply.

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- dual operating handles

  Transformer locations connected to the 33 kV system have an operating handle adjacent to and mechanically interlocked with the air break switch handle. In this case a safety sign shall be installed at these locations.

A.7 Transformer tank

The transformer tank is connected to the main HV earth wire at the air break switch frame in accordance with drawing EL0000930 or EL0000931.

A.8 Access ladder

Metal ladders constructed of more than one individual section have a separate earth connection for every section of the ladder. The most common type of ladder in use consists of two sections, the top section being fixed in position and the lower section folding to restrict access.

The connection to the top section of the ladder should be close to the top of the ladder to reduce the chance of a touch voltage between the top step of the ladder and the air break switch frame, under fault conditions. The connection to the bottom section of the ladder should be connected close to the bottom of the ladder, for similar reasons, but shall be higher than the earthing test links otherwise the links can be short-circuited by the two earth connections of the ladder in the case of a folding style ladder when the ladder is in the unfolded position.

Fibreglass ladders and other ladders made of non-conductive materials are not required to be connected to earth.

A.9 Signs

All pole mounted transformer installations with a primary side voltage of 33 kV and above require a metal notice plate reading "Open air break switch and close earth switch before ascending" shall be provided at the bottom of the ladder as, unlike the 11 kV locations, there is no physical barrier. For signage requirements for pole mounted transformer installations (33 kV and above) refer to drawing EL0008409.

A.10 Test links

Where the supply main switchboard (and thus the LV earth electrode system connection) is mounted on the same pole as a substation, then the test links for both the HV and LV earthing systems shall be provided and installed as follows:

- to allow either the low voltage or high voltage earth electrodes to be disconnected from their respective earthing systems for the purpose of periodical testing over the life of the substation. The substation may remain on-line and a link arrangement is typically provided

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whereby the two systems are temporarily connected. The earth electrode system to be tested may then be disconnected. Both the HV and LV earthing systems are then earthed by the other electrode network. This link arrangement is typically housed in an insulated box (or equivalent) to protect against touch potentials between the two earth systems

- such that conductors or metallic parts of the LV earthing system are insulated to at least 0.6/1 kV insulation level
- to be accessible for test purposes and mounted approximately 2.7 m from ground level. This height allows for clearance above the mechanical protection of the earthing conductors
- with clear labelling indicating the respective earthing system.

Where the LV is an unearthed system then the test links are typically provided for the HV earth system. The HV shall be isolated when testing in this situation.

A.11 Mechanical protection of earthing conductors

The main HV and LV earthing conductors, that is any 70 mm^2 earthing conductors, shall be effectively protected from mechanical damage from ground level to a height of 2.4 m. This protection is typically achieved using a tallow wood batten or by installing the main earth conductor in a PVC conduit and protecting the PVC with a steel sleeve. The steel sleeve is typically used in high theft areas and is subject to the EPR assessment.

A.12 Switchboards (pole mounted)

All pole mounted substation installations are typically provided with non-metallic switchboards for the housing of LV equipment.

Existing installations with metallic switchboards may make use of an insulating coating such as "Emerclad". Once correctly applied to the exterior surface of the switchboard the risk of a dangerous touch voltage between earthing systems will be reduced to an acceptable level. However, an economic assessment is made of the maintainability requirements of each location based on local knowledge, such as the likelihood of vandalism, and compared to the option of replacing the board with a non-metallic enclosure.

A.13 Automatic reclosers

The metal case of a pole mounted auto-recloser is connected to the main HV earth.

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A.14 Line air break switch

A line air break switch used only for sectionalising a feeder shall not have its air break switch frame earthed as there is no equipment requiring the earth. This requirement remains even if an overhead wire is associated with the line, that is, a tee off from the overhead wire is not required.

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Appendix B Fibreglass padmount substation

Historically fibreglass padmount substations utilising the arrangement identified in EL0005630 have been used throughout the network, however, they are no longer used and are not intended for future construction.

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