SAPTA

Government of South Australia
Department for Infrastructure and Transport

Traction DC Substation Design and Construction – Tram System Standard

Asset Management/Rail Commissioner>

TP2-DOC-003520

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1. Introduction

The South Australian Public Transport Authority (SAPTA) is a Directorate within the Department for Infrastructure and Transport (DIT) responsible for the delivery of public transport services.

SAPTA on behalf of the department manages the Adelaide Metropolitan Public Transport Network (AMPRN). As part of the execution of responsibilities of this role, it must have a governance structure which includes the adoption of standards, policies, and procedures.

The Adelaide Tram Network (ATN) is part of the AMPRN and comprises the Glenelg, Hindmarsh, East Link and Festival Plaza tram lines. The ATN includes a diverse range of public transport assets including track, signals, communications, tram stops, traction systems, overhead wire, electrical engineering and rolling stock.

2. Purpose

This standard forms part of the engineering management system is intended to ensure that the traction power system serving the Adelaide Metropolitan tram network is not subject to any risks not deemed to meet the ‘So Far as Is Reasonably Practicable’ (SFAIRP) principles under Rail Safety National Law (RSNL).

This standard stipulates the minimum performance and functional requirements for the traction power substations for the ATN network.

3. Scope

The requirements of this standard apply to all existing and new DC traction substations’ construction and installation, including all cabling and equipment from the main incoming power supply through to distribution at the pantograph interface, which includes, but not limited to:

- All equipment located within the property limit of the DC traction substation.
- The 600V DC positive system which includes the positive feeder cables, conduits, and pits from the DC traction substation up to and including the cable termination at the interface with either the overhead wiring system (e.g., an overhead switch or feeder tap to trolley) or an existing cable termination (e.g., a pillar box or existing cable pit); and
- The DC negative return system which includes the negative feeder cables and buses, conduits, and pits from the substation up to and including the rail bonds.

The scope of this document does not include:

- The DC negative return system which includes the negative feeder cables and buses, conduits, and pits from the substation up to and including the rail bonds.
- Remote negative cables (aerial or underground).

The requirements in this standard have been derived from the following sources:

- International and Australian Standards listed in section 37 *Related legislation and documents*.
- Yarra Trams Traction Substation Design and Construction.
- Local subject matter experts within SAPTA (DIT).

Interpretation of any technical meanings of the specifications and addressing of technical disputes regarding this specification must be decided by the SAPTA system engineering team, whose decision must be final and binding.

The tenderers/project proponents must familiarise themselves with site conditions before quoting against tenders based on this specification. Conditions particular to individual sites, including availability of HV supply, communication cables with spare capacity, access for maintenance work, and any special conditions concerning installation and commissioning of SCADA system must be clarified in a pre-bid meeting to be arranged by the purchaser with the tenderers.

4. Related Documents

The design and construction of DC traction substations must be consistent with the best engineering practices and must comply with all the referenced documents listed below.

These referenced documents must be read in conjunction with this standard.

Unless stated otherwise, all referenced documents must refer to the most recent published versions of them at the time of invitation to tender.

Where no equipment specification exists, the general principles outlined in this document must be applied along with the requirements of the relevant Australian Standards, International Standards, Industry codes of practice, guidelines, policies, and rules as well as government regulations and other legislative documents.

Wherever a conflict exists in the requirements of these documents, clarification on the hierarchy of such requirements must be sought from DIT/SAPTA.

DOCUMENT NAME	DOCUMENT NUMBER
Traction Power Network tram system	TP2-DOC-003521
Tram SCADA standard	CE2-DOC-003522
Communications Network Principles and Practices for Public Transport - Engineering Standard	AR-TP-EL-SPE-00110011
Guideline for Low Voltage Electrical Earthing and Bonding for the Adelaide Metro Tram Network	TP2-DOC-002020
Guidelines for Protective Provisions Related to Electrical Earthing & Bonding for Adelaide Metro Electrified Rail Network	AR-EL-STD-0102
Torrens Connect MOC	[SQE-FRM-NIL-0006]
Pit and Conduit Standard for Signalling and Communication Cables	PTS-MS-10-SG-STD-00000094
Standard Drawing - Tram Network - Electrical System Overview - Single line diagram	TP2-DRG-006980
Development and Approval of Engineering Waivers	PR-AM-GE-807

5. References

- *SAPN Service & Installation Rules*
- *Electrical installations (known as the Australian/New Zealand Wiring Rules) - AS 3000*
- *Electrical Installations – Selection of Cables - AS 3008*
- *Electromagnetic compatibility (EMC) - AS/NZS 61000 series*
- *High-voltage switchgear and control gear – Common specifications - AS 62271.1*
- *ICNIRP Guidelines: Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)*
- *ICNIRP Guidelines: Guidelines for limiting exposure to electric fields induced by movement of the human body in a static magnetic field and by time-varying magnetic fields below 1 Hz*
- *Railway applications – Electromagnetic compatibility – Part 1: General - EN 50121-1*
- *Railway applications – Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world EN 50121-2*
- *Railway applications – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus EN 50121-5*
- *Railway applications – Fixed installations – DC switchgear EN 50123 series*

- *Railway applications – Insulation co-ordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment EN 50124-1*
- *Railway applications – Insulation coordination – Part 2: Over voltages and related protection - EN 50124-2*
- *Railway applications – Supply voltages of traction systems - EN 50163*

6. Compliance

Notwithstanding the specific requirements in this standard, the Designer must fully comply with:

- All applicable national and international standards listed in related documents.
- Rail Commissioner Management of Change Procedure PR-RCMC-009 for the types of changes specified in it.
- Advice must be sought from the Principal's or Rail Electrical Engineering representative for any clarification or conflict regarding the standards listed in the above clauses.

Any party who is involved in the specification, design, construction, installation, test, or commissioning of DC traction substations must fully comply with this standard and the Master Specification RW series.

Deviation from this standard constitutes a requirement for a waiver; waiver process PR-AM-GE-807 must be followed.

'Must' statements are mandatory in the context of compliance with requirements stipulated in this standard.

'Should' statements are considerations in the context of compliance with requirements stipulated in this standard.

'So far as is reasonably practicable' statements must at a minimum result in the provision of a technical risk assessment including proposed list of design controls to demonstrate compliance to this standard.

Any party who is involved in the specification, design, construction, installation, test, or commissioning of DC traction substations for SAPTA must complete and return a statement of compliance with this standard (Electrical Tram Running Certificate). Assessment of compliance must be provided for each requirement, defined by one of three permissible responses:

- Compliant;
- Partially compliant; or
- Non-compliant.

Where a waiver has been determined is required, waiver process PR-AM-GE-807 Must be followed.

7. Description

At present, the ATN's traction power system contains seven traction substations (MS1 and MS2 are combined into 1 substation in the same location under the Morphett St bridge); these substations are commonly referred as 'converters' because of the AC/DC conversion.

South Australian Power Network (SAPN) supplies power to the ATN's DC traction substations, the 11kV AC supply goes through to the rectifier transformer and then via the rectifier so the alternating current gets converted to direct current (600V DC) that supplies a bus bar and then distributed via individual circuit breakers and feeder cables, delivering power to track side section switches powering the overhead trolley wire. The return cable, known as the negative return cable, is bonded to the track via the substation negative bus bar connecting to the negative pole of the rectifier. The converters are enclosed in small rooms which are air conditioned to dissipate the heat generated by the equipment.

The overhead wiring is divided into different electrical sections, using section insulators. Typically, an electrical section is fed from two different traction substations and the overhead wires on adjacent tracks are connected in parallel to the same section. In many sections, an auxiliary side feeder is connected in parallel to the overhead wiring to increase the total cross-sectional area of the positive conductors.

The 600V DC traction system is unearthed; the rails are not directly connected to earth, but in most cases, they are embedded in the road surface and may not be considered floating. All rails are used for the traction return current (i.e., there are no dedicated signalling rails) however on approaches to level crossing track signalling track circuits are used and there are no rail-to-rail bonds. As part of the process of dc distribution there are various external assets that are subject to stray current damage. For this reason, the traction power system also includes components for electrolysis mitigation built into electrolysis protection systems. The HV AC and LV AC systems are earthed.

