Substation Earthing Design

Design Standard

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Western Power's Engineering & Design Function is responsible for this document

CONTACT

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Contents

Revision Details

Version	Date	EDM Version	Summary of change
0	22/12/15	2	First Issue
1	15/05/15	4	Updated to align with AS2067:2016 changes
2	01/05/20	5	Updated to AMS template and addressing open items from the issues register
3	18/11/22	6	Updated Section 17.7.14
4	12/06/23	7	Addressed issues register items 25 to 37 inclusive.
5	Oct 2023	8	Standard Online Update
6	Dec 2023	9	Updating formatting plus addressed issues register items 39-42.

1. Introduction

The purpose of this Engineering Design Instruction (EDI) is to assist engineers in designing the earthing systems for transmission zone and terminal substations.

A substation earthing system generally comprises a combination of buried or driven earth rods and buried, interconnected, bare conductors. These are generally joined to form a buried earth electrode system or earth grid.

1.1 Purpose and scope

The purpose of an earthing design is to meet the following requirements:

- To ensure that accessible non-current-carrying metallic structures and equipment are maintained at the same potential.
- To limit earth potential gradients such that step, touch, and transfer voltages will not endanger the safety of people under normal and fault conditions.
- To provide a neutral earthing point for the power system associated with the installation to ensure the correct operation of protective devices during earth faults.
- To provide a common earth for electrical devices and metallic structures to reduce or eliminate static build-up.
- To stabilise the voltage-rise during transient conditions.
- To dissipate lightning strikes and other overvoltage's.
- To limit interference on other assets such as control and communication cables, and metallic pipes.

The scope of this Engineering Design Instruction is to cover:

- The earthing design methodology and process for an installation and to ensure safety during different phases of construction.
- The definition of the inputs and parameters into an earthing design.
- The establishment of acceptable safety criteria, step voltage, touch voltage and earth potential rise.
- The risk-based cost benefit analysis of different earthing mitigation methods.
- The assessment of third-party assets.
- The selection of material, portable earthing and connectors for the earthing system.
- The application for Greenfield and Brownfield substations.

This Engineering Design Instruction is intended for use by persons undertaking earthing designs for the Western Power network (WPN). The approach taken is the probabilistic approach that aligns with AS2067-2016 and is defined in ENA Doc 025, EG-0. This approach uses a risk-based design process that aims to ensure a safe and robust earthing design, whilst at the same time finding a balance between cost, practicality and risk management. By following this process, we reduce risk on the network so far as is reasonably practicable (SFAIRP), whilst demonstrating engineering due diligence and compliance with AS5577.

1.2 Acronyms

Acronym	Definition

1.3 Definitions

Term	Definition
Design Instruction	Describes in detail a particular type of design. This is the "how" to implement a design with clear boundaries defined.
ASC PVC	Annealed Stranded Copper Conductor with PVC insulation
ALARP	As Low As Reasonably Practicable
BASC	Bare Annealed Stranded Copper Conductor
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis (Software)
EPR	Earth Potential Rise
HDFCB	Hard Drawn Flat Copper Bar
MEN	Multiple Earthed Neutral
OHEW	Overhead Earth Wire
SHE	Safety Health and Environment Function
Common connection	Connection between equipment/steelwork and bund ring, or the building internal earth ring. The conductor shall be ASC PVC (Bk) or ASC PVC (Gn/Ye).
Direct connection	Connection between equipment/steelwork and the main substation earth grid.
Down conductor	Connection from an overhead earth wire to the local earth grid.
Downlead	Conductor used between outdoor equipment/steel work and the main substation earth grid. The conductor shall be ASC PVC (Bk).
Looping connection	Connection between two pieces of equipment or steelwork, without a further connection to the main substation earth grid or earth ring inside the building.
Parallel connection	Connection between the equipment and the steelwork that the equipment is installed upon.
SFAIRP	So Far As Is Reasonably Practicable

V_{touch} (allowable)	The voltage acceptable as defined by AS2067:2018 and EG0
V_{step} (allowable)	The voltage acceptable as defined by AS2067:2018 and EG0

1.4 References

References which support implementation of this document

Reference No.	Title

2. Supporting Documentation[1]

3. Compliance

This Engineering Design Instruction complies with all higher-level Western Power technical documents and relevant Australian Standards.

This Engineering Design Instruction should encompass all requirements of the relevant Australian Standards which are current at the time of issue. These relevant Australian Standards are listed in Table 3.1 below. A period will be set when the standard needs to be reviewed. If significant changes occur on an Australian Standard which affects safety, then an out of cycle review can be completed.

Table 3.1: Australian Standards and International Standards

Standard Number	Standard Title
AS 3000 - 2018	Electrical Installations – Wiring rules
AS 2067 - 2016	Substations and high voltage installations exceeding 1kV a.c.
AS 3835.1 - 2006	Earth potential rise—Protection of telecommunications network users, personnel and plant
AS 4853 - 2012	Electrical hazards on metallic pipelines
AS 60479.1 - 2022	Effects of current on human beings and livestock
ENA EG1 - 2006	Substation Earthing Guide

1 See Western Power Internal Document

Standard Number	Standard Title
ENA EG-0 - 2022	Power System Earthing Guide
IEEE80 –2013	IEEE Guide for Safety in AC Substation Grounding
IEEE81 - 2012	IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System
IEEE837 - 2014	IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding
IEC62561.7 –2018	Lightning protection system components (LPSC) – Part 7: Requirements for earthing enhancing compounds

4. Functional Requirements

This Engineering Design Instruction is intended to be used by Substation Engineering staff and by companies completing outsourced design work for Western Power, as it outlines the Western Power requirements pertaining to earthing design for transmission substations.

5. Safety in Design[2]

Safety in Design (SID) must be considered when completing all substation design work. SID focuses on making the design safer and easier to understand, with the aim to eliminate and mitigate potential hazards during the detailed design phase of a project. As the earthing system is a fundamental component of every transmission installation, it can affect the safety and wellbeing of individuals from as early as the start of the construction all the way to the end of asset life. The earthing system shall be designed in such a manner that maintains the safety of all workforce personnel, critical assets and the surrounding public community.

Some examples of Safety in Design in earthing design include:

- Consideration for future maintenance and testing of the earthing system e.g. are the earthing pits located away from live equipment, if possible?
- Construction staging and temporary fencing requirements;
  e.g. Can a temporary fence be installed safely, and how will it be connected to the existing earth grid, if at all?
- Practicality of portable earth stirrup and stub locations
  e.g. Are the stub locations easy to reach with the portable earth leads?
- Security and anti-theft solutions to protect earthing materials (see Section 22.6 for more information)
- Site specific considerations for special locations; are there nearby conductive surfaces with a higher contact coincidence? e.g. drink fountain, playground equipment, swimming pool etc.

[2] See Western Power Internal Document

As a checkpoint in every design stage of the project, the earthing design shall be reviewed as part of a Risk Workshop in collaboration with the project design team.

All projects are required to have a SID Hazard Register to include evidence of all measures implemented to eliminate or reduce risks.

6. Overview of the Main Design Elements

The earthing design process consists of performing an earthing analysis and study to meet the safety criteria by selecting the earthing arrangement and components to achieve this goal.

The earthing design process covers the following aspects:

- Understanding of all the earthing design inputs (Section8).
- Determining the safety criteria to design the earth grid. (Section9)
- Preparing an earthing layout for the site and modelling an earth grid. (Section 10, 11, 12, and 22)
- Assessing third party assets that are in the vicinity for possible EPR transfer potential, touch potential and hand-to-hand potential hazards. (Section 22)
- Providing additional mitigation methods to comply with the safety criteria. (Section 13)
- Performing a risk-based cost benefit analysis to determine if additional earthing mitigation is reasonably practicable. (Section 14)
- Determining all the earthing connection details to equipment and the earth grid. (Section 15, 16, 17, 18 and 19)
- Understanding the AC supply arrangements and earthing requirements. (Section 21)
- Performing construction inspections and testing. (Section 22)
- Performing commissioning injection testing for validation of the earthing design. (Section 24)

7. Earthing Design Process[3]

The earthing design process covers the steps required to effectively implement an earthing design. It is important to gather all relevant inputs prior to undertaking the earthing design. Computer software packages can be used to model the earthing system and to determine the safety criteria.

The earthing report specifies construction and commissioning tests which need to be co-ordinated so that the earthing design can be validated against field measurements.

[3] See Western Power Internal Document

8. Input Parameters

The following section covers the key input parameters required to model the earthing system. The earthing system model is used to determine values of maximum projected earth potential rise (EPR).

8.1 Soil Resistivity

The soil resistivity is an important parameter in the earthing system design. Soil is one of the paths for fault current to flow back to the source.

8.1.1 Site Measurements – Site Access[4]

8.1.2 Site Measurements[5]

8.1.3 Computer Modelling of Soil Resistivity[6]

8.1.4 Report[7]

8.1.5 Backfill

Where there is imported backfill of greater than 250mm depth, then a further verification soil resistivity measurement is required with the new backfill in place.

8.2 Primary Fault Clearance Time[8]

Western Power Operational Technology Area is to be consulted to obtain the primary fault clearance times.

8.3 Fault Level[9]

The Western Power Grid Transformation Area is to be consulted to obtain the fault levels of the network.

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[4] See Western Power Internal Document
[5] See Western Power Internal Document
[6] See Western Power Internal Document
[7] See Western Power Internal Document
[8] See Western Power Internal Document
[9] See Western Power Internal Document

8.4 Dial Before You Dig

Third party asset details are available via the dial before you dig website.

http://www.1100.com.au/#

When transmission OHEW and distribution feeders are modelled then the dial before you dig area must be increased to include any third-party assets in the vicinity.

8.5 Site Visit

All earthing designs require a site visit regardless of soil resistivity data availability.

The purpose of the site visit is to:

- Confirm all dial before you dig assets, and their location.
- Where there is an exposed steel pipeline, follow the pipeline to identify the nearest, exposed valve pit and accurately record this location once it has been located.
- Assess any other metallic objects (such as property fences, bollards, park benches, train lines, gates) which might not be available on dial before dig plans. These are located outside the substation. Ensure that distances from the substation are measured so that they can be modelled.
- Determine the location where all distribution feeders terminate into the distribution network.
  - Confirm the earthing arrangement at the termination location.
  - This also includes any metallic objects or third-party assets that are along the feeder route.
- Confirm the presence of overhead earth wire on the transmission lines exiting the substation.
  - Verify that the OHEW terminates into the substation.
    - Via an overhead connection to the gantry or disconnector; or
    - Via a *down conductor* from one of the last poles which runs into the substation.
  - Verify all existing electrode positions along the overhead earth wire route with respect to the pole numbers.
  - This also includes any metallic objects or third-party assets that are along the transmission line OHEW route.
- Confirm the termination location of any underground transmission cables leaving the substation, and their earthing arrangement.
- Determine any existing insulating ground covering (crushed rock or bitumen) in and around the substation. This includes determining the approximate depth of the ground cover.

