ElectraNet

Substation Earthing

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This functional requirements document is in line with the organisation's 1-11-ACS-01 Substation Earthing Asset Class Strategy

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Contents

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1. Definitions

In this document the following words and expressions will have the following meanings:

Item	Meaning
AS	Australian Standard, as publication by Standards Australia (Standards Association of Australia).
Brownfield Sites	Brownfield sites are those where a bench or a portion of the bench exists and there is already a form of earthing system which requires assessment and augmentation.
CDEGS	Current Distribution Electromagnetic Interference Grounding Soil Structure Analysis software design package.
Contractor	A contractor engaged by ElectraNet or a Customer (including a third party IUSA provider engaged by a Customer or any contractor engaged by such third party IUSA provider) to perform any design, construction or related services in relation to assets or infrastructure which are connected, or to be connected, to ElectraNet's transmission network.
Customer	A party who wants to establish or modify a connection to ElectraNet's transmission network but does not include a third party IUSA provider.
CVT	Capacitive Voltage Transformer.
Designer	A party who designs assets or infrastructure which are connected, or to be connected, into ElectraNet's transmission network.
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.
earth grid riser	Insulated conductor installed from the earth grid underground to surface equipment.
earth rod	Earth electrode consisting of a metal rod installed into the ground, commonly vertically.
ECC	Earth Continuous Conductor
effectively earthed	Effectively earthed is defined as a sufficiently low impedance such that for all system conditions the ratio of zero-sequence reactance to positive-sequence reactance (X0/X1) is positive and less than 3, and the ratio of zero sequence resistance to positive-sequence reactance (R0/X1) is positive and less than 1. Effectively grounded systems will have a line-to-ground short circuit current of at least 60% of the three-phase short-circuit value.
EGVR	Earth Grid Voltage Rise is calculated by multiplying the earth grid resistance by the fault current.
EMC	Electromagnetic Compatibility.

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Item	Meaning
EPR	Earth Potential Rise. Voltage between an earthing system and a remote earth.
FCDIST	Fault Current Distribution Analysis. FCDIST calculates fault current distribution in multiple terminals, transmission lines and distribution feeders using minimum information and a simple set of data concerning the network.
Greenfield Sites	Greenfield sites are those built on new benches.
IEEE	Institute of Electrical and Electronics Engineers.
Maximum Fault Level	The current highest fault level of a substation at system normal excluding uncommitted generators.
NER	National Electricity Rules.
PEC	Parallel Earth Conductor.
PED	Portable Earthing Device.
PVC	Polyvinyl chloride.
RESAP	Soil Resistivity Analysis. RESAP is used to determine equivalent earth structure models based on measured soil resistivity data.
SAP	The Asset Management System used by ElectraNet, which provides an asset register, routine maintenance program/scheduling, defect management, work orders and financial reporting.
Standard Drawing	A drawing developed by ElectraNet as a complete design to be used for construction. Standard Drawings are not intended to be revised or renumbered.
Step Potential	The difference in surface potential experienced by a person bridging a distance of 1 m with their feet without contacting any other earthed object.
Template Drawing	A drawing developed by ElectraNet as the basis for design. Template Drawings are intended to be revised and renumbered as required to complete the design.
third party IUSA	Has the same meaning as defined in the National Electricity Rules.
Touch Potential	The potential difference between the ground potential rise and the surface potential at the point where a person is standing while at the same time having a hand in contact with an earthed structure.
Ultimate Fault Level	The highest fault level expected in the future after all planned network augmentations have taken place.
VAB	Vehicle access barrier.

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2. Purpose

The purpose of this document is to describe the functional requirements for Substation Earthing and Bonding and their integration into a substation and the potential impacts on third party owned assets in the immediate vicinity of the Substation.

3. Scope

This document states the functional requirements with regard to Substation Earthing and Bonding, and integration into a substation, as well as items that need to be considered in the area surrounding the substation to ensure the safety of personnel and the general public. The scope includes all items in the field such as electrodes, risers, connectors. The scope of this document does not consider the earthing and bonding inside substation buildings.