8. Traction Power System Requirements

8.1. Traction Power Network

The design, configuration, and operation of the ATN traction power system must ensure that it is always possible for the trams to operate and meet the authorised design timetable requirements under N and N-1 conditions.

The following N-1 conditions must be considered:

- Substation rectifier outage.
- Substation Feeder Panel Failure.
- 600 V DC external isolator failure; and
- 600 V DC positive feeder cable failure.

Information: The substation rectifier outage may be caused by events such as the loss of HV AC supply, failure of the HV AC switchgear or failure of the rectification system.

For detailed Traction power network requirements, refer to the Traction Power Network Standard, TP2-DOC-003521.

The traction power Supervisory Control And Data Acquisition (SCADA) system must be installed to provide remote monitoring and control of the substation including all alarms and fire systems where connected. For full details, refer to the Tram SCADA Network Standard, CE2-DOC-003522.

An analysis of special event timetables should be undertaken to ensure satisfactory operation of the specified rolling stock fleet under such conditions.

8.2. DC Substation Requirement

8.2.1. Design Principles

All design activity must be undertaken by engineers with engineering design competency in accordance with:

- the CSCR,
- Master Specifications PC-RW30, PC-EDM1 and PC-EDM2,
- PR-AM-GE-1170 Assessment of Engineering Competency for Rail Safety Workers, and
- Master Specification PC-PM3 Contractor’s Personnel & Training.

The Designer must identify discrepancies in referenced documentation and seek clarification from the Department as required.

The Designer must follow the Waiver Procedure PR-AM-GE-807 if any part of this standard cannot be met.

8.3. Human Factors

The Designer must meet the requirements for Human Factors in accordance with Master Specification PC-RW20, which considers, but is not limited to, the points below:

- ATN operational training, staffing, and resourcing requirements
- Lifting/maneuvering of heavy equipment to and from the building and switchyard
- Building and switchyard design which must allow for heavy loads and large doors/gates.
- Allowance for pulling heavy cables through conduits/ducts/trays.
- All electrical equipment must be capable of being operated and maintained by a 5 to 95 percentile person.
- Safe and unrestricted access to all parts of equipment where operations and settings must be carried out.
- Safe and unrestricted access to all maintainable parts for inspection, maintenance, and emergency situations.
- Accessibility requirements described in the relevant regulations and standards for public transport in Adelaide.

8.4. Safety

- The Designer must comply with the requirements of Safety in Design outlined in PC-RW30.
- The Designer must ensure that the design of the substation and its equipment incorporates safety to humans for all aspects of the equipment life cycle.
- The following safety principles must be followed in the design and operation of the substation:
    - The system design must require positive actions to be taken in a prescribed manner to either begin or continue system operation.
    - The safety of the system in the normal automatic operating mode must not depend on the correctness of actions or procedures used by operating personnel.
    - There must be no single-point failures in the system that can result in an unacceptable or undesirable hazard condition.
    - If one failure combines with a second failure, which can cause an unacceptable or undesirable hazard condition, the first failure must be detected, and the system must achieve a known safe state before a second failure can occur.
    - Software faults must not cause an unacceptable or undesirable hazard condition.
    - Interlocking must be included in the design of equipment to prevent incorrect operation of equipment and inadvertent access to hazardous environments within the substation.
    - The design must ensure that isolated sections of an installation cannot be inadvertently energised from parallel connected secondary sources (for example, auxiliary transformers are supplied from the star secondary winding of the rectifier transformer).

8.5. Risk Management

The Designer must comply with the requirements of Risk Management outlined in Master Specification PC-PM4.

The Designer must document the risk management process and maintain an up-to-date risk register using the latest ATN template document in the Rail Commissioner's Safety Management System.

8.6. Waste and Hazardous Substances Management

- Regarding waste management, the Designer must comply with the following:
  - Environment Protection Act; and
  - The Environment Protection (Industrial Waste Resource) Regulations 2009.
- The following hazardous substances must not to be used in any part of the substation installation:
  - Asbestos.
  - Polychlorinated biphenyls (PCBs).
  - Sulphur hexafluoride (SF6).
  - Lead.
  - Mercury; and
  - Cadmium.

9. Traction Substation Functional Requirements

Important Information:
The technical requirements specified in this standard are aligned with existing traction power DC substations in the ATN.
DIT/SAPTA reserves the right to update such requirements based on a specific project's circumstances and/or technical components advancement.

9.1. General

- The DC traction substation must contain the following major subsystems:
  - Incoming high voltage power supply system.
  - Rectification system.
  - 600 V DC positive system.
  - DC negative return system.
  - Earthing system.
  - OVPD (VLD) with Stray current monitoring system.
  - Low voltage auxiliary power supply system.
  - Control and SCADA systems; and
  - Substation building and ancillaries system.

Information: A typical Single Line Diagram is provided in the referenced documents section under drawing N. TP2-DRG-006980

- Unless stated otherwise, the Designer is fully responsible for the design of all subsystems and groups of equipment which are contained within the DC traction substation.
- Note: For brownfield substations, the responsibility of the Designer may be limited to specific subsystems and groups of equipment within the DC traction substation.
- The Scope of Works must specify SAPN as the Distribution Network Service Provider, which will supply power to the substation and the characteristics of that power supply. Unless stated otherwise, the incoming supply must be dual three-phase high voltage AC at a frequency of 50 Hz and the voltage must be 11 kV.
- The Distribution Network Service Provider may have specific requirements, in addition to the standard requirements defined in the Electricity Distribution Code. The Designer must ensure that the substation meets all these requirements.
- The incoming high voltage power supply system must include, but is not limited to, the following equipment:
  - Supply high voltage AC cables, conduits, and pits.
  - High voltage AC switchgear and the associated control system consisting of,

- but not limited to:
  - HV circuit breakers
  - Earthing switches
  - Current transformers
  - Voltage transformers
  - Protection relays
  - Metering equipment.
  - Interconnecting HV AC power cables, pits, and conduits; and
  - Interfaces with the high voltage earthing system, substation earthing system, rectification system and control system.

Note: Most of this equipment is typically located inside the substation.

- The incoming high voltage power supply system must comply with the SAPN specifications for the following components (to be provided):
  - HV AC Switchgear and Control.
  - Transducer and Measurement Device.
  - Cables; and
  - Outdoor Cable Pits.

9.2. AC Incoming Supply

The converter station's HV incoming supply equipment must be designed to provide most efficient operation, maximum reliability and minimised maintenance time and cost. The equipment must also meet the dual objectives of functionality and minimum life cycle cost.

Note: Each substation must be supplied by two independent (ideally from two separate feeders) 11 kV supplies with provision of bus tie-breakers to allow for both traction transformers to be fed by only one of these. Interlocking between the two supplies must be in accordance with SAPN conditions of supply requirements. The preference is to have a tie-breaker between the incoming high voltage feeder breakers. The designer should consult with the electricity supply authority to determine the Authorised configuration of the HV switchboard. If a tie breaker is allowed, it should not be possible to close both HV supply circuit breakers and the HV tie circuit breaker together and thus connect the two incoming HV AC supplies. The HV tie-breaker interlocking scheme should be approved by the electricity supply authority. The outputs of the rectifiers may be connected to the same 600 V DC bus.

9.2.1. Conditions of Supply

The Contractor must ensure that the converter station meets SAPN's Conditions of Supply requirements, including, but not limited to, Section 10 of the SAPN Service and Installation rules in its entirety. The designer/project must liaise with SAPN's Customer Solution Manager to request fault levels, harmonics load balance and other relevant characteristics specific to each site.

9.2.2. HV AC Circuit Breakers

The minimum specifications for the HV AC CBs must be as below:

- Number of poles: 3
- Rated voltage: 12 kV
- Rated frequency: 50 Hz
- Rated normal current: 630A
- Rated short time withstand current: 25 kA/1 second
- Rated breaking capacity: 25 kA
- Power frequency withstand voltage: 28 kV
- Impulse withstand voltage: 75 kV
- Degree of protection: IP3X, indoors

9.3. Rectification System

The rectification system must convert the incoming HV AC power supply to 600 V DC. The rectification system must include, but is not limited to, the following equipment:

- Rectifier transformer;
- Rectifier converter;
- Interconnecting power cables, conduits, and pits; and
- Interfaces with the incoming high voltage supply, 600 V DC positive system, DC negative system, low voltage auxiliary system, electrolysis mitigation system, substation earthing system and control system.