- Confirm if there are any swimming pools, lakes or water recreational activities in the vicinity of the substation and record their location. A SPIDAWeb aerial photograph map shall be used to provide an indication of the locations.

8.5.1 Private Property Access[10]

9. Safety Criteria

The design safety criteria are a set of potential limits that must not be exceeded in order to achieve a compliant earthing design.

Safety criteria voltage limits are determined using CDEGS and risk assessed using Argon. Where achievement of safety limits determined using CDEGS is impossible, impractical, or uneconomical, Argon can instead be used to determine safety limits which achieve negligible risk, or when negligible risk is not achievable, a risk as low as reasonably practicable (ALARP). Note the first preference is for the earthing design to comply with safety limits determined using CDEGS.

These safety criteria voltage limits include:

9.1 Earth Potential Rise (EPR) Limit

The EPR limit is the maximum voltage difference that can be experienced from the ground due to an earth fault.

9.2 Touch Potential

This is defined as the potential between one hand to two feet.

9.3 Step Potential

This is defined as the potential between both feet when on the ground.

9.4 Hand to Hand Potential

This is defined as the potential between one hand to the other hand.

9.5 CDEGS Software[11]

The first preference for earthing design is to use CDEGS software to determine the value of the safety criteria voltage limits.

[10] See Western Power Internal Document
[11] See Western Power Internal Document

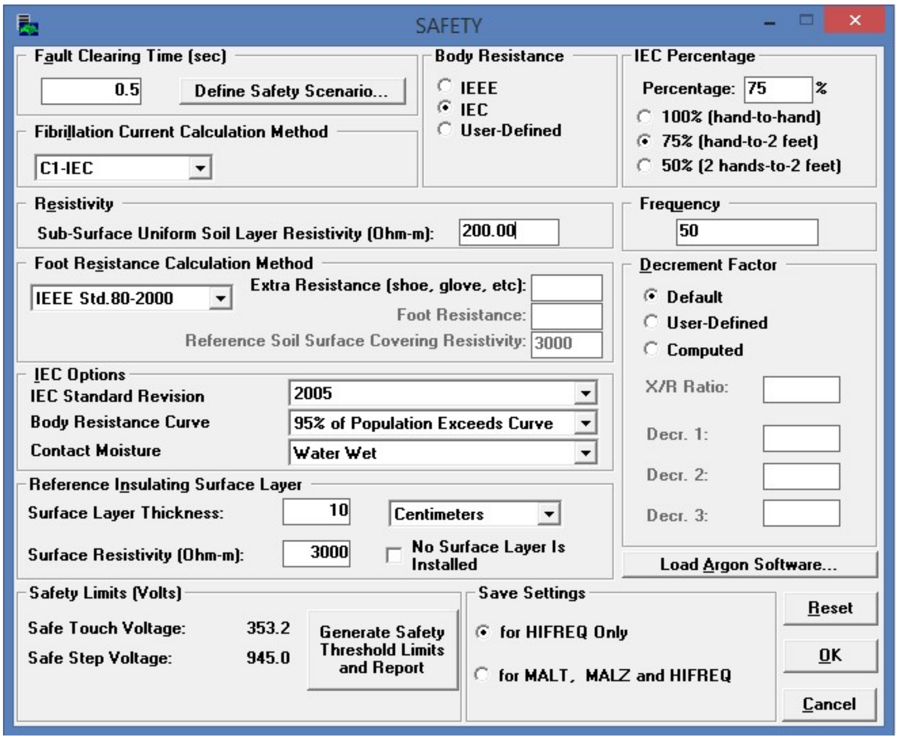

Figure 9.1: Screenshot from CDEGS Software

9.5.1 Body Resistance[12]

9.5.2 Fault Clearance Time[13]

9.5.3 IEC Percentage[14]

9.5.4 Frequency[15]

9.5.5 Resistivity of Sub-Surface[16]

9.5.6 Foot Resistance[17]

[12] See Western Power Internal Document
[13] See Western Power Internal Document
[14] See Western Power Internal Document
[15] See Western Power Internal Document
[16] See Western Power Internal Document
[17] See Western Power Internal Document

9.5.7 Decrement Factor[18]

9.5.8 IEC Options[19]

9.5.9 Reference Insulating Surface Layer[20]

9.5.10 Fault Simulation[21]

9.6 Argon Software[22]

In compliance with AS2067:2016, the designer must also undertake a direct probabilistic approach and include the probability of fatality at these safety criteria voltage limits. This allows a risk analysis of the safety criteria voltage limits to determine the most appropriate mitigation option.

This probability of fatality can be calculated using the Argon software.

Should Argon show that the CDEGS voltage limits do not result in negligible risk of fatality, lower limits as determined by Argon should be used for the earthing design.

Should it be impossible, impractical, or uneconomical to achieve the limits determined by CDEGS, Argon may be used to determine higher limits which result in negligible risk of fatality. This option needs to be assessed and approved for specific cases where required by Western Power, Substation Design.

Should these limits still prove unachievable, it may be necessary to instead accept voltage levels which reduce the risk to so far as is reasonably practicable (SFAIRP) as determined by Argon. Note Argon software does not have the ability to determine risk so far so is reasonably practicable (SFAIRP) so in this case the ALARP region is considered. SFAIRP and ALARP in this case are considered the same.

Earthing designs which result in voltage levels in the Intolerable Risk range are not acceptable.

The disproportional factor used should be presented to Western Power for consideration before any designs are finalised.

18 See Western Power Internal Document
19 See Western Power Internal Document
20 See Western Power Internal Document
21 See Western Power Internal Document
22 See Western Power Internal Document

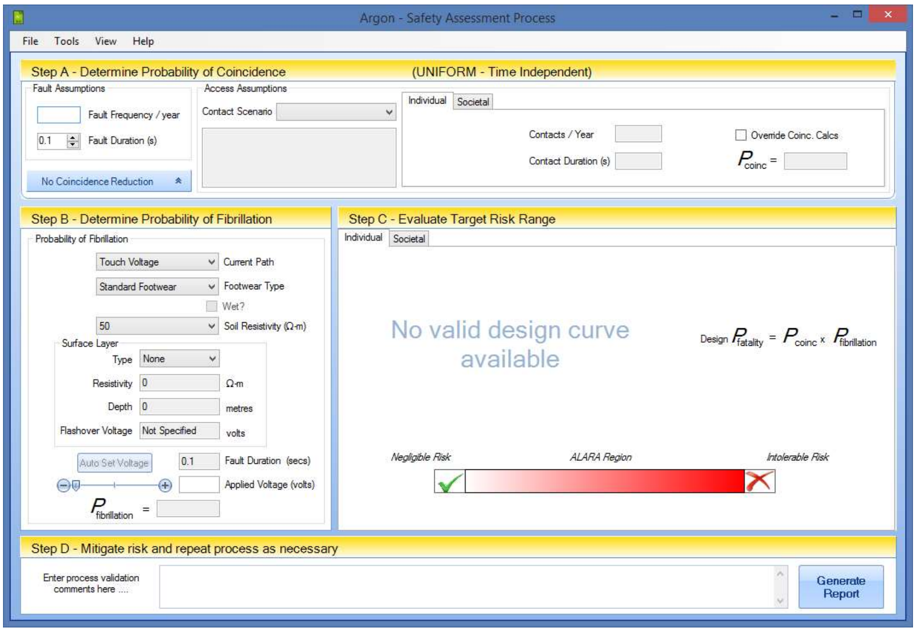

Figure 9.2: Screenshot from Argon Software

The Argon software parameters are described below:

9.6.1 Fault Frequency[23]

9.6.2 Fault Duration[24]

9.6.3 Contact Scenario[25]

9.6.4 Current Path[26]

9.6.5 Footwear Type[27]

9.6.6 Soil Resistivity and Surface Layer[28]

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23 See Western Power Internal Document

24 See Western Power Internal Document

25 See Western Power Internal Document

26 See Western Power Internal Document

27 See Western Power Internal Document

28 See Western Power Internal Document

9.6.7 Applied Voltage[29]

9.6.8 Risk Output Analysis[30]

10. Basic Earth Grid Functional Design

The basic earthing system consists of the following components:

- Earth electrodes.
- Earth conductor.
- Earth joints.
- Downlead connecting the earthgrid and equipment.
- Ground covering.

10.1 Earth Electrodes

The term earth electrode refers to earth rods installed in a vertical arrangement.

- Earth electrodes shall be located in each corner of the substation site.
- Earth electrodes shall be located in a regular pattern as possible along the earth grid perimeter.
- Additional earth electrodes should be installed:
    - Near where the lead from the neutral bushing of a transformer is connected to the earth grid,
    - In the proximity of surge diverters, lightning masts, earth switches and gantries (Note: - Gantries provide path for lightning), and
    - Near the earth connected bushing of a NEC (Note: - not required when installed in proximity of the main transformer earth electrode).

10.2 Earth Grid

The earth grid conductor shall be BASC and shall be sized according to Section 17.

The basic grid pattern for the earth grid shall consist of the following:

- A continuous conductor loop surrounding the inside perimeter of the substation and each circuit to enclose as much area as practicable.

[29] See Western Power Internal Document
[30] See Western Power Internal Document

    - If there is a fence touch potential issue, grading ring shall be installed outside the fence as per Section 13.2.
- Within the loop, conductors laid in parallel lines and along both sides of equipment circuits to provide for short, duplicate earth connections.
- Frequent cross connections between the foundations to complete the grid design.
- Cross connections at all earth grid crossings.
- A depth of 450 mm below the finished ground level.
    - Variations in depth required to pass under cable trenches etc. is permissible for short sections of earth grid.
- A backfill free of sharp particles to avoid damage to the BASC earth grid.

In substations within high security risk areas, copper clad steel can be used as an alternative to BASC. See Section 22.6 for further information.

10.3 Earth Joints

The earth grid conductor needs to be joined between BASC-BASC connections, BASC-ASC and HDFCB-ASC. Refer to Section 18 for joint selection.

10.4 Download[31]

All *downlead* connections between the earth grid conductor and the equipment shall be made using ASC Black PVC conductor.

In substations within high security risk areas, copper clad steel can be used as an alternative to ASC Black PVC conductor. See Section 22.6 for further information.

10.5 Ground Covering

A ground cover layer of 100mm of crushed rock shall be installed inside all greenfield substations and new circuits added to brownfield substations. The crushed rock layer must be installed on compacted ground.

A bitumen or crushed rock ground covering layer is sometimes used outside the substation to improve the touch and step potential around the perimeter fence of the substation.