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4. Referenced Documents

The table below lists applicable legislations, standards, referenced documents.

Legislation	
SAEA	Electricity Act 1996 (SA)
SAER	Electricity (General) Regulations 2012 (SA) under the SAEA
NER	National Electricity Rules
ETC	Electricity Transmission Code TC/08
SAA HB59:1994	Ergonomics - The human factor - A practical approach to work systems design
Standards	
IEEE Std 81:2012	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System
IEEE Std 837:2014	Standard for qualifying permanent connections used in substation grounding
AS/ISO 1000:1998	The international system of units (SI) and its applications.
AS/NZS 1125:2001 + Amdt 1:2004 (R2017)	Conductors in insulated electric cables and flexible cords
AS 1746:1991 (R2016)	Conductors - Bare overhead - Hard-drawn copper
AS 2067 :2016	Substations and high voltage installations exceeding 1 kV a.c.
AS/NZS 3000:2007	Electrical Installations (known as the Australian/New Zealand Wiring Rules)
AS 3798:2007 + Amdt 1:2008	Guidelines on earthworks for commercial and residential developments
AS/NZS 3835.1:2006	Earth potential rise - Protection of telecommunication network users, personnel and plant - Code of practice
AS 4853:2012	Electrical hazards on metallic pipelines
AS 7000:2016	Overhead line design
IEC/TS 60479-1:Ed 4.1 (English 2016)	Effect of current on human beings and livestock Part 1 General aspects
IEC/TR 60479-5:Ed 1.0 (Bilingual 2007)	Effect of current on human beings and livestock - Part 5 Touch Voltage threshold values for physiological effects
CIGRE Technical Brochure 535:2013	EMC within Power Plants and Substations, Working Group C4.208

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5. Functional Requirements

The functional requirements of an earthing and bonding system must ensure the following:

a) Safety of people;

b) Protection of equipment; and

c) Operational security.

The functional requirements must satisfy the requirements of the latest edition of AS 2067.

5.1 Safety Requirements

The earthing system is categorised as a safety critical system. The earthing system must:

a) Ensure the safety of personnel and the general public through the management of prospective touch and step voltages;

b) Managing the risks associated with EPR transferred onto third party plant, staff and users (i.e. telecommunications, railways, pipelines) in accordance with Electricity Regulations, applicable Standards and Guidelines; and

c) Provide equipotential bonding to conducting items in the vicinity of the earthing system.

5.2 Design Requirements

Input parameters to the design requirements are:

(i) Soil model in accordance with IEEE-81

(ii) Fault level and contributions;

(iii) Fault clearing time; and

(iv) System X/R.

The earthing system must be designed using latest version of the CDEGS design software package.

The Designer must use suitable CDEGS earthing design module to model the grid and any third party infrastructure if it has been affected by development of the relevant substation infrastructure. The Contractor must demonstrate due diligence in investigating and allowing for future metallic structures within the vicinity which may impact safety of the earthing system as well as effect of the earthing system on the public safety and on surrounding infrastructure.

When two electrical installations are in close proximity the earthing systems can be designed as either standalone earth grids or as a combined earth grid system as dictated by the project requirements. When two earth grids are to be connected, a duplicated ECC, sized as a minimum equal to the earth grid conductor, must be provided.

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All substation earthing systems must be designed to ensure the following functional requirements are met:

a) Earthing systems must be designed to have 100% availability for the life of the substation. The earthing systems for a substation must have a minimum design life of 50 years.

b) Underground conductors of the earthing system require strength without needing to be bent and must be bare hard drawn copper to the requirements of the latest edition of AS 1746. The maximum design or operating temperature for bare copper and joints is 250 ºC.

c) Risers from the underground earth grid to the substation equipment require flexibility and must be annealed soft drawn stranded copper with green / yellow stripe PVC insulation complying with the latest revision of AS 1125 to minimise surface interface corrosion. The maximum design or operating temperature for PVC insulated conductor temperature is 160ºC.