9.3.1. Rectifier Transformers

Each rectifier must be supplied with an epoxy resin encapsulated dry type rectifier transformer. The transformer must meet the requirements of AS 60076.11-2006 with the additional overload rating as specified for the rectifiers in Table 1 below.

ITEM	REQUIREMENT
No-load voltage: • Primary • Secondary	• 11 000 V • 2 windings. Each must have a line voltage sufficient for 600 V DC output at the station under full load
Rating – kVA:	To suit 600 kW rectifier
Frequency – Hz:	50
Type of cooling:	Natural air cooling
Impedance:	8.5% (or as nominated by the contractor for design)
Number of primary phases:	3
Tap changing device:	Off circuit ±2.5%, ±5%
Vector Symbol:	Dd0y11
Temperature Class of Insulation:	F
Temperature Rise of Winding by Resistance:	100°C (50°C maximum ambient)
Impedance voltage at normal frequency and ratio:	Vendor to advise
System Highest Primary Voltage:	12 000 V
Rated Lightning Impulse withstand voltage:	75 kV (primary)
Rated Power Frequency withstand voltage:	28 kV (primary)
Bushings	Normal polluted atmosphere
Sound level (Average)	65 dB(A) at max rated load
Degree of Protection	IP 21, indoor IP00 (protected by internal walls)
Testing:	Routine + Temperature rise

Fittings:	3 RTD's per LV Lifting lugs Diagram + rating plate Earth Screen Bi-directional wheels

9.3.2. Rectifiers

- Each rectifier must be a 3-phase, 12-pulse parallel bridge type.
- The preferred protection is over-current (instantaneous and inverse time) and rate of rise of current. However, other types of protection can be considered if they perform the function of minimising equipment damage during fault conditions.
- Fuse protection of diodes is not acceptable, but characteristics of the diodes supplied must ensure that failure of one arm must not cause damage to the other arm.

Technical Data of the rectifiers is as follows:

Table 2: Rectifier Data

Rated Power of each rectifier	600kW
Nominal Voltage	600V @ 100% load
	638V @ no load
Duty class	VI (modified)
Nominal output current (see note 4 below)	100% load continuously. 150% load for 2 hours 300% load for 1 minute 450% load for 15 seconds
Coupling	2 bridges in parallel with IPT
Diode arrangement	1 diode per leg for each bridge
Total number of diodes	12
Pulse number	12
Reverse voltage margin	2.46
Ambient temperature	50°C
Max. junction temperature	120°C.
Cooling System	AN (natural, by air convection)
Surge protection	• Capacitor across each diode • RC Surge Suppressor across DC • Terminals of each bridge
Thermal protection	• One (1) alarm thermostat per bridge • One (1) trip thermostat per bridge
Technical standard	AS 60146.1-2002

Notes:

- *Reverse current protection is to be provided in the negative isolator cubicle.*
- *The protection relay in the AC switchgear is set to provide thermal protection to the rectifier.*
- *The rectifier is rated to withstand a short circuit for 200ms.*
- *Overloads are not cumulative. Each rectifier must be capable of carrying each of the overloads specified above, immediately following operation for 2 hours at full load in an ambient temperature of 50°C.*

9.4. Harmonic Filter and Smoothing Reactor (if fitted)

If harmonic filtering is fitted to achieve performance requirements, the filter must be complete with discharging resistor and switch so that the capacitors can be discharged for maintenance purposes.

Suitable fuses or other protection must protect the filter equipment. The number of fuses must be kept to a minimum and they must be HRC fuses of proven breaking capacity.

An ammeter or other indication must be supplied so that the total filter current can be measured when in service.

9.5. 600V DC Positive System

9.5.1. Voltage

The traction power voltage requirements must comply with the SAPTA Standard, Infrastructure - Network Power - Traction Power – Design and Construction doc. Number: TP2-DOC-00352.

9.5.2. 600V DC Fault Levels

The Designer must allow for the maximum DC bus fault level at the specified system voltage, and:

a) The Designer must ensure that all circuit paths that feed the faults are rated to take the DC fault current until the AC protection operates.
b) The 600V DC positive system must transfer power from the rectification system to the overhead wiring system. The 600 V DC positive system must include, but is not limited to, the following equipment:
   - 600V DC rectifier circuit breaker panel(s) (includes the circuit breakers, short-circuiting switches, protection relays and associated control systems).
   - 600V DC positive bus
   - 600V DC transfer bus.
   - 600V DC bus-tie circuit breakers (for split bus arrangements).
   - 600V DC feeder panels (includes the feeder circuit breakers, transfer buses, short-circuiting switches, protection relays and associated control systems).
   - 600V DC outgoing substation feeder external isolators.
   - 600V DC positive feeder cables, conduits, and pits from the DC traction substation up to and including the cable termination at the interface with either the overhead wiring system (e.g., an overhead switch or feeder tap to trolley) or an existing cable termination (for example, a pillar box or existing cable pit).
   - Interconnecting 600V DC power cables, conduits, and pits Interfaces with the rectification system, control system/SCADA, DC negative system and substation earthing.

Note: Minimum requirements for DC circuit breakers are: drawable metal clad, arc fault contained, high speed DC circuit breakers complete with automatic shutters, over-current, line fault and line test protection facilities.

HIGH SPEED DC CIRCUIT BREAKERS CHARACTERISTICS	
Number of poles	1
Rated Voltage	600V DC
Rated Impulse Voltage	20kV DC
Rated current	3600A
Rated short circuit breaking capacity	20kA
At 10ms time constant	100kA
Degree of projection	IP30

9.6. DC Negative Return System

In combination with the rails, the DC negative return system must ensure the traction current returns to the substation. The DC negative return system must include, but is not limited to, the following equipment:

- Negative cubicle (includes main substation negative bus, negative isolators, and measurement shunts);
- DC negative cables, DC negative feeder cables, rail bonds, conduits, and pits.
- Voltage limiting device; and
- Interfaces with the rectification system, control system/SCADA 600 V DC positive system, electrolysis mitigation system and substation earthing system.

The DC negative return system must include the negative feeder cables and buses, conduits, and pits from the substation up to and including the rail bonds.

All traction bonding connections must contain a minimum of two DC negative feeder cables, each rated for the full normal current, installed between the rail bond and the main substation negative bus.

The designer should consider the inclusion of active remote monitoring of rail voltage and stray currents when considering the type of VLD to be installed in the substations (some devices come with this function), this would complement the existing electrolysis mitigation capabilities (In accordance with section 17.9 of TP2-DOC-002020, *Guideline for Low Voltage Electrical Earthing and Bonding for the Adelaide Metro Tram Network*, for appropriate mitigation strategies).

The DC outgoing negative cables must be accessible in the substation to enable access for negative current measurement by clamp-on ammeters.

Note: The bonding cables and cable connections are the part of the traction current return path most vulnerable to damage or vandalism. Consequently, the design of all traction bonding connections must allow for at least one parallel cable or connection to become disconnected. In this circumstance the remaining cables or connections must still allow the normal designed return traction current to flow without causing further damage.

Follow the requirements in *TP2-DOC-002020, Guideline for Low Voltage Electrical Earthing and Bonding for the Adelaide Metro Tram Network*, for appropriate mitigation strategies.

9.7. Earthing System

The earthing system must maintain the safety of the operators, public and equipment at all times. The earthing system must include, but is not limited to, the following equipment:

- Substation earth grid and associated equipment (e.g., electrodes).
- Equipotential bonds.
- Frame leakage protection.
- Interfaces with the internal substation equipment, control system, voltage limiting device, electrolysis mitigation system, adjacent earthing systems, and external metallic infrastructure within the influence of the substation earthing system (e.g., fences, water pipes).

All parts of the Earthing System must comply with applicable National and International standards.