[31] See Western Power Internal Document

11. Modelling of Earthing System

11.1 Steps to Mitigate Non-Compliant Standalone Earthing Design

Once all the initial inputs are provided into the earthing model the first simulation of an earth fault in the model will provide an indication of its compliance with the safety criteria.

Where compliance is not achieved, complete further modelling and assessment in the following order:

- Model the Transmission Line OHEW or Transmission underground cable/s.
- Model deeper electrodes inside the substation and see if this has a significant impact on the earthing system.
- Model the Distribution feeders to the first termination point outside the substation.
- Model any third party assets in vicinity of the substation, transmission line or distribution line
- Refer to Section 13 for other mitigation methods.

11.2 Modelling of Transmission OHEW[32]

11.3 Modelling of Transmission Underground Cable[33]

11.4 Modelling of Distribution Feeders[34]

11.5 Modelling of Swimming Pools[35]

11.6 Ultimate Development Considerations

All greenfield earthing designs shall consider the ultimate development of the site.

Where possible, the earth grid placement should consider the location of future circuits, transformers and buildings so that the earth grid is not disturbed during future construction.

The model should furthermore include the site security system such as camera auxiliary supplies. These may include metal cubicles and camera pillars near the fence line with cable connections to the relay room.

[32] See Western Power Internal Document
[33] See Western Power Internal Document
[34] See Western Power Internal Document
[35] See Western Power Internal Document

12. Evaluation of Earth Potential Rise (EPR)

The EPR typically reduces with increasing distance from the site due to the ground impedance. The magnitude of earth potential rise together with the earth grid design influences the calculated step and touch potentials that will be present during a power system fault inside and outside the substation. Reduction in EPR will always result in a reduction of the resultant step and touch potentials.

Where calculated touch voltages are below the V_{touch} (allowable), and calculated step voltages are below the V_{step} (allowable), then an acceptable design has been achieved. However, the voltage rise on third party assets and transfer potentials also needs to be considered to ensure a fully compliant design.

If the earth system model does not yield step and touch voltages lower than V_{step} (allowable) and V_{touch} (allowable) respectively, safety compliance is not achieved. The designer must then use mitigation methods so far as is reasonably practicable (SFAIRP) to reduce the EPR and residual risk.

13. Mitigation Methods

The following mitigation methods are to be followed in order of preference.

13.1 Insulating Metallic Objects[36]

13.2 Fence Touch Potential Issue[37]

13.2.1 Isolation Panel[38]

Where there is a potential transfer between the substation fence and an external (customer) fence, then an isolation panel shall be used.

13.3 Deep Electrodes for Substations[39]

36 See Western Power Internal Document
37 See Western Power Internal Document
38 See Western Power Internal Document
39 See Western Power Internal Document

13.4 Connecting the Transmission OHEW[40]

13.5 Protection Upgrades[41]

13.6 Circuit Breaker Upgrades[42]

13.7 Deep Electrodes for Transmission Line OHEW[43]

13.8 Ground Enhancing Compound[44]

13.9 Include the Distribution N-E[45]

13.10 Counterpoise Conductors[46]

Designs for counterpoise earthing must be discussed with the Substation Design to decide if earth pits are required for future testing and if this is an acceptable solution.

13.11 Extending the Transmission OHEW to the Downstream Substation[47]

13.12 Registering mitigation strategies implemented that must be maintained during its life

All mitigation methods implemented that must be maintained during its life must be risk assessed and discussed with Operational Asset Performance group to determine the maintenance strategy. If the design is completed by someone external to Western Power, then the solution must be discussed with Substation Design.

40 See Western Power Internal Document
41 See Western Power Internal Document
42 See Western Power Internal Document
43 See Western Power Internal Document
44 See Western Power Internal Document
45 See Western Power Internal Document
46 See Western Power Internal Document
47 See Western Power Internal Document

14. Risk-based Cost vs Benefit Analysis[48]

Different mitigation techniques can be modelled, but the final decision will be made based on the cost of the mitigation vs the benefits gained. A risk-based cost benefit analysis is used to ensure any risk mitigation is applied in an economic way and so far as is reasonably practicable (SFAIRP). By doing this we ensure that the cost to implement an option is not grossly disproportionate to the cost of benefits gained.

The methodology uses the Argon software to determine the Western Power risk value – the probability of fatality P_f. Mitigation options that reduce this risk value are assessed, taking into account the cost of mitigation (in present value) and the benefit gained (the reduction in risk of fatality). Both cost and benefit values are compared to give a cost disproportionality (Note: Western Power uses a disproportion factor (DF) of 3). Options that are grossly disproportionate in cost (DF > 3) are not considered. The preferred mitigation is selected based on the option that reduces the risk value to as low as reasonably practicable (ALARP).

Note: Any calculated risk value higher than 1 x 10-4 is unacceptable by Western Power and must be mitigated.

15. Equipotential Bonding vs Fault Current Carrying Capacity[49]

Earthing conductor is sized for either equipotential bonding or fault current carrying capacity.

All conductors shall be sized for the ultimate fault level based on the planning criteria. Refer to Appendix A.2.6 of Network Standard – Transmission Network Configuration and Rating.

The main consideration is the fault level at the point of connection. All 415V supplies, supplies to secondary systems and DC systems are fault limited by the station transformer or source of 415V or DC supply. This means that the conductor installed inside the buildings can be reduced.

Section 16 covers the different applications with the required conductor sizes.

16. Selection of Earthing Conductor

Refer to Appendix B for further reference information.

16.1 Earthing System Ratings[50]

Three standard ratings have been adopted for the design of new substation earthing systems. These are 25 kA/0.5sec, 40 kA/0.5sec and 50kA/0.5sec. These ratings are based on the predicted horizon fault levels for voltages from 6.6 kV to 330 kV. Refer to Appendix A.2.6 of Network Standard – Transmission Network Configuration and Rating.

48 See Western Power Internal Document
49 See Western Power Internal Document
50 See Western Power Internal Document

The design rating for a substation earthing system shall be nominated by Grid Transformation Function.

All earthing system components, for each of the standard design ratings, have been selected to ensure that they are suitably rated to withstand the design earth fault current for the design fault duration without mechanical damage, overheating or unduly drying out the surrounding soil.

16.1.1 Building secondary equipment earthing

The secondary equipment located inside the substation buildings is fault limited by the 415V station supplies to the building. The following ratings have been used:

- 160kVA transformer (6kA 415V fault level) for 25kA/0.5sec sites.
- 315kVA transformer (10kA 415V fault level) for 40kA/0.5sec sites.
- 500kVA transformer (18kA 415V fault level) for 50kA/0.5sec sites.

Where the 415V station supplies are larger than these assumed transformer sizes (for the relevant fault level), then a detailed fault level and conductor sizing calculation is required.

16.2 Conductor Selection[51]

Annealed stranded copper conductor is the preferred earthing conductor material. This choice of conductor permits the utilisation of different underground connectors, which allows the conductor to be rated in accordance to its own highest temperature.

The sizing of earthing conductors is based on both electrical and mechanical properties. The required cross-sectional area (size) of an earthing conductor is determined by its electrical properties. Mechanical considerations simply prescribe the minimum conductor size that should be used for an earthing application.

The electrical rating of an earthing conductor is governed by the following factors:

- Fault current magnitude,
- Fault current duration,
- Conductor conductivity, and
- Conductor and connector thermal breakdown limitations.

Therefore, once the earthing system rating has been established, (prescribing definite values for the fault current magnitude and duration), a selection of the appropriate copper earthing conductors for various applications can be made in accordance with Table B.4 and Table B.5 (see Appendix B).

For indoor applications PVC conductors shall be Green/Yellow colour.

[51] See Western Power Internal Document

For outdoor applications all PVC conductors shall use a black colour.

XLPE Black flexible conductor can be considered for applications with difficult bends and connections. Contact WP Substation Design Engineer for approval.

Applications not listed in Table B.4 and Table B.5 must be assessed on a case-by-case basis.

16.3 Corrosion

The geotechnical survey needs to be completed for each site to determine if there are any corrosive soil types in the location of the substation.

This is important in considering the earthing conductor life expectancy of the substation.

Where possible corrosive soils/sites shall be avoided. Where this is not possible then Erico GEM25A ground enhancing compound shall be installed around all BASC conductors and electrodes.

Substation Design and Asset Performance function must be notified of corrosive soil sites as they may require additional maintenance checks on the earthing conductor.

16.4 415V Supplies

Where there are 415V supplies which require an earthing connection then the earth shall be provided as part of cable. (e.g.: 2c +E or 4c +E) Some applications for this include air conditioner compressors, air conditioner controller box, air conditioner blower units, building lighting (using TPS) and fire protection panels.

For details on calculating the earth loop impedance refer to Engineering Design Instruction – AC Auxiliary Systems.

16.5 Brownfield Applications[52]

When looking at Brownfield sites an analysis of all existing earthing conductors is required. Refer to Table B.4 and Table B.5 (see Appendix B) for the typical fault rating of conductor. Table B.2 (see Appendix B) has a list of HDFCB (hard drawn flat copper bar) sizes and their corresponding ratings.

If the earth bar or conductor is under rated then additional earth grid needs to be installed to uprate the earthing system.

[52] See Western Power Internal Document

17. Earthing Arrangements

17.1 Drawings

For a full list of earthing drawings refer to Appendix A.

17.2 Earth Electrodes and Earth Grid

The term earth electrode refers to vertically driven or drilled earth rods.

The term earth grid refers to horizontally laid BASC conductor or flat copper bar.

Driven earth rods are to be used where soil conditions are favourable. Earth rods are constructed of several sections coupled together to form a single unit. The complete unit includes a driving point and driving head. Standard earth rod sections are 250 µm copper bonded steel, 15 mm in diameter.

The required electrode depth shall be specified on the earthing layout drawing and should be at a depth of 8m or more pending the earthing study. (Minimum depth 8m for Earth electrodes).

The earth electrode shall be joined to the earthing grid by a copper connector.

To facilitate separate measurement of the earth resistance of the main earth grid and earth electrode, a length of insulated copper conductor is required between the main grid conductor and the earth electrode.

The earthing electrode shall be protected using black heat shrink at the transition into the ground.

The first electrode installed on any new earthing designs need to have the resistance measurement taken to verify that the earthing design matches the site conditions.

It is assumed that the current entering the earth grid from a *downlead* divides according to a 70% - 30 % split. Consequently, grid conductors are sized to carry only 70% of the maximum earth fault current.

17.2.1 Deep or Drilled Electrodes

Deep electrodes are electrodes that are longer than 12m.

Drilled electrodes are required where driving of the electrodes is difficult or impossible due to adverse soil conditions.

Where deep electrodes or drilled electrodes are to be used, holes are to be drilled to allow installation of earth electrode rods to the required electrode depth. The drilled hole diameter shall be 100mm or more, and to be at a depth of 150mm below the required electrode depth. The Erico GEM25A product in a wet slurry mixture shall be used to backfill the hole.