d) The maximum grid area must be 150 m^2 for Greenfield substations as well as for major expansions of existing substations where new bulk earthworks are required, or where new sections of earth grid are being established for the first time.

e) The design depth for the substation earth grid must be 500 mm, below the substation finish ground level prior to the application of the surfacing layer, unless otherwise approved for Greenfield substation applications. For existing substations the design of the earth grid extensions must match the depth of the existing design.

f) For Greenfield Sites, the Step Potential and Touch Potential must be determined considering the slowest back up protection operating time between protection clearing time as stipulated in NER Chapter 5 Table S5.1a.2 Column 4 for voltage more than 100 kV (as applicable) and protection time provided by ElectraNet for system voltages less than or equal to 100 kV.

g) The minimum size of the main earth grid conductors must be based on 70% of the specified ultimate fault current and the backup clearing of the circuit breaker (i.e. the clearing time that would apply under circuit breaker fail conditions).

h) Risers must be capable of withstanding the worst case fault scenario.

i) Minimum yard earthing conductor cross sectional area for copper (covering the main earth grid conductors and risers) is 70 mm^2 for mechanical strength and life durability of the asset.

j) Equipotential potential bonding is required for all exposed non-fault carrying conductive (or metallic) items which include metallic fences, VABs, lighting poles, lightning masts, metallic kiosks, grates, metallic cable trench covers to ElectraNet's Standard Drawings and Template Drawings.

k) The earthing of fault-carrying conducting primary equipment structures to the earth grid through riser(s) must be in accordance with ElectraNet's Standard Drawings and Template Drawings.

l) Each riser must be sized for the full fault current as specified. Where primary plant, such as instrument transformers and circuit breakers, are installed, one of the fault carrying risers to the support structures must be

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extended to the “main tanks” or “mechanism boxes” using copper conductors.

m) Where primary plant, such as earth switches and surge arresters, are installed, one of the fault carrying risers to the support structures must be extended to the base of the earth switch blade and surge arrester earthing terminal using copper conductors.

n) Compression type earthing connections as well as exothermic welding connections in accordance to IEEE 837 are acceptable to ElectraNet. Bolted and brazed connections may only be used for above ground.

o) Metallic (conducting) fences must be suitably earthed to either the main grid or their own grid according to the design. The number of earthing points must be determined by safety requirements and ElectraNet’s Standard Drawings.

p) Fences must be earthed at every gate- post, wherever there are changes in direction and at every fourth post along straight runs in the fence. Fence safety signs must be in accordance with statutory requirements and ElectraNet’s Standard Drawings.

q) The initial design must be conducted without the requirement for surface treatment and without considering any fault current flowing via overhead earth wires connected to the substation earth grid. Optimisation to earth grid design must be conducted as deemed acceptable by ElectraNet.

r) Surface treatment will be always required as a substation surface finish layer. The minimum requirement must be the use of 100 mm thick layer of gravel with the tested electrical resistivity of minimum 3000 Ω m. However, some designs may require 40 mm thick layer of hot mix asphaltic bitumen as surface treatment inside the substation.

s) When safe step and touch voltages cannot be achieved outside the perimeter fence of the substation, a minimum of 1.5 metres wide of 40 mm thick layer of hot mix asphaltic bitumen must be installed.

t) The design of the substation earth grid must include as a minimum earth rods (or vertical electrodes) in each corner of the main earth grid. The minimum length of the earth rod must be 3 metres.

u) A grading ring at a depth of 500 mm must be installed one metre outside the substation perimeter fence and connected to the main earth grid.

v) Three metre wide isolation panels must be installed on all external fencing systems adjacent to the substation to prevent the transfer of hazardous potentials. The design of the isolation panels must be in accordance with ElectraNet’s Standard Drawings and Template Drawings.

w) Provision for portable earthing devices must be made when designing the equipment structures and overhead strung buses for the connection of working earth points as per ElectraNet’s Standard Drawings and Template Drawings.