The Contractor must design, install, and connect a suitable earthing grid within the converter station area to achieve a maximum earth resistance of 1-ohm and step and touch potentials complying with AS 2067. An earthing study at the substation location is to be performed prior to the design being started.

All non-current carrying metal enclosures or parts of AC equipment, including switchgear and rectifier transformers must be securely connected to the earth mat. Enclosures for DC equipment such as rectifiers, DC switchgear and DC busways and metallic ladders supporting DC traction power cables must not be earthed to the earth grid.

A frame leakage relay must be fitted as part of the converter station to detect leakage between the dc metallic structures and earth. Where metallic structures connect grounded with non-earthed equipment, e.g., the bus connection between the rectifier and rectifier transformer, adequate insulation must be provided where the sections join. The DC traction power system must not be earthed at any point, either inside the station or along the route.

A Rail Earth Contactor (REC) must be utilised to monitor potential between the negative busbar and the station earth. The REC must connect earth and negative when dangerous potentials are detected.

9.8. Electrolysis Mitigation System

The Designer must determine if electrolysis mitigation equipment is required in the substation.

The designer must evaluate the need of electrolysis mitigation equipment at the new substation location. If such equipment is deemed to be required, the Designer must integrate the equipment into the substation Consultation with the SAEC should be considered in the implementation of the electrolysis mitigation system design and settings.

All parts of the Electrolysis mitigation system must comply with applicable National and International standards.

9.9. Low Voltage Auxiliary Power Supply System

The low voltage auxiliary power supply system must include the following systems:

- Dual three-phase AC RMS auxiliary power supply: this must provide power for equipment such as the substation lighting, general power outlets and the battery charger.
- Automatic changeover facility between the two LV AC supplies.

Note: One of the auxiliary power supplies (not both, for shutdown maintenance reasons) can be derived from the traction power supply if sufficiently independent from other street supplies.

- 24V DC reliable auxiliary power supply, with at least three chargers/rectifiers for redundancy. In the event of a temporary loss of the AC auxiliary power supply, substation batteries must provide power to essential equipment (e.g., the control system) until the AC auxiliary power supply can be restored.

The low voltage auxiliary power supply system must include, but is not limited to, the following equipment:

- Auxiliary power transformers.
- Associated switching and control system.
- Battery and battery charger.
- Low voltage AC and DC switchboards.
- Interconnecting cables; and
- Interfaces with substation equipment.

Note: The arrangement of batteries and charger is to be such that routine battery maintenance activity does not require outage of the converter station. The Battery Charger control unit must be a smart module type that can send watchdog alarms and remaining time on the battery in hours to the SCADA system.

The designer should consider the installation of a solar powered system including solar battery storage to supplement auxiliary power supplies and to increase reliability during power outages.

The design must include remote monitoring and control of auxiliary power supplies (including solar if installed) with the capability to select which one is in operation. Also, the monitoring of the 24V DC reliable power supply must include battery voltage, battery temperature, charger status and temperature.

9.10. Control and SCADA Systems

The substation must have a Supervisory and RTU Marshalling Panel housing the terminations to the SCADA RTU interface equipment.

The supervisory panel must provide facilities for termination of all key station alarms and controls required for remote monitoring and operations. All control equipment communication is to have IP protocols. Serial communications are not accepted.

The Tram Electrical SCADA system is planned to consist of a primary server at the Operations Control Centre (OCC) with a Remote Terminal Unit (RTU) at the converter station.

The converter station must include suitable interface for control and monitoring of all primary equipment on the single line diagram, associated control and protection equipment as well as any additional interfaces that are required for the correct operation and monitoring of the station. The design of the converter station may include use of an RTU and screen based HMI to provide control or indication functions and suitable for future integration into the Tram Electrical SCADA system The design of the controls and indications within the converter station should be such to facilitate integration into the Tram Electrical SCADA system If an RTU and HMI is not used then the terminal limit between works to be undertaken under this Specification and the above referenced specification must be at a converter station RTU panel. Works up to and including the RTU panel, including field signals being cabled and connected to the RTU panel terminals, must be allowed for under this Standard.

For all the control and SCADA System's requirements, refer to the Tram SCADA Network Standard, CE2-DOC-003522.

9.11. Current and Voltage Transformers

9.11.1. Current Transformers

Current Transformers (CT) must be supplied to operate protection and metering. The protection and measuring current transformers must comply with AS 60044.1.

The current transformers must be at least equal in short time current rating to that specified for AC circuit breakers. The current transformers must be brought out to a set of isolatable test terminals suitable for shorting and earthing the CT secondary windings and checking the protection and metering system by means of a portable current injection test unit.

The rectifier protection CTs must be at least Class 10P100 and metering CTs must be at least Class 1, 20VA. CT ratios are to suit the installed equipment and meet any protection coordination requirements of SAPN.

9.11.2. Voltage Transformers

Voltage Transformers (VT) must be provided for metering as shown on the single line diagram. The VTs must comply with AS 1243 and 60044.2 and SAPN requirements. They must have suitable fuse protection.

9.12. Instrumentation

Instrumentation must be provided for visual indication of current, voltage and power as indicated on the single line diagram. Accuracy must be at least Class 1.5.

9.13. Auxiliaries (AC and DC)

Auxiliary equipment must be provided to maintain operation of the major station equipment. This must include but not be limited to:

- Auxiliary transformer to provide a 240 V, single-phase ac supply.
- Isolating transformer, to provide a 240 V AC backup from SAPN.
- Battery charger and battery to supply 24 V DC.
- AC and DC auxiliary boards for distribution of auxiliary circuits; and
- Building lighting and power.

9.14. Reliable Auxiliary Supply (Control Voltage)

- The rated nominal voltage of closing and opening devices and of auxiliary and control circuits must be 24V DC supplied by a substation battery system.
- Unless stated otherwise, the control voltage must comply with the requirements of section 6.4 of AS 62271.1.

9.15. Substation Building and Ancillaries System

a) The substation building and ancillaries system, including civil works (e.g., drainage, water, sewerage, etc.) must comply with the Department's specifications for the following components:
   - Buildings; and
   - Outdoor Cable Pits.

b) The fire rating and number of access/egress doors must comply with the Building Code of Australia, AS/NZ 2067, SAPN requirements, AS 3000 and any other relevant regulations.

c) The building or separate housings must be adequately cooled for the equipment installed to ensure it is maintained within its operating range. The air conditioners and pressurisation fan equipment used must be selected to ensure sound level meet the relevant Codes.

d) The building must have pressurisation fans installed in all rooms to minimise dust ingress.

Note: Also refer to Section30.1 below.

10. Service Performance Requirements

10.1. Operating Conditions

a) Unless stated otherwise, DC traction substation equipment and subsystems must operate at their nominal performance under the operating conditions outlined in Table 4.

Table 4: Operating conditions

DESCRIPTION	INDOOR EQUIPMENT (INCLUDING UNDERGROUND)	OUTDOOR EQUIPMENT
Ambient air temperature	-5˚C to +50˚C	-5˚C to +50˚C
Relative humidity	Up to 95% (condensation may occasionally occur)	Up to 95% (condensation may occasionally occur)
Altitude	Up to 1000 m	Up to 1000 m
External vibration and seismic tremors	Negligible[1]	Negligible[1]
Solar radiation	Negligible	1.1 kW/m[2] (equivalent to black body temperature of 80°C)
Pollution degree	PD3A (According to Table A.4 of EN 50124-1)	PD4 (According to Table A.4 of EN 50124-1)

[1] Unless stated otherwise, the *Designer* may neglect seismic tremors vibrations caused by sources external to the substation.

[2] It is assumed that the equipment is in shade and protected from direct sunlight.

b) The Designer must prevent condensation in situations where equipment performance may be compromised by its presence. Prevention methods may include, for example, special design of the building or housing, suitable ventilation and heating of the substation or use of dehumidifying equipment. External conduits and pits should be segregated form substation environments and should not allow excessive moisture to enter the substation environment.

10.2. Transport and Storage Conditions

Unless stated otherwise, DC traction substation equipment and subsystems must be subject to the following transport and storage conditions:

- Minimum ambient temperature: -25˚C;
- Maximum ambient temperature: 55˚C; and
- Anticipated high levels of shock, vibration, and inclination during transportation to site.