17.3 HDFCB Earth Bars

In some Brownfield sites HDFCB earth bar was initially used for the earth grid. In all new installations on Brownfield sites, BASC conductor shall be used.

The HDFCB earth bar was sized depending on the fault rating of the site. Refer to Section 16.5 for confirming the size of earth bars on Brownfield sites.

17.4 Outdoor Structures – Electrical Plant

17.4.1 General

Direct connections to the earth grid shall be made between:

- All outdoor, above ground, conductive metal parts that might accidentally become energised, such as metal structures, machine frames, metal housing of switchgear, transformer tanks, metal cubicles, guards etc.
- All fault current sources such as surge diverters, capacitor banks or coupling capacitors, reactors, power transformers, current transformers, voltage transformers, earth switches, lightning masts and, where appropriate, machine neutrals, yard lighting and power circuits.

Downleads shall be of ASC PVC(BK) conductor determined in accordance with Table B.4. Selection of copper earthing conductors for outdoor applications

(see Appendix B).

In all substations, a standard single hole M16 copper cable lug using stainless steel bolts and nuts shall be employed for termination of all above ground earth copper conductors. (Refer to Appendix F)

17.4.2 Outdoor Structure Connections[53]

Direct connections to structures shall be bolted at the base. The *downlead* shall be terminated using a tinned lug. Where a conductor is to be bolted to a painted structure, the paint shall be removed from the contact area at the earth termination point.

Where two *direct connections* are made to each structure, (i.e. 2x120mm^2 or 2x150mm^2), then a single bolt termination for each connection shall be used.

Where provision is to be made on structures for the connection of portable earths, the *downlead* shall terminate in a lug which bolts onto the structure behind the portable earth brass stub. This lug needs to have a sufficiently large palm so that the brass stub can be bolted tightly over it and must be drilled with a 17 mm diameter hole to suit the M16 stud required for the brass earth stub.

It is both industry best practice and recommended by the standards (ENA EG1:2006 and IEEE Std 80:2013) to have N-1 provision for earthing connection to the earth grid. Both standards

[53] See Western Power Internal Document

recommend that the connection of the fault current source equipment (e.g. transformer, circuit breakers, earth switches, and surge arresters) to the earth grid satisfy the following two requirements:

- The equipment shall be connected to the earth grid via two downleads, which can each independently withstand the total earth fault current.
- These conductors should be placed on different sides of the equipment's foundation in at least two directions to avoid the possibility of common mode failure.

Where equipment is mounted on a painted or ungalvanised steel structure or a structure made from non-conducting materials such as concrete, the *downlead* shall extend from the earth grid to the equipment in all cases.

Where multiple branches stem off one conductor (i.e. 'T' connections), the joint and any exposed conductor shall be covered by a suitable heat-shrink product. (I.e. Raychem's Cable Tap Encapsulation Kit).

Downleads shall terminate onto items of equipment using tinned copper lugs and bolted joints.

17.5 Crushed Rock

Crushed rock shall be installed in all new greenfield substations, and any additions to brownfield substations (area surrounding new circuits). The crushed rock must be included in the earthing model. The crushed rock layer shall have the following properties:

- Aggregate size is ungraded (straight) 20mm as per AS2758.7 Table 1.
- Electrical resistivity exceeds 3000 Ω.m when wet.
- Minimum depth of 100mm
- Installed above the finished ground level.
- Installed above a compacted ground layer.

When installing crushed rock in brownfield substations, care must be taken to ensure the new ground level does not cause clearance issues with adjacent assets.

17.6 Ground Enhancing Compounds[54]

Ground enhancing compounds are to be added to sites that have corrosive soil conditions and/or when additional mitigation is required.

A hole is to be drilled, electrode installed, and then backfilled using a ground enhancing compound.

Similarly, for horizontal grid conductors, ground enhancing compound can be added as the backfill.

[54] See Western Power Internal Document

17.6.1 GEM25A (Erico) [55]

GEM25A is an earth enhancing compound, supplied by Erico.

17.7 Primary Plant

For all primary plant installed onto galvanised steel structures the steel structure will form part of the used fault path.

17.7.1 Power Transformers and Iron Cored Reactors

A bund ring shall be incorporated into all new transformer and iron cored reactor bund designs. This bund ring shall be of BASC conductor and be below crushed rock level inside the bund. The BASC conductor is to be secured to the edge between the bund floor and the bund wall.

Two direct connections are required from the bund ring to the earth grid, one each on opposite corners of the bund ring.

These connections shall be made through a penetration 50mm below the top of the bund wall, to avoid creating a tripping hazard. Bund oil containment level shall be designed below this penetration to maintain integrity of the bund seal.

The direct connection to the earth grid shall be as close as practicable to the main tank common connection.

Two common connections are required from the main tank to the bund ring, one each on opposite sides of the tank.

Two common connections are required to the bund ring where the radiators are not an integral part of the tank.

See Section 17.7.3 for details of neutral earthing requirements.

A common connection to the bund ring shall be provided for any steel grating, stairs or handrails located in the bund area.

All common connections between the bund ring and the equipment or steel work is to be protected with conduit.

17.7.2 Power Transformer Cable Box

A common connection from the transformer bund ring shall be provided to the common earth bar for high voltage cable screens in all power transformer air-boxes using conductor sizing according to Table B.4. Selection of copper earthing conductors for outdoor applications

[55] See Western Power Internal Document

(see Appendix B).

17.7.3 Power Transformer Neutral Earthing

The integrity of these connections to earth is critical as they provide the power system earth on which protection operation and insulation coordination of the power system relies.

Power and earthing transformer neutrals shall have the required number of common connections to the transformer bund ring to suit the required fault level. These connections shall be as short and direct as is practical. Transformer manufacturers shall attach a cable tray vertically along the side of the transformer. The conductor shall be cable-tied to the tray and terminated by either a single bolt or double bolt lug onto a horizontal palm fitting on the neutral bushing (not back to back).

17.7.4 Earthing Transformers (Earthing Compensators)

Earthing transformers shall have one common connection from the tank to the transformer bund ring. See Section 17.7.3 for details of neutral earthing requirements for power transformers.

17.7.5 Station Transformers

Station transformers shall have one direct connection from the transformer earth bar to earth grid. For further information, refer to the Substation Secondary System Design EDI.

A 4C+E cable must be used to connect the station transformer to the AC changeover board.

17.7.6 Surge Arrestors and Voltage Transformers

For each phase of the surge arrestor or voltage transformers (CVTs, CCVTs, CTVTs and VTs) the following shall be provided:

- One direct connection from the equipment base to the earth grid. (A bolted connection can be made at the base of the structure for the direct earth grid connection.)
- One looping connection from the equipment base to the steel structure that the surge arrestor or VT is mounted on.
- The earth connections shall be kept as short as possible and with minimal bends from the structure to the earth grid.

These requirements also apply for power transformers with surge arrestors mounted on them.

- One direct connection from each surge arrestor base to the earth grid is required. (The surge arrestors must not be connected to the bund ring, but need to be connected to the earth grid outside of the bund.
- The power transformer tank acts as a structural looping connection to the earth grid.

Surge counters are no longer purchased or installed as a standard on surge arresters. Where existing surge arresters (complete with counters) are to be relocated, the surge counters are not to be refitted.

17.7.7 Current Transformers

For each phase, one looping connection from the base of the equipment to the galvanised steel support structure shall be provided. A direct connection to the base of the galvanised steel support structure is also required.

Current transformers that are provided with an external capacitive voltage tap for testing purposes must be earthed to prevent internal discharge. Such earthing shall be achieved by the use of a flexible copper link. This link will be supplied by the manufacturer.

17.7.8 Circuit Breakers, Disconnectors and Support Insulators

One looping connection from the base of equipment to the galvanised steel support structure shall be provided. Provided that the support structure is of galvanised steel, a grid connection to the base of the structure is adequate. Refer to Section 17.7.10 for disconnector operating mechanism earthing requirements.

Circuit Breakers with a manufacturer supplied structure do not require a looping connection from the pole to the breaker base, unless specified by the manufacturer. Circuit breakers with a manufacturer supplied structure may have designated earthing connection points on the structure. Where applicable, refer to the specific electrical assembly drawing for the make and model of the circuit breaker concerned for details on what earthing connections are to be made to these earthing points.

Disconnectors and the disconnector station post insulators to have looping connection between the disconnector support beams and galvanised steel columns.

Standalone support structures do not require individual station post insulators to be earthed, a grid connection to the base of the structure is adequate.

17.7.9 Earth Switches

One looping connection from the base of equipment to the galvanised steel support structure shall be provided.

Two looping connections from each earth switch blade to the galvanised steel support structure shall be provided.

Provided that the support structure is of galvanised steel, a grid connection to the base of the structure is adequate.

Refer to Section 17.7.10 for earth switch operating mechanism earthing requirements.

17.7.10 Disconnector and Earth Switch Operating Mechanisms

For disconnectors, one direct connection from the down-rod to the galvanised steel support structure shall be made near the operating handle. The flexible conductor used for this connection shall be with maximum stranding sizing of 0.2mm, be single insulated and have a nominal operating temperature of 90°C.

For both disconnectors and earth switches, one physically separate connection is required from the operators' earth mat (at yard surface level) using ASC PVC(BK) conductor and connected to a convenient point on the structure. Then, one connection from this point must be made to the operating handle with a flexible braid or $70mm^2$ flexible conductor having a minimum rating of 6 kA. A pipe clamp shall be used to connect to the operator handle when the manufacturer doesn't provide an earth attachment point.

17.7.11 Disconnector and Earth Switch Operator Mats

For all disconnector or earth switch operator handles then a horizontal or vertical operator mat shall be provided which matches the handle operation direction.

The operator mat is to be positioned such that it is on a level surface and not clashing with cable trenches.

17.7.12 MV Cable Sheaths

For all cable sheaths that are required to be earthed at the switchboard, the cable sheaths shall be brought back to the earth bar individually and shall not be grouped in any way.

The preferred method is to ensure that the cable has been stripped back and terminated with enough cable sheath to connect directly to the switchboard earth bar. Where the individual cable sheath is too short then a short section of ASC PVC (BK) conductor shall be used between the end of the cable sheath and the switchboard earth bar.

The cable sheath only needs to be terminated at one end inside the substation:

- For transformer incomer cables, the sheath is to be earthed at the transformer earth bar.
- For earthing transformer cables, the sheath is to be earthed at the transformer earth bar.
- For bus-coupler cables, the sheath is to be earthed at the switchboard circuit breaker connected end.
- For feeder, capacitor and station transformer cables, the sheath is to be earthed at the switchboard.

17.7.13 MPS Transformer Cable Sheaths

For all MPS transformers located inside the substation, the cable sheaths are terminated at the MPS.