x) A parallel earthing conductor must be installed within the cable trenches and conduits. The minimum size of the PEC is 70 mm^2. The PEC must be of the same cross sectional area as the main earth grid. The PEC must be connected to each piece of primary plant. The PEC must be connected cable to the gland plate in the plants marshalling kiosk. The purpose of this connection to the EMC earth bar within the trench is to provide

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electromagnetic shielding of the control cables and to provide a parallel path for any stray fault current that will occur during fault conditions.

y) Insulated PVC copper conductor must be used as a PEC when installed in conduits and bare copper conductor must be used when the PEC conductor is installed in cable trenches. When installed in cable trenches, the PEC must be connected to the main earth grid at each grid crossing point. When installed in conduits, the PEC must be either earthed to the cable trench or to an earth bar inside a cable pit.

z) All steel reinforcing in concrete foundations, aprons and floor slabs – on which a person can walk including concrete under all gate crossings, must be in accordance with ElectraNet's Standard Drawings and Template Drawings.

5.3 Design Deliverables

The final earth grid design for a specific project is to be detailed in an earth grid layout drawing showing the following details as a minimum:

a) Conductor type, size and depth of burial;

b) Gravel/ bitumen thickness and design resistivity (if applicable);

c) Ground rod detail including location, depth and length;

d) Earthing risers to the equipment and operator loops;

e) Earth grid design impedance;

f) Fault current (Both design fault level and Ultimate Fault Level in which the earthing system is deemed safe and functional for its purpose);

g) Fence relocation and connections (if applicable); and

h) Material list.

All calculations and supporting documentation for the earthing system must be submitted to ElectraNet for approval/validation as detailed in this document.

The Designer must submit a design report that must include as a minimum the following information:

(i) Calculation and plot of soil resistivity and test method;

(ii) Determination of the worst case fault current value;

(iii) Calculation of minimum conductor size;

(iv) Tolerable voltage limits (50 kg and 70 kg step and touch limits);

(v) Main earth grid design;

(vi) Access gates touch voltages;

(vii) Design Touch voltages (within substation and 1 metre outside);

(viii) Design Step voltages (within and outside substation);

(ix) Maximum earth grid voltage rise (EPR);

(x) 1500 V, 1000 V and 430 V voltage gradients;

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(xi) Telecommunication earthing;

(xii) Actual installed earth grid capacity (based on final current injection test) with respect to highest single phase to ground fault level;

(xiii) Details of other infrastructure in the vicinity of the substation (e.g. fences, pipelines, rail etc.), both present and future;

(xiv) Risk assessment of the earthing system designed, including installation method, impact on the public and on surrounding infrastructure; and

(xv) All input parameters considered for the design.

5.3.1 Design Model

The Designer must submit a design report along with the electronic version of the CDEGS design model to ElectraNet for review and records.

5.4 Constructability Requirements

Earthing and bonding systems involve the installation of horizontal, vertical or inclined electrodes buried or driven into the general mass of the earth. Connections to cables screens, equipment, structures, fences and overhead earth wires are also included.

In addition to meeting all of the Greenfield and brownfield construction requirements as recommended in Clause 8.5 of AS2067 the following construction requirements are required:

a) Backfill material must surround the conductor by at least 150 mm and must be between pH levels of 6 and 10. Resistivity of fill material must be of similar or less resistivity than the natural soil. Fine soils such as natural clay, bentonite or loam are acceptable.

b) The Contractor must use only material passing through a 9.5 mm sieve as the first 150 mm of backfill on top of the earthing conductors. A test certificate must be provided to prove compliance with this clause.

c) Vertical electrodes must be driven in using appropriate tools. Where the vertical electrodes are used and cannot be directly driven, they must be installed in 75 mm bore holes. The bore holes must be back filled with a 50/50 bentonite and gypsum slurry mix.

d) Where an earth grid riser is attached to an earthing point near the base of a structure and an earthing connection needs to be extended to a piece of primary equipment or to a portable earthing lead connection point, the entire fault carrying path to the main earth grid must use copper along the entire length. Steel must not form part of the fault current path at the joint.