10.3. Noise

Unless stated otherwise, the Designer must submit a Noise Report which provides evidence of compliance and includes at least the following:

- Design considerations and plan for compliance.
- Noise level measurements on site prior to construction works commencing; and
- Noise level measurements on site upon completion of commissioning of the electrical equipment.

10.4. Inside the DC Traction Substation

Noise levels inside the substation must comply with all requirements of the Occupational Health and Safety Act. In particular, the levels must comply with the SafeWork SA ‘Managing noise and preventing hearing loss at work’ code of practice.

10.5. Outside the DC Traction Substation

Noise levels outside the substation must comply with all requirements of the Environment Protection Authority SA.

10.6. Electromagnetic Compatibility

Unless stated otherwise, the Designer must submit an Electromagnetic Compatibility (EMC) Report which provides evidence of compliance and includes at least the following:

- Design considerations and plan for compliance;
- EMC measurements on site prior to construction works commencing; and
- EMC measurements on site upon completion of commissioning of the electrical equipment.

All equipment and subsystems within a DC traction substation and the DC traction substation itself must comply with the following standards, regarding electromagnetic field emissions and immunity:

- EN 50121-1.
- EN 50121-2.
- EN 50121-5.

All equipment and subsystems within a DC traction substation and the DC traction substation itself must comply with the following standards, regarding exposure limits for electromagnetic fields:

- ICNIRP Guidelines: Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz).
- ICNIRP Guidelines: Guidelines for limiting exposure to electric fields induced by movement of the human body in a static magnetic field and by time-varying magnetic fields below 1 Hz.
- AS/NZS CISPR 22 for master station equipment and AS/NZS CISPR 11 for other system equipment.

All equipment must be suitable for operation in the vicinity of other electrical plant and must be immune to electromagnetic interference when subjected to field strengths up to 10 volts per meter over a frequency range of 10kHz to 1000MHz.

10.7. Special Conditions

The Designer must consider specific situations where a substation or its equipment are exposed to special service conditions. Situations may include, but are not limited to:

- A substation is to be installed near a main arterial road or factory and therefore may be subject to abnormal levels of pollutants and dust.
- A substation is to be installed in a very exposed area and therefore the substation building and/or outdoor equipment may be subject to significant adverse wind conditions.
- A substation is to be installed in an area where it may be affected by small animals or micro-organisms.
- A substation is to be installed close to the ocean and therefore may be subject to abnormal levels of salt in the air.
- A substation is installed in publicly accessible areas or without appropriate fencing.
- A substation is installed near road or tram traffic.

Information: In these specific situations, the Scope of Works must specify any special design requirements for the substation

11. Minimum Design Requirements

11.1. Rectifier Transformer – Specific Requirements

Each transformer must comply with the relevant Australian Standards, in particular:

  - AS 60076.11-2006 Power Transformers
  - Insulation Coordination

Each transformer must be capable of continuous operation at rated power without exceeding the temperature rises specified in AS 60076.1-2014 as well as the cyclic loadings to match the rectifier.

Each transformer must be of the epoxy resin (Class F insulation) encapsulated type, with natural air cooling and installed in the converter station building.

Each transformer must be provided with a suitable enclosure to prevent contact with live conductors. These enclosures must be sufficiently ventilated to allow natural cooling to be effective.

Tap changing must be of the off-load type. It must be clearly labelled and conveniently located to provide ease of changing. Each transformer must be capable of providing maximum rated output continuously on all taps.

Thermal protection must be provided for each rectifier transformer by a suitably calibrated thermal device. Two levels of thermal protection must be provided. The first level must provide an abnormal temperature alarm and the second must trip the transformer on high temperature.

An earthed screen must be provided between the primary and secondary.

If the transformers are in external room(s), doors are to have fortress key door interlocking with the primary side earthing isolator within the switch-room.

11.2. Rectifier – Specific Requirements

The rectifier must comprise two three phase bridges connected in parallel for twelve pulse operation as defined in AS 60146. The bridges must be designed to be fed by the two delta / wye secondary windings of the rectifier transformer.

The rectifier bridge must be capable of carrying the loading conditions described in Part 3, Clause 3 as well as withstand the maximum prospective short circuit for long enough to permit the equipment protective devices to operate and clear the fault.

The rectifier must be designed for easy maintenance and must be provided with positive and secure isolation from ac and dc sources.

Diode temperature rating must meet the overload requirements of the rectifier and have a reverse voltage rating of at least 2 200 volts.

While each rectifier will be nominally providing 600 V DC it could at times be subject to 800 V DC at the converter station output terminal due to regenerative braking output of the LRV's. The rectifier must be designed to suit this situation.
The diode heat sink bridge arrangement must be designed to allow easy access to all diodes and must provide adequate insulation and natural air cooling.

Thermal protection must be provided for the rectifier bridge to reliably detect an abnormal rise in diode / heatsink or cooling media temperature. Two levels of thermal protection must be provided. The first level must provide an abnormal temperature alarm and the second must trip the unit on high temperature.

11.3. AC Circuit Breakers – Specific Parameters

The circuit breakers must be manufactured and tested in accordance with AS 62271. The interrupter units in each pole must be readily accessible for inspection and designed for convenient removal and replacement.

The contacts of the interrupter must be held open by a positive fail-safe device and the closing arrangement be so designed as to give a positive closing action whilst overcoming the contact hold open device and must in no way be dependent on interrupter.

The circuit breakers must be of a totally enclosed metal clad design, with isolation and earthing facilities.

Closing of the circuit breakers must be by electrical operation, trip free and suitable for operation from the station auxiliary battery.

The circuit breakers must be arranged for operation, either close or open by local control or by remote supervisory control.

The circuit breakers high voltage bushings must comply with AS 1265 for a normal polluted atmosphere.

Facilities must be provided for earthing both sides of all feeder circuit breakers during maintenance and installation. The earthing must be provided by a mechanically interlocked, visible, fault make earth switch.

The transformer room(s) external doors (if this is the arrangement used) are to have fortress key door interlocking with the earthing isolator within the switch-room.

11.4. DC Circuit Breakers – Specific Parameters

The circuit breakers must comply with AS 1930, or equivalent international standard. Each panel must comprise a single pole 3,600A, 600V DC, manually operated rectifier output positive isolator. The rectifier positive isolator will be complete with an interlock magnet (to prevent manual operation unless certain conditions are satisfied) and auxiliary contacts.

The rectifier output busbar to incorporate the positive isolator and a front door viewing window must be provided.

The Contractor must note that the operating times of the circuit breaker are critical, and the Department recommends a maximum of 10 ms operation times for trips initiated by DC line protection.

It is preferred the high-speed circuit breakers are mounted on removable trolleys which are easily drawn in and out of the cubicle and connected or disconnected from busbars by means of power finger connectors and from auxiliary circuits by means of multiple connectors.

Each DC circuit breaker must be housed in separate metal screened compartments.

Each feeder dc circuit breaker must be identical to allow easy interchanging. Electrical and mechanical interlocks must be provided to prevent moving of the circuit breaker in or out of the compartment when it is closed.

The circuit breakers must be single pole, high speed, and trip free and electrically operated with electromagnetic holding. On the loss of a rectifier the feeder dc circuit breakers must remain closed unless the overhead wiring system has fallen below 400V. For voltages less than 400V the circuit breakers should open on under-voltage.

The circuit breakers must be arranged for opening and closing by local control or by remote supervisory control. The loss of the 24V DC supply must cause the circuit breakers to trip.

11.5. Auxiliary Equipment – Specific Parameters

11.5.1. Auxiliary AC Supply

- A single-phase dry type of auxiliary transformer of sufficient rating to carry all station auxiliary supplies must be provided for the station. The primary connection of the transformer must be connected to the low voltage terminals of the rectifier transformer or incoming 11kV supply. Adequate protection must be provided for transformer faults.
- The converter station must be supplied with a second (standby) auxiliary supply to allow maintenance to be carried out when both the rectifier transformers are out of service. The supply is envisaged to be from SAPN or an emergency generator via an isolating transformer, to be consistent with electrolysis mitigation measures in accordance with the Proposed Single Line Diagram – Appendix 1 of this Specification. The two main supplies and the standby auxiliary supply must be arranged to be automatically changed over when loss of one supply occurs. Status indications must be provided to the supervisory panel.