17.7.14 Indoor Switchboards[56]

A common connection shall be provided for earthing of each of the switchboard transformer incomer circuits and each end of the switchboard. The switchgear itself shall be earthed in accordance with the manufacturer's requirements.

Two separate earth conductors shall be provided from the transformer incomer circuit(s) earth bar to the transformer cable box earth bar. The fault level and fault clearance time is to be verified for the size of this earth conductor.

The earth cables are to be installed as close as possible to the power cables (same trench).

17.7.15 Outdoor Switchgear[57]

Two separate earth conductors shall be provided from the earth grid next to the cable termination structure to the transformer cable box earth bar. The fault level and fault clearance time is to be verified for the size of this earth conductor.

The earth cables are to be installed as close as possible to the power cables (same trench).

17.7.16 Transportable Buildings[58]

In a transportable building the base frame of the building shall be used as a common earthing point. Earth pads are to be welded to the base frame in locations for earthing of the equipment and stairs.

17.7.17 Indoor GIS[59]

Indoor GIS earthing connections are to follow the manufacturer recommendations. The manufacturer shall provide an earthing plan showing all locations that require earthing.

17.7.18 Capacitor Banks and Capacitor Out of Balance (C.O.O.B.) CTs

A *direct connection* from the base of each cubicle or support structure to the earth grid must be made.

[56] See Western Power Internal Document
[57] See Western Power Internal Document
[58] See Western Power Internal Document
[59] See Western Power Internal Document

17.7.19 Air Cored Reactors

Two separate *direct connections* are required to each air cored reactor support structure. This effectively creates two earthing points to connect the air cored reactor support insulators. Each air cored reactor support insulator needs to be connected to an earthing point.

Where there are space limitations, or difficulty in bending the ASC PVC (Bk) conductor to each air cored reactor support insulator, then a copper bar can be installed in the centre of the air cored reactor support structure.

There are to be no closed loop earths for any air cored reactors. Refer to the manufacturers details for recommended magnetic field clearances for closed loops.

17.8 Transmission Line Termination Structures and OHEW

17.8.1 Inside Substations[60]

If the overhead earth wire is attached to a steel structure then a direct connection from the base of the steel structure to the earth grid shall be used.

If the overhead earth wire is not attached to a steel structure then a direct connection using a bi-metal clamp to the down conductor from the earth grid shall be used.

For structures made of a non-conducting material such as concrete or wood, the downlead shall bolt onto the earth wire utilising a detachable bi-metal lug connection.

17.8.2 Outside Substations

Where a transmission line overhead earth wire terminates outside the substation, the earth wire shall be directly connected to the substation earth grid using ASC PVC (Bk) conductor, sized to carry the full fault current (considering the 70% - 30 % current split). See Section 17.2 for details.

Where the connection crosses under the substation fence, two cases must be considered as follows:

- Where the fence and its associated grading wire are connected to the main earth grid, the direct connection shall be inside the substation approximately in line with the transmission line circuit being terminated. The connection shall be run in conduit.
- Where the fence and its associated grading wire are isolated from the main earth grid, then the direct connection shall be to the closest part of the main earth grid. The connection shall be run in conduit.

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17.9 Outdoor Structures - Other

17.9.1 Fences and Gates[61]

A direct connection from every second fence post and every corner post must be made.

Each post used to secure gates shall have a direct connection, and have a separate earth connecting both gate posts. (Note: This includes restricted vehicle access posts.)

A gate grid with spacing of no more than 1m shall be included for all gate openings.

Where required to mitigate touch potential issues a grading ring shall be included 1m outside all new fences. The grading ring shall be connected to every second fence post. Where the fence is a solid wall then the grading ring shall be connected to the earth grid to match the earth grid spacing. Standard grading ring conductor material is BASC, but can copper-clad steel (CCS) can be used as an alternative in high security risk areas (See Section 22.6).

Where the fence is on the boundary then alternative solutions to limiting touch potentials to the fence need to be considered.

Where a palisade topping section is installed on a solid wall every second palisade topping section-to-section joint shall have a direct connection to the earth grid. A looping connection shall be installed on every alternative section-to-section joint where it doesn't connect to the earth grid.

Isolation Fence Panel

An isolation fence panel is used to prevent transfer potential along a fence. When an external fence is connected or is in close proximity to the substation fence then isolation panels can be used.

An isolation fence panel is made from non-conductive materials such as wood or brick. An isolation fence panel is not to have any method or means of connection to the earth grid.

17.9.2 Capacitor Bank Compound Fencing

A *direct connection* from each fence post to the earth grid must be made.

No closed earth loops shall be created from earthing of the fencing.

17.9.3 Air-Core and Shunt Reactor Fencing

A *direct connection* from each fence post to the earth grid must be made.

In some instances, each side of reactor compound can have a *direct connection* to the corner post, and then *looping connections* to each fence post for one side of the compound only. The

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corner fence posts must not be connected together, and the *direct connections* must connect to different parts of the earth grid. This must be assessed on a case by case basis.

No closed earth loops shall be created from earthing of the fencing.

Where it is not possible to meet the no closed earth loop requirement or magnetic contour clearance requirement then a suitable alternative non-conductive fencing material shall be used.

17.9.4 Safety Screens

As a minimum, a *direct connection* from every second fence post to the earth grid must be made.

17.9.5 Marshalling Boxes and Power Distribution Boards

A *direct connection* from the support structure to the earth grid must be made.

One *looping connection* from the structure to the equipment must be made (equipotential bonding).

17.9.6 Lightning and Lighting Masts

A *direct connection* from the base of the mast to the earth grid must be made.

17.9.7 Field Cubicles

A *direct connection* from the field cubicle framework to the earth grid must be made.

In each field cubicle there shall be two earth bars. One shall be installed on the swing frame door, and the other installed at the base of the cubicle. The earth bar installed at the base of cubicle must be used for the *direct connection* to the earth grid. A *looping connection* between the two earth bars must be $6mm^2$ multi-strand building wire with maximum stranding sizing of 0.2mm.

The earth bars shall be attached directly to the cubicle framework.

17.9.8 Valve Pit Pipework

A *direct connection* from the metallic pipework to the earth grid must be made. A *looping connection* from one side of the valve to the other is required so that both metallic pipes are connected. The earthing connection to the metallic pipework is done using pipe clamps.

17.9.9 Other External Metallic Structures

A *direct connection* from the earth grid must be made to each of the following:

- Metal bollards,
- Restricted vehicle access posts,
- Mini-cubes,
- 32A and 100A outlet posts,
- Bund valve switch posts,
- Signposts, and any other metallic posts

17.9.10 Communication Towers[62]

Refer to the relevant Technical Specification.

17.10 Buildings

17.10.1 General

All earthing conductor inside buildings must be ASC PVC (Bk) or ASC PVC (Gn/Ye) conductor.

The *direct connections* to the internal earth ring in the relay room or the switchroom ground floor level, shall be brought in via the cable trenches (cleated to the walls above the secondary cables) or cable ladders.

The *direct connections* to the internal earth ring in the switchroom basement shall be brought in through a 30mm diameter hole drilled into the cable basement wall and be sealed with a ROXTEC RS50AISI316 product.

17.10.2 Earth Ring

All buildings must have an external earth grid ring of BASC conductor located 1m away from the building.

All buildings must have an internal earth ring of ASC PVC (Bk) conductor. The internal earth ring shall have two *direct connections* to the earth grid, on diagonally opposite corners of the internal earth ring.

The internal earth ring must be either mounted on top of the cable ladder, located underneath computer flooring, cleated to the wall, or cleated to the support steelwork.

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17.10.3 Reinforcement Steel Bars

The reinforcement steel bars shall be welded to form a concrete floor earth grid with maximum spacing of 2m. The welding shall be a 2 x 10mm long, 3mm fillet weld (GP).

CADWeld B164-2Q ground plate is to be installed flush with the top of the concrete slab. The ground plate must be welded to the reinforcement steel bars which form the concrete floor earth grid. A ground plate shall be installed at one location for each concrete floor slab. Only one location is required to prevent circulating currents in the floor slab reinforcement steel bars. The ground plate shall have a *common connection* to the building earth ring.

17.10.4 Metallic Cable Ladder

A *common connection* from the internal earth ring must be made at a minimum of every 10m for all metallic cable ladders.

At every metallic cable ladder joint or junction, the metallic cable ladder must have a *looping connection* on one side of the metallic cable ladder.

17.10.5 Stairs and Handrails

A *common connection* from the internal earth ring must be made to any internal steel stairs or handrails.

Where there is a bolted joint connection between the handrail and the steel stairs then only one *common connection* is required for both the handrail and the steel stairs.

Once a *common connection* is established between one of the steel stair steps and the internal earth grid, then each step must have a *looping connection* on both sides of the step.

17.10.6 Roof

For tilt-up concrete buildings or other buildings constructed of non-conductive material, a *direct connection* from the roof to the earth grid must be made. A *direct connection* must be made at a minimum of two locations at opposite corners of the building. The connection to the roof beam can be done using one of the bolted connections in the roof beam. Any paintwork must be removed between the earthing lug and the roof beam. A maximum size of 95mm^2 conductor shall be used for the roof connection due to limitations in the tilt-up concrete panel wall thickness and conduit size allowable to be installed in the concrete panel wall.

For transportable buildings where the entire building is constructed of a conductive steel frame, no direct earthing connections to the roof beams are required.

17.10.7 Other

A *common connection* from the internal earth ring must be made to all building steel supports or framework. Any paintwork must be removed between the earthing lug and the steelwork.

17.11 Building – Equipment

17.11.1 Protection Equipment and Automation (IEC61850) Cubicles

A *common connection* from the protection or automation cubicle earth bar in the base of the cubicle to the internal earth ring must be made.

In each protection or automation cubicle there shall be two earth bars. One shall be installed on the swing frame door, and the other is to be installed at the base of the cubicle. The earth bar installed at the base of cubicle must be used for the *common connection*. A *looping connection* between the two earth bars must be 6mm^2 multi-strand building wire with maximum stranding sizing of 0.2mm.

The earth bar shall be attached directly to the cubicle framework.

The earth conductor to the local earth bar shall be ASC PVC (Gn/Ye), of minimum size 2.5mm^2. These earthing connections include cable screens, metal relay cases, metal test links, cubicle frames, swing frames etc. These connections shall utilise suitable copper crimps.

17.11.2 Protection Equipment – Dexion Racks

An earth conductor in the form of HDFCB shall extend along the entire length of the racks. Where this arrangement exists it shall be retained. The HDFCB is to be sized according to Table 8 (see Appendix B).

The earth conductor to the local earth bar shall be ASC PVC (Gn/Ye), of minimum size 2.5mm^2. These earthing connections include cable screens, metal relay cases, metal test links etc. The bar shall be tinned at such connection points and the connection made with 5 mm screws tapped into the bar.