In addition, for Brownfield Sites, the following must be considered

e) During construction, any temporary fences, or metallic structures brought to site must be earthed to the substation existing earth grid.

f) Precautions must be taken when extending an existing earth grid or when joining an existing earth grid to a new section of earth grid.

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5.5 Operability Requirements

The earthing and bonding system must operationally:

a) Be capable of providing a low resistance path to remote earth to ensure fault currents are directed to ground and dissipated for all earthed items for the duration of the response time of the protective system (fault duration);

b) Be capable of limiting the earth potential rise such that the likelihood that a person is exposed to a hazardous voltage and potentially fatal electric shock (step, touch and transfer potentials) is reduced to within prescribed limits under fault conditions (earth grid);

c) Maintain all conductive plant and equipment at the same potential;

d) Not create potentially hazardous conditions (i.e. step, touch and transfer) to external third party metallic structures in the vicinity of the substation;

e) Be capable of providing a low impedance path to earth for lightning strikes to ensure that lightning currents are directed to ground and dissipated, such that all primary plant is protected from direct lightning strikes (lightning towers/poles, aerial earthing conductors);

f) Provide two independent earthing connections to equipment structures, each of which are capable of carrying the maximum expected fault current for the longest expected clearing time;

g) Provide a zero potential voltage reference for equipment which require it (e.g. transformer, CVT, capacitor banks, surge arrester, secondary systems);

h) Provide a defined area upon which an operator stands such that an equipotential is maintained between the operator and the equipment the operator is connected to. Operator earth mats, switching mats, or earth loops must be installed.

i) Provide electromagnetic screening for the shielding of control cables along their length from the control room to the primary plant. A PEC must be used throughout the yard;

j) Provide visual indication of the earth configuration at key locations (main earth bar at transformer);

k) Provide for connection and isolation for operation and testing of the earthing system (earth test links, earth stakes);

l) Restrain the earth conductor under normal conditions (saddles on earth risers and down conductors); and

m) The value of the earthing impedance is in accordance with the protective requirements and is continuously effective over the planned lifetime of the installation with due allowance for corrosion and mechanical constraints.

5.6 Commissioning Maintainability and Testing Requirements

The earthing and bonding systems require commissioning tests, ongoing maintenance and testing throughout the operating life of the substation. These

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must be carried out in accordance with the requirements of Clauses 8.6, 8.7 and 8.8 of the latest edition of AS 2067.

In addition to the requirements of AS 2067 the following acceptance criteria must be used for joints:

a) DC Resistance (ductor) Test. A dc resistance test must be applied to each connection with a minimum of 100 A current. The resistance must be less than 30 µΩ per joint for all copper to copper connections and less than 100 µΩ per joint for all other joint/connection types in the test path.

5.7 Soil Resistivity Testing

a) Soil resistivity testing is required for all Greenfield Sites before the start of the earthing design. Testing must be carried out on natural ground before starting any earth/civil work on site.

b) Checks must be made to ensure that underground and overhead infrastructure i.e. pipelines, cables, overhead lines as these will distort the test readings.

c) Sufficient small and large traverse measurements at multiple locations within substation platform and also beyond the substation platform must be performed so an accurate soil model can be derived for the site to develop design for safety to public.

d) Soil tests must be carried out using the Wenner method as described by IEEE 81.

e) The soil resistivity tests must be repeated after substation bench work is completed where substation site require over 600 mm cut or fill or over rocky sites.

f) Soil resistivity test plans must be provided for review by ElectraNet prior to site testing.

g) ElectraNet may choose to witness soil resistivity testing by Contractors.

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6. SAP Data Capture Requirements

The following information on all components of the substation earthing system, is required to be captured in SAP or relevant software database:

a) Device functional location;

b) All design and test reports associated with the earth grid must be linked to this functional location.

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ElectraNet

Contact Us

52–55 East Terrace, Adelaide,
South Australia 5000
PO Box, 7096, Hutt Street Post Office,
Adelaide, South Australia 5000

Phone **+61 8 8404 7966** or toll-free **1800 243 853**

Fax **+61 8 8404 7956**

Visit us online **electranet.com.au**