11.5.2. Battery and Battery Charger

- The converter station must be provided with a battery charger and batteries to supply the 24V DC auxiliary requirements of the station equipment.
- The battery charger must be rated to supply the total station 24V DC standing load and recharge for its battery.
- The nominal voltage of the battery bank must be 24V DC having a capacity to independently supply the station control requirement for 12 hours after loss of supply to or the failure of the battery charger.
- The batteries must be of the sealed low maintenance type preferably housed in the same cubicle as the battery charger.
- The installation must comply with AS 3011.

11.5.3. AC Auxiliary Panel

- The converter station must be provided with a 240 V AC 1-phase or 415V 3-phase auxiliary switchboard complete with automatic changeover facilities to connect either the rectifier auxiliary transformer or standby supply.
- Dedicated circuit breakers must be provided for each circuit which includes but is not limited to the following:
  - Station lighting.
  - Station power.
  - Air conditioner.
  - Cubicle heaters (if required).
  - Battery charger; and
  - Ventilation fans (if required).
- There must be at least three spare circuits.
- Adequate space must be provided for the installation of Security System and Fire Detection Equipment.

11.5.4. DC Auxiliary Panel

The converter station must be provided with a 24 V DC auxiliary supply panel. Double pole moulded case circuit breakers must be provided for each circuit which includes but is not limited to the following:

- Supervisory RTU equipment.

- High voltage circuit breakers.
- Rectifier control panel.
- DC feeder, circuit breakers; one for each circuit and
- Transformer rectifier protection. (AC protection and DC protection relays)

Note: There must be at least three spare circuits.

11.5.5. Supervisory Panel

The converter station must be equipped with a supervisory RTU panel fitted with suitable marshalling terminal panel. All station signal wiring must be wired to the marshalling terminals for connection to the supervisory equipment.

11.5.6. Rectifier Control Panel

- The converter station must be provided with a rectifier control panel for the complete station control, indicating and interlocking functions.
- The control panel must contain the necessary control equipment and instrumentation for the functional control of the complete station 600V DC system. This must include the ability to control locally or remotely through the supervisory system.

11.5.7. DC and AC Feeder Control Panels

Each DC and AC feeder control panel must have a switch to transfer control between supervisory and local control. The control panel must also contain the necessary equipment to enable local operation of the circuit breaker. Each control panel must also contain instrumentation to allow visual reading of key operational quantities such as equipment status, amps, volts, and alarms. The panel must also contain any necessary protection equipment with clear indication of its status. The protection equipment can be mounted on a separate cubicle if preferred. Protection relay displays must be fitted to the DC circuit breaker panels.

11.5.8. Converter Station Light and Power

- Station light and power must be supplied from the AC auxiliary panel. Power points must be sized and positioned to suit normal operation and maintenance of the station equipment.
- Lighting must consist of normal and battery packed emergency lighting.
- Appropriate weather and vandal proof lighting must be provided externally, including external lights over the main access door. The outdoor lighting must be controlled by a sensor switch.

11.5.9. Station Security

The station must be provided with a simple security system that raises an alarm at the control centre when the building is entered with contacts enabling connection to the RTU for remote alarm. The Supervisory panel is to have an ‘attendance’ selector fitted with a programmed ‘entry duration’ time.

11.5.10. Fire Protection

The station should be fitted with a simple fire detection system including smoke detectors. Alarms to be wired to the supervisory panel as part of the station alarms. Outputs in the form of voltage free spare contacts must be provided for future external connection. A fire alarm test switch is also required.

11.6. Earthing

- AC and DC earthing must be treated separately.

- AC equipment must be connected to the station earth mat. DC equipment must be insulated from the station earth mat.
- The track rail forms the negative return for the rectifier and must be kept separate from earth to ensure electrolysis is minimised.
- The DC equipment enclosures must be insulated from the station floor and AC equipment earths.
- Equipment layout must be carefully designed to avoid step and touch potential between the two systems. Step and touch potentials are defined in AS 2067.
- Isolation of the DC cubicles can be achieved by placing them on a sheet of nylon 3mm thick, or other similar insulating material.

12. Negative Busbar

A cubicle must be provided in the station to house the station negative busbar for connection of rectifier negative, track negative return cables, rail earth contactor and electrolysis drain cables (if required).

13. Supply Authority Metering

The Designer must provide a secure space for installation of SAPN tariff metering external to the converter station, including facilities to terminate segregated cabling from converter station ac switchgear measurement transformers (CT's, VT's). SAPN Service and Installation Rules Clause 9.13.2.1 requires a "clear space of 2.1M high by 1.2 m wide" however this is negotiable. "The minimum size meter panel for single HV metering installation must be 600mm × 600mm". Note that these meters are remotely interrogated and access by SAPN personnel is not required for meter reading purposes. Further information can be obtained from SAPN.

Note: The substation must comply with AS 2067.

14. Insulation Coordination

Insulation co-ordination must comply with the general principles established in AS 2067 and EN 50124-1. The applicable insulation levels and clearances from these standards are provided in Table 5 and Table 6.

Table 5: AC Insulation Levels and Clearances

NOMINAL VOLTAGE Un (r m s)	HIGHEST VOLTAGE Um (kV r m s)	RATED SHORT DURATION POWER FREQUENCY WITHSTAND VOLTAGE Ud (kV r m s)	RATED SHORT POWER FREQUENCY WITHSTAND VOLTAGE Ud (kV r m s)	MINIMUM PHASE TO EARTH CLEARANCE (mm)	MINIMUM PHASE TO PHASE CLEARANCE (mm)	NON-FLASHOVER DISTANCE (mm)	GROUND SAFETY CLEARANCE (mm)
230/400 V AC or 240/415 V AC	D	D	D	D	D	D	D
11 kV AC	12	28	95	160	185	175	2440
D: To be determined by the Designer and agreed with the client							

Table 6: DC Insulation Levels and Clearances

NOMINAL VOLTAGE Un (kV)	RATED VOLTAGE Une (kV)	RATED INSULATION VOLTAGE Unm (kV)	OV	RATED IMPULSE VOLTAGE Uni (kV)	POWER FREQUENCY WITHSTAND VOLTAGE LEVEL Ua (kV)	MINIMUM CLEARANCES IN AIR FOR THE STANDARD ALTITUDE RANGES[1] (mm)
0.6	0.72	0.9	4	8	3.6	14
[1]This value is based on PD4 pollution degree.						

- The Designer is fully responsible for providing suitable insulation levels for the equipment and must verify the values in Table 5 and Table 6.
- The applicable HV AC equipment includes but it's not limited to:
  - HV AC switchgear and control.
  - HV AC power cables.
  - Metering equipment.
  - Rectifier transformer; and
  - Auxiliary transformer (if connected to HV AC).
- Safety clearances for operational purposes and maintenance work must be in accordance with Table 3.1 of AS 2067
- In accordance with clause 3.2 of AS 2067, the choice of the insulation levels should consider the method of neutral earthing in the system and the characteristics and locations of overvoltage limiting devices to be installed.

Information: If the Designer can prove to SAPTA that lower insulation levels can be achieved through appropriate choice of surge protection, the rated lightning impulse withstand voltage requirements in Table 5 may be relaxed.

15. Earthing and Bonding

15.1. General

- The earthing and bonding system must comply with:
  - AS 2067.
  - ENA EG1 – Substation Earthing Guide.
  - AS 3000; and
  - EN 50123-7-1.
- Unless stated otherwise, the Designer must submit an Earthing Report which provides evidence of compliance and includes at least the following:
- Design considerations and plan for compliance.
  - Soil resistivity test results.
  - Field test results, validating the earthing grid; and
  - All other items listed in clause 8.9 of AS 2067.
- The complete earthing system design and construction is the responsibility of the Designer and must provide safety (both within and outside the substation fence) to all personnel (including the public), as well as protection of all equipment from damage during fault conditions. In particular, the Designer must apply the following principles:
  - The Designer must use the design procedure in accordance with AS 2067.
  - AS 2067 also stipulates that the responsibility of the Designer includes consideration of interactions with surrounding systems.
  - The earthing system must be vandal resistant and have physical protection from activities that may be carried out in the vicinity.
  - The earthing system construction must include reference measurement points for future earth testing.
  - The substation earthing system must contain a buried earth grid beneath the building and switchyard.
  - AS 2067: the earthing system must adopt the 'combined earthing system' principle.
  - The earth grid system must be designed for installation at a nominal depth of 500 mm below foundations level.
  - The earth grid must continue under and around the switchyard and be designed such that safe step, touch and transfer potentials are achieved.
  - Sub-ground jointing must be by cadwelding or brazing.