17.11.3 SCADA and Communications Equipment

A *common connection* shall be made from the internal earth ring to each SCADA and communication cubicle earth bar. (See Table B.5 – Appendix B)

17.11.4 Telephone Line[63]

All copper telephone lines brought into the substation shall be isolated using a telecommunication isolation device.

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[63] See Western Power Internal Document

A 1.5m radius from the telecommunication isolation device to the nearest earth reference must be maintained.

A rubber mat must be installed directly underneath the isolation device.

17.11.5 AC Supplies

A *common connection* shall be made from the building internal earth ring to all AC changeover board and AC distribution boards. (See Table B.1 – Appendix B)

17.11.6 DC Supplies

A common connection shall be made from the building internal earth ring to each DC charger, each battery stand and each paralleling board. (See Table B.1 – Appendix B)

Where battery stands are located in a battery room the common connection to the building internal earth ring must be made separately for battery 1 and battery 2. Where there are two stands per battery a looping connection between the two stands must be of equivalent size to the conductor used for the common connection.

17.11.7 Cable Supports and Cleats

A common connection shall be made from the building internal earth ring to each cable support structure. (See Table B.1 – Appendix B) Where practical, the earth connection to the internal earth ring can be a looping connection between each of the cable support structures provided a single bolt termination for each connection is used. (no back-to-back connections)

Where the reinforcement in the cable basement slab has been earthed then individual cable cleats don't need to be earthed. Where cables are supported on steel cable ladder however, the ladder shall be earthed.

17.12 Electrical Services

17.12.1 Air Conditioning

The air conditioning components obtain their earth connection via the 2c+E or 4c+E supply cable. This includes the air conditioner blowers, air conditioner compressors and air conditioner control box.

The earth conductor must be the same size as the phase conductor.

17.12.2 Outdoor GPOs

All outdoor GPOs obtain their earth connection via the structure that they are mounted on.

Where they are not mounted on a steel structure then a 2c+E or 4c+E cable shall be installed.

The earth conductor must be the same size as the phase conductor.

17.13 Secondary Cables

Refer to Section 9.4 - Cable Earthing of the Engineering Design Instruction - Substation Secondary Systems Design for information on secondary cable earthing.

17.14 Connection of Adjacent Installations

Where a substation is located adjacent to a generating station or to another substation, the earthing systems of these installations shall be tied together. The connection between the earthing networks shall be made with at least three connections using an ASC PVC (BK) conductor of the same dimension as the larger earth grid conductor of the two installations. These connections will typically be made in earth pits and must be clearly labelled as earth grid disconnection points.

The connection between the earth grids of each site must be installed so they can be disconnected and tested during routine maintenance. Where adjacent earth grids are reliant on each other to achieve a compliant earthing design, integrity testing of the connection points shall be undertaken during routine maintenance.

Where different voltage levels are enclosed within the same fence (for example a 132kV/22kV outdoor zone substation), they shall be considered as one installation.

17.15 Connection of Customer Substations

Requirements for interconnection with Customer substation earthing grids should be covered in the Customer Connection Requirements document created for the connection. Refer to Customer Connection Requirements EDI.

In extraordinary circumstances where a Customer cannot implement a compliant stand-alone earth grid, they may be permitted to also consider the effect of connection to the Western Power substation earth grid, either by direct connection to an adjacent substation or via overhead earth wire or underground earth cable. A Formal Safety Assessment is required, and the appropriate documentation completed to ensure the importance of this connection is known.

18. Earthing Joints and Crimps

18.1 Earthing Joints[64]

For all outdoor earthing joint connections, the following shall be used:

- Hytap C-Crimp (Burndy).
- Groundlok (DMC Power).
- CADWELD (ERICO).

For all works which are installed by Kewdale Construction, Hytap C-Crimp (Burndy) joints shall be used.

For all works which are installed by external contractors Groundlok (DMC Power) joints shall be used.

For all copper earth bar to BASC or ASC conductor CADWELD joints shall be used.

No bolted connection shall be direct buried in the ground or concrete.

For above ground earthing joints inside buildings Hytap C-Crimps (BURNDY) or Groundlok (DMC Power) shall be used.

Refer to Table B.2, Table B.3 and Table B.4 (see Appendix B) for the different earthing joint part numbers.

18.2 Earthing Lugs

A standard single hole M16 tinned copper cable lug using stainless steel bolts, nuts and washers shall be used for all above ground, outdoor terminations. Where the primary plant only comes with M12 connections then a standard single hole M12 tinned copper cable lug shall be used.

A standard single hole M12 tinned copper cable lug using stainless steel bolts, nuts and washers shall be used for indoor terminations.

Each lug shall terminate individually to the structure or earth point. Each individual earth riser requires its own bolted connection to the structure. Two earth risers cannot be connected to the structure using the same bolted connection.

For all earthing crimp lug connections the following shall be used, in order of preference:

- Carroll Crimp Lugs
- Groundlok (DMC Power).

Refer to Table B.3. Standard Earthing Lug Suppliers and Sizes

(see Appendix B) for earth lug part numbers.

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Refer to Appendix F for further information.

19. Portable and Fixed Earthing

19.1 Portable Earth Stubs

The earthing stub locations have been chosen with the following assumptions:

- Disconnector structures can have separate crews working either side of a disconnector therefore sufficient stubs need to be provided for two sets of portable earths.
- A disconnector with earth switch requires a portable earth stirrup connection on the earth side during maintenance of the earth switch.
- For outdoor capacitor/reactor banks, stub(s) shall be provided at the gate of the compound. This allows attachment of the earth end of the portable earth set before an operator enters the compound to apply the reactor earths.
- Surge arrestors and line VT portable earth facilities are generally required during annual testing.
- Where multiple earth stubs are required on a π structure, they can be located either one per leg or two on one leg.

19.2 Existing D-Bracket Portable Earth Stubs[65]

Where the older D-bracket portable earth connection points are found then they need to be upgraded with new portable earth stubs.

D-brackets may require reinforcing to accept a portable earth stub.

19.3 Earth Stirrups

The earthing stirrup locations have been chosen with the following considerations in mind:

- Earth stirrups should be attached to flexible stranded conductor at every portable earthing attachment point. Stirrups are to be installed even if the conductors are horizontal. This prevents potential damage to the stranded conductor from repeated application of portable earth clamp jaws.
- Where earth stirrups need to be retrofitted then conductor stirrups are preferred over palm stirrups.
- Check that new stirrups will not compromise electrical clearances.
- Where tubular bus is connected to a disconnector, the fixed end which has the earth stirrup may be installed at either end support. It is not essential the earth stirrup is immediately adjacent to the disconnector. This permits flexibility in orienting busbar

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tubes if it is desirable for the disconnector to connect to the expansion end of the busbar tube due to lower imposed forces.

- Stirrups / conductor connection points should be able to accept two portable earth lead clamps.
- Stirrups should not be installed adjacent to oil or gas filled equipment such as current transformers and power transformer bushings as the additional stresses (especially if a fault occurs) could damage the seals. Exceptions to be approved on a case by case basis.

19.4 Application of Portable Earthing - 132kV and below[66]

Portable Earthing (PE) points (brass stubs & earthing stirrups) for Transmission Zone and Terminal Substations for 132kV and below shall be provided at the positions listed in Table 19.1 below.

Table 19.1. Earthing Stub & Earthing Stirrup locations and quantities for Zone and Terminal Substations 6.6kV – 132kV

Plant type	Earthing stub quantity for 40kA/0.5sec and 50kA/0.5 sec (132kV)	Earthing stub quantity for 25kA/0.5 sec (6.6 - 66kV)	Earthing Stirrup Location (1 stirrup per phase)
Disconnector (DIS)	4 (2 per leg of π structure)	2	On each side of Disconnector
Surge Arrestor (SA)	2	1	Surge Arrestor dropper conductor (close to SA termination)
Voltage Transformer (VT)	2	1	Voltage Transformer dropper conductor (close to VT termination)
Cable Termination / Sealing End	2	1	On conductor adjacent to sealing end.
Capacitor Bank Compound	2 (Outside Gate)	1	On Series Reactor terminal palms
Capacitor Out Of Balance (C.O.O.B) CT	2 (On fence post near OOB CT)	1 (On fence post near OOB CT)	No stirrup required.
Air-Core Shunt Reactor	2 (Inside compound near Reactor Neutral generally on fence post)	1 (Inside compound near Reactor Neutral	On reactor terminal palms.

66 See Western Power Internal Document

		generally on fence post)	
Gantry Structure	2 (Only when underslung disconnectors used)	1 (Only when underslung disconnectors used)	N/A
Combined CT/VT (CCV)	2	1	Located on conductor between the CT/VT and SA
Post Insulator structures in long span (≥ 9m) *	2	1	Busbar stirrups adjacent to post insulator

19.5 Terminal Yards (330kV & 220kV) [67]

Portable Earthing (PE) points (brass stubs & earthing stirrups) for Transmission Terminal yards shall be provided at the positions listed in Table 19.2 below.

Table 19.2. Earthing Stub & Earthing Stirrup locations and quantities for Terminal yards with individual structures for each phase

Plant type	Earthing stub quantity for 50kA/0.5sec (330kV)	Earthing stub quantity for 25kA/0.5 sec (220kV)	Earthing Stirrup Location (1 stirrup per phase)
Disconnector (DIS)	4 per phase (2 per leg)	2 per phase (1 per leg)	Each side of a busbar and line disconnector.
Surge Arrestor (SA)	2 per structure (phase)	1 per structure (phase)	Surge arrestor dropper conductor (close to SA termination)
Voltage Transformer (VT)	2 per structure (phase)	1 per structure (phase)	Voltage Transformer dropper conductor or line side of VT (Take into consideration access issues due to corona rings)
Cable Termination / Sealing End	2 per structure (phase)	1 per structure (phase)	On conductor adjacent to sealing end.
Independent Earth Switch (ES)	2 per structure (phase)	1 per structure (phase)	Suitable location near earth switch
Air-Core Shunt Reactor	2	1	On reactor terminal palms

[67] See Western Power Internal Document

	(Inside compound near Reactor Neutral generally on fence post)	(Inside compound near Reactor Neutral generally on fence post)	
Current Transformer (CT)**	2 per structure (phase)	1 per structure (phase)	Located on conductor adjacent to CT.
Post Insulator structures in long span (≥ 9m) *	2	1	Busbar stirrups adjacent to post insulator

** Where there are partially developed 1 ½ CB bays there is a requirement to install additional earthing stirrups for the CTs.

19.6 Portable Earth Leads

Each site shall have the following minimum quantity of portable earthing sets, each rated at 25kA / 0.5s. The quantities are applicable to substations where the fault current/duration is within the rating of a single set (25kA / 0.5 sec).