- The design must provide for the connection of a substation main earth bar to the outside earth grid. There must be some means to visually and electrically confirm the connection of the substation main earth bar to the external earth grid. The disconnection point for testing must be at the main earth bar. In accordance with clause B1.1 (f) of AS 2067, facilities should be provided to test earth electrodes without disconnection of the earthing system from the energised substation.
    - The design must provide for connection of earth grid to building reinforcing bars; and
    - The contractor must perform all field test stipulated in AS 2067.
- Unless stated otherwise, the ATN earthing system must be separate from the Distribution Network Service Provider earthing system.
- Unless stated otherwise, the frame of 600V DC cubicles and 600V DC cable trays must be connected to earth in accordance with Figure 1. The insulating material, installed between the frame of 600V DC cubicles and earth or the 600V DC cable trays and earth, must provide an isolation resistance of at least 1 MΩ.

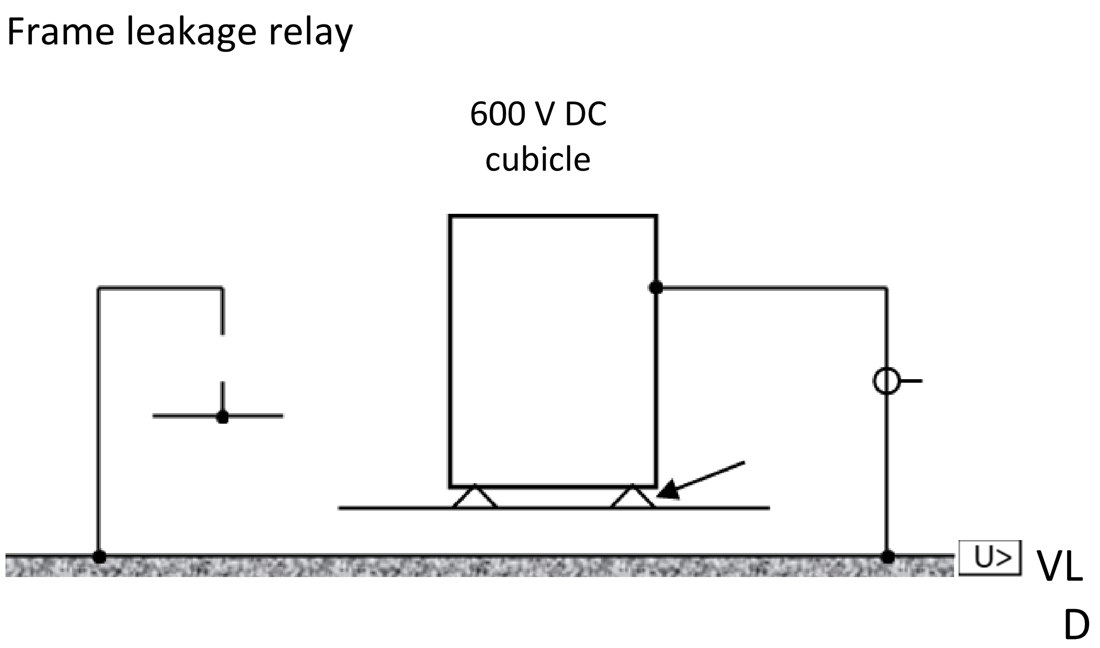


Figure 1: 600 V DC system earthing principle (Adapted from EN 50123-7-1 Figure 4a)

- The Designer must ensure that personnel in the vicinity of all substation equipment are adequately always protected from hazardous step and touch potentials, and that there is sufficient physical separation between equipment that is earthed and equipment that is connected to the 600 V DC negative system so that substation personnel cannot inadvertently come into contact both types of equipment at the same time.
- In accordance with Figure 1, frame leakage protection relay(s) must be provided and connected between the following:
    - The frame of 600 V DC cubicles and earth; and
    - 600 V DC cable trays and earth.

Information: The number of relays to be provided and their respective location are defined in the Specifications and/or the Scope of Works

- If a breakdown occurs between the frame of any 600V DC cubicle or 600V DC cable tray and earth causing a current to flow, the frame leakage relay must operate. In accordance with EN 50123-7-7, detection of a frame fault must cause a mass trip of all in feeds to the 600V DC cubicle or 600V DC cable tray to isolate the fault.

15.2. Voltage Limiting Device

Voltage limiting device(s) must be provided and connected between the main substation negative bus and the earth bus. The designer must determine the number and location of the VLDs.

16. Protection and Control System Requirements

16.1. AC Protection

- Protection relays and current transformers must be supplied to meet the protection of the converter station equipment and the protection coordination requirements of SAPN.
- The rectifier transformer must be fitted with over-current, overload and earth fault protection which must isolate the rectifier unit should a fault occur in the rectifier transformer, rectifier or associated cabling and busbar.
- The relays must be of electronic type with selectable time characteristics.
- The overload relay must have time characteristics suitable to match the thermal over-current and overload characteristics of the rectifier transformer and semiconductor rectifier equipment. This must be in addition to the thermal protection described in other sections of this Specification.

16.2. Rectifier Protection

- The rectifier must be protected against AC overvoltage, DC overvoltage and abnormal thermal conditions.
- The AC overvoltage protection must protect the rectifier assembly from AC switching surges.
- The DC overvoltage protection must protect the filtering and rectifier equipment against DC over-voltages, and must fall into the following two categories:
- Protection against switching surges from operations such as high-speed DC circuit breakers; and
- Protection against lightning surges.
- Thermal protection is required.

16.3. DC Feeder

- The feeder protection to include both di/dt and OCIT protection on each DC feeder.
- The protection must discriminate between normal Tram loads and either a faulty Tram or a fault on the OHW which could be of a low level.
- The protection must coordinate with the rectifier equipment so that a feeder fault does not isolate the rectifier. DC feeders should only isolate the feeder section they are connected to.

16.4. DC Feeder Control

- An automatic reclose scheme must be provided for each DC feeder.
- If, after a DC feeder circuit breaker trip, a voltage (nominally 600V DC) is detected on the outgoing feeder a close command must be sent to the DC feeder circuit breaker.
- A reclose system capable of performing several recloses with adjustable time delay between recloses must be supplied. A lockout feature must cause the DC circuit breaker to open and stay open once the set number of recloses have occurred.
- It will be necessary to know the condition of the OHW to operate the reclose scheme safely. This could be done by testing the resistance of the OHW and making comparisons with predetermined values. If the resistance is too low, then the DC feeder circuit breaker would be prevented from closing. The testing would

occur at regular time intervals to allow for the fault to be cleared. A lock out feature would be required to turn the testing scheme off once a pre-set number of tests had occurred.

17. Frame Leakage Protection

- As specified elsewhere in this Specification all DC cubicles must be insulated from the main station earth. A frame leakage protection relay must be installed between the cubicle and the station earth.
- The relay must be of a low impedance type with adjustable tripping current. It must be failsafe in that in the case of loss of control voltage it will trip the AC and DC circuit breakers.
- A voltage clamping device must also be provided to ensure that the potential between the AC and DC equipment cubicles does not rise dangerously under fault conditions.

18. Rail/Earth Protection

- The negative rail voltage with respect to the station earth must be continuously monitored. Should the voltage rise to a dangerous level the negative and station earth must be connected by a DC contactor.
- The converter station can stay in service after the contactor has closed. However, the tramway operator must be warned so that action is taken to find the cause and reset the rail earth contactor. The resetting is required as soon as possible to mitigate electrolysis.