- For a typical zone substation with indoor MV switchboards, 10 sets @ 9m length.
- For a typical zone substation with outdoor MV busbars, 14 sets @ 9m length.
- For a terminal substation with a transformer, 16 sets;
  - 8 sets @ 11m length for 220-330kV and
  - 8 sets @ 9m length for 6.6-132kV
- For a switching terminal yard (without transformer), 6 sets @ 11m length.

Generally, one operating stick per site is sufficient.

19.6.1 Fault Rating greater than 25kA

If the zone or terminal substation has a fault level greater than 25kA then the quantities of portable earth leads needs to be doubled.

19.7 Portable Earth Lead Rating[68]

There are two portable earth lead ratings in the network:

- 130mm^2 AL with a rating of 21kA/0.5s.
- 150mm^2 AL with a rating of 25kA/0.5s.

[68] See Western Power Internal Document

These ratings are calculated based on a factor of 76% of the ultimate capacity to comply with recommendation of IEEE1246. The fault level for the 150mm^2 portable earth takes into consideration the IEEE recommendation but the 130mm^2 portable earth does not.

For all new applications, 150mm^2 portable earth leads shall be installed.

When the fault level exceeds 15kA then any 130mm^2 portable earth leads need to be replaced with 150mm^2 portable earth leads.

19.8 Portable Earth Lead Storage Facilities

Portable earths should be stored in a location which provides:

- Good access – Access is required from ground level; steps are to be avoided to eliminate risks associated with manual handling of heavy equipment up and down stairs. Preference is to use wheeled assistance for transporting portable earth leads through the switchyard such as a fibreglass wheelbarrow.
- Convenient location – close to where they are used.
- Adequate storage space

A label shall be attached to each portable earth storage facility which specifies that size of the leads, and the procedure for if the portable earth leads are temporarily relocated from site.

20. Third Party Assets

20.1 Telecommunications

AS3835.1 provides the Australian EPR hazard voltage limits for telecommunications personnel and equipment during an earth fault scenario.

The Category is determined from the primary fault clearance times.

20.2 Metallic Pipelines

AS4853 provides the design approach for compliance to touch voltage limits for both above ground and underground pipelines.

20.3 Metallic Pipelines – Water Corporation

Earthing design processes and procedures are set out by the Water Corporation as per the 'Earth Potential Rise – Water Pipeline AC Interference Process and Technical Requirements for Land Development Projects' and 'Water Corporation's Design Standard DS23 "Pipeline AC Interference and Substation Earthing"

The Water Corporation documents need to be requested from the Water Corporation.

The Water Corporation 'Earth Potential Rise – Water Pipeline AC Interference Process and Technical Requirements for Land Development Projects' specify that a deterministic method for calculation of touch voltage limits is to be used in accordance with AS60479.1:2010.

To avoid transfer potential hazards associated with water pipelines entering the substation for water supply purposes, a 2m min length of PVC water pipe shall be used where any copper pipe water supply crosses the substation fence.

20.4 Swimming Pools in Vicinity of Substations[69]

If there are swimming pools constructed in the vicinity of the substation, an assessment must be made by the Earthing Designer to calculate the deterministic voltage limit and model the surface potential to ensure adequate protection for households within the area.

20.5 Third Party Mitigation Methods

20.5.1 Protection Upgrades[70]

20.5.2 Earthing System Re-design[71]

20.6 Requestor Responsibility

The requestor of the earthing design is responsible for liaising with the third-party asset owner on the implications of the earthing design, and the impact on their asset.

The requestor also needs to notify the third party when a commissioning test is required.

21. AC Auxiliary Supply Earthing

Refer to Section 17.12 for details for air conditioning and outdoor GPOs.

All building services such as lighting and GPOs shall be installed using cables with an earth core which is sized to match the phase conductor.

Refer to Section 17.7.5 for details for earthing of station transformers.

69 See Western Power Internal Document
70 See Western Power Internal Document
71 See Western Power Internal Document

21.1 415V Street Supplies[72]

Installation of new 415V street supplies should be avoided where possible. When a street supply transformer which provides a 415V supply to a transmission substation needs to be upgraded or replaced then consideration should be given at the time to replace the 415V supply with a dedicated station transformer located in the transmission substation. This needs to be assessed on a site by site basis and consideration be made to other 415V supplies which may also be fed from the same street supply.

22. Construction Staging and Safety

22.1 Inductive Interference

The purpose of this Earthing EDI is to protect personnel from potential 'conductive' interference. 'Inductive' interference refers to situations where a fault current flowing in power cables or lines may cause inductive interference in nearby cables or metallic structures. This has potential risk to personnel if appropriate staging during construction is not considered.

22.2 Staging

Where there are multiple construction stages with different energisation timeframes then each stage needs to be considered in the assessment of the earthing design. Staging needs to be considered on a case by case basis and the earthing requirements for a project staging needs to be identified for each stage as part of the earthing design and reflected in the HMR.

The earth tails connections to the Earth grid above ground shall be installed prior to the installation of metallic structures. This is to ensure any metallic structures have earth provisions and are earthed avoiding risk of induction during the different stages of construction.

Similarly, there is a risk of induction for fencing installed underneath a live overhead line during construction. In this situation, the earth ring surrounding the substation boundary shall be installed with earth tails provision above ground. The earth tails are to be installed on the fence posts prior to the installation of fence panels. Every second post will require a direct earth connection to the grid/ring.

22.3 Fencing

There may be cases where the site is only partially developed or where all equipment is located some distance from the perimeter fence. This results in large open spaces between the fence and the earth grid. This can also mean that a temporary construction fence is sometimes installed between the work area and the live substation.

[72] See Western Power Internal Document

There are three options that need to be assessed:

- The perimeter fence and/or temporary construction fence are to be isolated from the earth grid, or
- They are connected to the earth grid, or
- The fence is to be constructed of non-conductive material.

When isolated from the earth grid the fence will still be earthed. However, the isolated fence will have a single grading wire buried beneath the fence and earth electrodes installed such that the fence earth grid is not interconnected in any way to the main substation earth grid.

22.4 Temporary Buildings

The location of temporary buildings used in construction activities need to be considered in the earthing design. It is preferred that the temporary building is located inside the substation. When located inside the substation then it must be connected to the earth grid.

When the temporary building is located outside the substation it must be a minimum of 5m from the boundary and must not be connected to the substation earth grid.

The temporary building is to be located with a minimum distance of 2m from any conductive materials.

All temporary building pipework is to be non-conductive.

22.5 Construction 415V Supply

The construction 415V supply for the temporary building can be from the substation 415V distribution board provided there is adequate spare capacity, and the temporary building is located inside the substation earth grid where the 415V is supplied. A 4c+E cable shall be used to connect the temporary building.

Where there is not enough capacity within the substation then the temporary buildings are to be supplied from a standalone generator located within 3m of the temporary buildings or an isolation transformer located separate from the existing earth grid.

Distribution street supplies must be assessed on a case-by-case basis.

22.6 Earth Grading Ring

Substations located in high security risk areas often have issues with theft of the outer earth grading ring (standard copper conductor). In these areas, copper-clad steel can be used as an alternative grading ring conductor to deter theft and damage.

Property and Fleet (facilities management) shall be consulted and a risk assessment undertaken to determine whether copper-clad steel is required for a specific design.

23. Construction Inspection and Testing[73]

Refer to Earthing Design Transmission Substation – Construction Inspection and Testing Requirements.

24. Commissioning and Testing

24.1 Electrode and Earth Grid Injection Testing[74]

The Substation Design Engineer is to provide details in the earthing design report of any injection testing that is required.

Any testing to be done onsite during construction must be captured in the SODW or PEA.

After the earthing grid has been commissioned, the designer must validate the field test results to the design values. Where the earth grid design require modification due to test results obtained during construction or commissioning, the Earthing Report shall be updated to capture these changes.

[73] See Western Power Internal Document
[74] See Western Power Internal Document

Appendix A: Earthing Drawing List[75]

[75] See Western Power Internal Document

Appendix B: Earthing Conductor, Busbar, Crimps and Lugs Tables

Table B.1. Typical HDFCB Earth Bar sizes found in Brownfield Sites.

HDFCB Earth Bar Size [mm2]	Fault Rating [kA] (0.5 sec)	Fault Rating [kA] (1 sec)
12.5 x 2.5	10	7
25 x 2.5	20	14
40 x 2.5	32	22
25 x 5	40	28
50 x 3	48	34
38 x 5	60	43
50 x 4	63	45
63 x 4	80	56
80 x 4	101	72

Table B.2. Standard HDFCB Earth Bar sizes based on standard fault rating levels.

CONDUCTOR SIZE		
25kA/0.5 sec	40kA/0.5 sec 25kA/1 sec	50kA/0.5 sec
40 x 2.5mm²	25 x 5mm²	38 x 5mm²

Table B.3. Standard Earthing Lug Suppliers and Sizes

Cable size [mm²]	Lug Bolt Size	Carroll Crimp Lugs	Groundlok Part Number
16	M12	S16-12	GC910B04GT
35	M12	S25-12	GC910B02GT
50	M12	S50-12	GC910B002T
70	M12	S70-12	GC910B002T
70	M16	S70-16	GC910B002T-M16
95	M12	S95-12	GC910B003T
95	M16	S95-16	GC910B003T-M16
120	M12	S120-12	GC910B025T
120	M16	S120-16	GC910B025T-M16
150	M12	S150-12	GC910B030T
150	M16	S150-16	GC910B030T-M16

Table B.4. Selection of copper earthing conductors for outdoor applications

CONDUCTOR FUNCTION	CONDUCTOR MATERIAL	CONDUCTOR SIZE		
		25kA/0.5 sec	40kA/0.5 sec or 25kA/1 sec	50kA/0.5 sec
(a) Metallic primary plant structure connection per structure leg (downlead)	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(b) Grid conductors	BASC	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(c) Transformer grading ring (located inside the bund)	BASC	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(d) Transformer neutral connections	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(e) Transformer grading ring to earth grid connection (opposite corners)	ASC PVC(Bk)	2 off 2 x 70mm^2	2 off 2 x 120mm^2	2 off 2 x 150mm^2
(f) Transformer tank connections (opposite corners)	ASC PVC(Bk)	2 off 2 x 70mm^2	2 off 2 x 120mm^2	2 off 2 x 150mm^2
(g) Transformer radiator frame & cable sheath earth bar connections	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(h) CT, CB, DIS and DES	ASC PVC(Bk)	1 x 70mm^2 (looping)	1 x 120mm^2 (looping)	1 x 150mm^2 (looping)
(i) Surge arrestor or VT connections (per SA or VT)	ASC PVC(Bk)	1 x 70mm^2 (direct) + 1 x 70mm^2 (looping)	1 x 120mm^2 (direct) + 1 x 120mm^2 (looping)	1 x 150mm^2 (direct) + 1 x 150mm^2 (looping)
(j) Capacitor and C.O.O.B CTs connections	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(k) (1) Air cored Reactor connections (no closed loops) (2) Air cored reactor support insulators (no closed loops) (3) Reactor earth bar (if required)	ASC PVC(Bk) ASC PVC(Bk) HDFCB	2 off 1 x 95mm^2 1 x 70mm^2 40 x 2.5mm^2	2 off 1 x 120mm^2 1 x 120mm^2 25 x 5mm^2	2 off 1 x 150mm^2 1 x 150mm^2 38 x 5mm^2
(l) Disconnector down rod connection to steel structure	ASC PVC(Bk) (flexible)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(m) Earth switch blade connections	ASC PVC(Bk)	2 x 70mm^2 (looping)	2 x 120mm^2 (looping)	2 x 150mm^2 (looping)
(n) Disconnector and earth switch operating handle connection to operator earth mat (equipotential bonding) Where the manufacturer doesn't supply a braid with a minimum 6kA rating then flexible conductor shall be used.	ASC PVC(Bk)	1 x 70mm^2 (Or 6kA braid to handle)	1 x 70mm^2 (Or 6kA braid to handle)	1 x 70mm^2 (Or 6kA braid to handle)
(o) Metallic marshalling box, cubicles, field cubicles (etc) connections	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(p) Handrail, steel stairs, grating and steel platforms connections (connected to building outside and any other outdoor application)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(q) Lightning mast connections	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(r) Low level lighting mast connections (if shielded from direct lightning strikes by taller masts and/or earthwires – otherwise (q) applies)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(s) Connection of earth electrodes to grid	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(t) Overhead earthwire connections (connected to pole/tower down conductor)	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(u) Fence grading conductors	BASC	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(v) Fence and gate post connections (including safety screens, capacitor bank fencing)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(w) Bollards, sign posts, mini-cube , 32A and 100A outlet posts, bund valve switch posts, and restricted access vehicle barriers connections	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(x) Bund valve pit pipework connections (one side of the valve + jumper to the other side of the valve)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2

ASC PVC(Bk) = Annealed stranded copper conductor – PVC black, **BASC =** Bare annealed stranded copper conductor, **HDFCB =** Hard drawn flat copper bar

Table B.5. Selection of copper earthing conductors for indoor applications

CONDUCTOR FUNCTION	CONDUCTOR MATERIAL	CONDUCTOR SIZE		
		25kA/0.5 sec	40kA/0.5 sec or 25kA/1 sec	50kA/0.5 sec
General				
(a) Connection of each of the building earth ring/s to common earth grid	ASC PVC(Bk)	2 x 70mm^2	2 x 120mm^2	2 x 150mm^2
(b) Building external earth ring	BASC	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(c) Building internal earth ring	ASC PVC (Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(d) Handrail, steel stairs and steel platforms – main earth connection	ASC PVC (Gn/Ye)	1 x 35mm^2	1 x 70mm^2	1 x 95mm^2
(e) Steel stair steps – loop between steps on both sides	ASC PVC (Gn/Ye)	1 x 16mm^2	1 x 16mm^2	1 x 16mm^2
(f) Cable ladder – main earth connection at minimum of every 10 meters.	ASC PVC (Gn/Ye)	1 x 35mm^2	1 x 70mm^2	1 x 95mm^2
(g) Cable ladder – loop between cable ladder connection on both sides	ASC PVC (Gn/Ye)	1 x 16mm^2	1 x 16mm^2	1 x 16mm^2
(h) (1) Common connection for indoor protection, control and mimic cubicles (2) Common connection for DC systems (3) Common connection for SCADA and automation cubicles (4) Common connection for Communication cubicles (5) Alternatively for dexion racks	ASC PVC (Gn/Ye) HDFCB	1 x 35mm^2 25 x 5mm^2	1 x 70mm^2 25 x 5mm^2	1 x 95mm^2 25 x 5mm^2
(i) Common earth conductor for AC changeover boards and distribution boards	ASC PVC (Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(j) Building roof beam connections (Minimum two locations per roof at opposite corners)	ASC PVC(Bk)	1 x 70mm^2	1 x 95mm^2	1 x 95mm^2
(k) Building metallic supports and framework connections	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(l) Building ground plate connections	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
Switchroom				
(l) Switchroom basement earth ring to the Indoor switchgear (both ends of switchgear earth bar, and all transformer incoming circuit/s earth bar)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(m) Indoor switchgear incomer circuit/s earth bar to Transformer cable sheath earth bar (located at the transformer cable box)	ASC PVC(Bk)	2 x 70mm^2 *	2 x 120mm^2 *	2 x 150mm^2 *
(p) Switchroom basement earth ring to Primary cable clamp unistrut supports (not required if floor re-bar is earthed)	ASC PVC(Bk)	1 x 70mm^2	1 x 120mm^2	1 x 150mm^2
(q) High voltage cable screen earthing (single phase cable sheath to indoor switchgear main earth bar)	ASC PVC(Bk)	1 x 95mm^2	1 x 95mm^2	1 x 95mm^2

ASC PVC = Annealed stranded copper conductor, **BASC =** Bare annealed stranded copper conductor, **HDFCB =** Hard drawn flat copper bar

* Note: The fault level and fault clearance time needs to be verified for the size of the earth conductor from the switchboard earth bar to the transformer cable sheath earth bar.

Table B.6. Standard Outdoor Earthing Joints

Connection Description	Conductor Types	Conductor Sizes	Hytap C-Crimps (Burndy) Part Number	Groundlok (DMC Power) Part Number	CADWELD (Erico) Mould Part Number	CADWELD (Erico) Welding Material
Cable end to Cable end (Parallel splice)	Grid copper cable to grid copper cable connections. Used between underground grid connections.	$70mm^2$ x $70mm^2$ $120mm^2$ x $120mm^2$ $150mm^2$ x $150mm^2$	2 off YGHC26C26 2 off YGHC29C29 4 off YGHC34C34	GC720B002-002 GC720B025-025 GC720B030-030	PTCY4Y4 PTCY6Y6 PTDY7Y7	115 250 300
Structure Cable end to Grid cable end (Parallel splice)	Grid copper cable to flexible copper cable connections. Used to connect underground grid conductors to Structures.	$70mm^2$ x $70mm^2$ $120mm^2$ x $120mm^2$ $150mm^2$ x $150mm^2$	2 off YGHC26C26 2 off YGHC29C29 4 off YGHC34C34	GC759B002-002 GC759B025-025 GC759B030-030	PTCY4Y4 PTCY6Y6 PTDY7Y7	115 250 2x150
Crossing Cable (Lapped Cables)	Underground copper grid cables crossing.	$70mm^2$ x $70mm^2$ $120mm^2$ x $120mm^2$ $150mm^2$ x $150mm^2$	2 off YGHC26C26 2 off YGHC29C29 4 off YGHC34C34	GC759B002-002 GC759B025-025 GC759B030-030	XBQY4Y4 XBQY6Y6 XBZY7Y7	200 300 400
Cable to Earth Rod	Underground grid copper cable to 15mm earth rod	$70mm^2$ x 15mm rod $120mm^2$ x 15mm rod $150mm^2$ x 15mm rod	2 off YGHP34C26 2 off YGHP34C29 4 off YGHP34C34	GC749B002-562 GC749B025-562 GC749B030-562	GRCP143Y4 GRCP143Y6 GRCP143Y7	90 90 115

Table B.7. Standard HDFCB Earthing Joints

Connection Description	Conductor Types	Conductor Sizes	CADWELD Mould Part Number	CADWELD Welding Material
Cable to Flat copper Bar	Underground grid copper cable to flat earth bar **(3mm thick HDFCB)**	$70mm^2$ $95mm^2$ $120mm^2$ $150mm^2$	LJCCAJY4 LJCCAJY5 LJCCAJY6 LJCCAJY7	90 90 90 115
Cable to Flat copper Bar	Underground grid copper cable to flat earth bar **(4mm thick HDFCB)**	$70mm^2$ $95mm^2$ $120mm^2$ $150mm^2$	LJCEALY4 LJCEALY5 LJCEALY6 LJCEALY7	90 90 90 115
Cable to Flat copper Bar	Underground grid copper cable to flat earth bar **(5mm thick HDFCB)**	$70mm^2$ $95mm^2$ $120mm^2$ $150mm^2$	LJCFALY4 LJCFALY5 LJCFALY6 LJCFALY7	90 90 115 115

Table B.8. Standard Indoor Earthing Joints

Connection Description	Conductor Types	Conductor Sizes	Hytap C Crimp (Burndy) Part Number	Groundlok (DMC Power) Part Number
Cable end to Cable end (Parallel splice)	Grid copper cable to grid copper cable connections. Used between underground grid connections.	$70mm^2$ x $70mm^2$ $120mm^2$ x $120mm^2$ $150mm^2$ x $150mm^2$	2 off YGHC26C26 2 off YGHC29C29 4 off YGHC34C34	GC888B002-002 GC888B025-025 GC759B030-030
Cable end to Grid cable end (Parallel splice)	Grid copper cable to flexible copper cable connections. Used to connect equipment in the buildings.	$70mm^2$ x $35mm^2$ $70mm^2$ x $70mm^2$ $120mm^2$ x $70mm^2$ $120mm^2$ x $120mm^2$ $150mm^2$ x $95mm^2$ $150mm^2$ x $150mm^2$	2 off YGHC26C2 2 off YGHC26C26 2 off YGHC29C26 2 off YGHC29C29 3 off YGHC34C29 4 off YGHC34C34	GC759B002-02G GC888B002-002 GC759B025-002 GC888B025-025 GC759B030-003 GC759B030-030

Appendix C: Conductor Sizing[76]

[76] See Western Power Internal Document

Appendix D: MV Cable Sheath Sizing

The cable sheath should be long enough to terminate directly to the indoor switchgear. Where the cable sheath is too short then a short section of ASC conductor can be used to terminate between the cable sheath and the indoor switchgear main earth bar.

400mm^2 cable (Stock Code EE2168) has a screen earth fault rating of 10kA/1 second.

500mm^2 cable (Stock Code EE1291) has a screen earth fault rating of 15.6kA/1 second.

630mm^2 cable (Stock Code EE1280) has a screen earth fault rating of 13.2kA/1 second.

It is assumed that the ASC conductor has a T_m of 155 °C. This corresponds to a size of 70mm^2 for cables below 400mm^2 and 95mm^2 for cables above 400mm^2. For simplicity, 95mm^2 has been chosen for all cables.

Appendix E: Ground Enhancing Compounds[77]

[77] See Western Power Internal Document

Appendix F: Lug Selection[78]

[78] See Western Power Internal Document

Appendix G: Approval Record and Document Control[79]

[79] See Western Power Internal Document