19. Inter-Tripping Protection

The design of secondary systems and controls must allow for future installation of inter-tripping protection. This requirement may be met by the provision of a spare relay output contact and a spare trip input per feeder. Spare inputs and outputs for future inter-tripping must be connected to the RTU panel.

20. Outdoor Positive Isolator

The outdoor positive isolator is required to provide a separate external method of isolating and terminating overhead connections in the event of a major fire or other event when the converter station may be difficult to access. This allows the station to be fully isolated in emergency. Isolation will require both 11kV ac and the 600Vdc to be disconnected. As the final installation location of the building is still to be decided, the Contractor must offer a suitable outdoor isolation panel fitted with a suitable isolator and terminals that may be fitted to the outside of the converter station building or adjacent fence or other location. Overhead wiring will be terminated to this point with a cable connection from the isolator panel to the DCCB.

21. Protection System

- Unless stated otherwise, the protection system must comply with the requirements of the equipment specifications and the following standards:
  - HV AC protection system: AS 2067 and AS 3851; and
  - 600 V DC protection system: EN 50123-1, EN 50123-2, EN 50123-7-1.
- At all times, the primary consideration for the protection system must be to protect persons exposed to the traction power system (e.g., substation staff or members of the public). A secondary consideration is to protect electrical equipment and a final consideration is to minimise delays to operations.
- Unless stated otherwise, in consultation with SAPTA, the Designer must provide suitable protection settings for all protective devices in the substation (i.e., the normal scope must include settings for incoming high voltage supply, low voltage auxiliary supply, battery charger, rectification system, 600 V DC rectifier and bus tie circuit breakers, 600 V DC positive bus. The protection settings must not interfere with the design output capability of the substation.
- The Designer must be responsible for meeting the protection coordination requirements of the relevant Distribution Network Service Provider with respect to the incoming high voltage supply.

- All protection wiring between equipment must be hardwired.
- Where an earthing design relies on fault clearing times and equipment maintenance requirements the designer must clearly define the requirements for incorporation into operational and maintenance systems.

The Configuration of HV CBs, 600V DC CBs and all respective settings must be designed to maximise the safety, reliability, and availability of the outgoing supply.

Information: The specific behavior of the protection system will depend on the system configuration and other requirements defined in the specifications and Scope of Works. In particular, the specifications and/or Scope of Works must nominate which equipment failure scenarios allow automatic restoration of power (auto-reclose) and the conditions under which power may be restored.

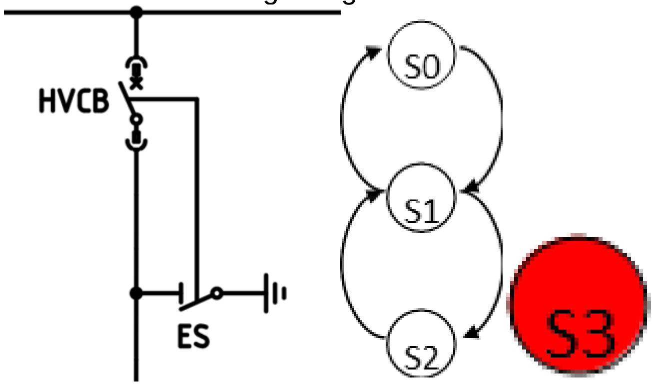
22. Lightning and Surge Protection

- Unless stated otherwise, the lightning and surge protection system must comply with the equipment specifications, the requirements of Table 4 and the following standards:
    - AC surge protection system: AS 2067, AS 1768 (lightning protection for buildings), AS 1307.2 (AC surge protection devices); and
    - 600V DC surge protection system: EN 50124-1, EN 50124-2, EN 50526-1.
- Lightning and surge protection must be provided for all equipment that is exposed to the risk of lightning or surges (but multiple items of equipment might be protected by one device as part of a zoned system). The need for protection against lightning surges is essential unless the location provides an inherent zone of protection from lightning surges.
- Lightning and surge protection systems must present a low risk to workers in the event of a nearby or distant lightning strike. As a result, the safety of personnel working on or near the surge protective equipment must be considered when designing the layout of the surge protective equipment or the route for earth conductors.
- Surge protected wiring must be segregated from non-surge protected wiring to prevent coupling of surges between the wiring. Earth wires are to be considered as non-surge protected wiring. The amount of segregation must be suitable for the expected level of surge on the non-protected wiring.
- When considering lightning and surge protection, the equipment selection principles must be as follows:
    - must be fit for purpose.
    - must match the insulation coordination requirements and the detailed equipment specifications for all equipment supplying the surge zone; and
    - surges must be kept within the tolerances of the equipment being protected.
- All entry points for surges must be considered. Lightning and/or surges occur, enter, or are induced into the system through one or several of the following:
    - HV AC system.
    - LV AC system.
    - 600V DC system.
    - DC negative system.
    - Communication lines.
    - Earth grid; and
    - Electrolysis system.

23. Interlocking

For the purpose of this standard and the substation equipment specifications, interlocking must be defined as an electrical, electronic, or mechanical device or system which prevents an element from changing state due to the state(s) of another element(s), and vice versa. Figure 2 provides an example of the interlocking principles for an earth switch in withdrawable HV AC switchgear. The following definitions must apply:

- Mechanical interlocking: A device or system which prevents a change in state by blocking motion. For example, trapped key systems—a mechanical lever preventing the closing of an earth switch while a circuit breaker is racked in.
- Electrical interlocking: A device or system which prevents a change in state using logic in a wired circuit. e.g., a relay logic circuit which prevents the closing of a circuit breaker.
- Electronic interlocking: A device or system which prevents a change in state using logic in software. e.g., electronic interlocking using the software in a PLC or protection relay.



S0 – HVCB = Racked out; ES = Open
S1 – HVCB = Racked in; ES = Open
S2 – HVCB = Racked out; ES = Closed
S3 – HVCB = Racked in; ES = Closed

Figure 2: Interlocking – General Principles and Worked Example – High Voltage Earth Switch

Information: Whenever practical, preference should be given to mechanical interlocks.

In the event of the loss of auxiliary power, the interlocking should be designed to be fail-safe.

All interlocking wiring, if applicable, between equipment must be hardwired.

24. Control Panels

Local electrical control and/or indication for each item of equipment must be from control panels, which are situated on the equipment they control or indicate, unless stated otherwise. Terminology used to describe control operation points must be consistent with SAPTA's electrical sectioning diagrams.

Additionally, a single central substation control and indication panel must be provided and located in a safe zone within the substation. Requirements for the central substation control and indication panel are given in the SCADA Standard, document CE2-DOC-003522.

25. Equipment Interfaces / SCADA

All equipment must be able to be electrically controlled and/or indicated locally and remotely through the SCADA system. SCADA requirements are prescribed in the SCADA standard, document CE2-DOC-003522.

26. Labelling and Identification

- Unless stated otherwise, the substation labelling, identification and marking must comply with AS 2067, AS 1319 and AS 3702.
- Cubicle identification and terminal markings must be in accordance with IEC 60445.
- Signage, warning signs (for example warning notices) or safety instruction notices must be displayed where there is a potentially ambiguous or dangerous situation.
- In accordance with AS 2067, where an item of equipment consists of two or more units with access to the rear, such labelling must also be located on a fixed portion at the rear of each unit.

- Nameplates must be provided for each item of equipment as specified in the relevant specifications and must be durable, visible, and legible.
- The colors on insulation must be continuous for the entire length of the conductors. The colour on bare busbars must be clearly visible without giving the impression that it is a form of insulation.
- A system of permanent numbering for identification of cables must be used. The numbers must be allotted in a logical manner so that parts of the circuit can be readily identified, and the purpose and destination of any wire can be determined from the wiring diagram. The wire number must appear on both ends of each wire. The numbers must be securely attached to the cables and be easily readable. The numbers must be adjacent to the cable termination and must read from left to right. Labelling must only be removable after the wire has been released from its termination.
- All electronic equipment must generally be rack mounted with each module and circuit board clearly labelled with its function, location, and particular characteristics such as power supply rating.
- Terminals must be provided and connected to allow use of any spare signal capacity inherent in the equipment. All terminals must be clearly labelled.

27. Efficiency

In accordance with paragraph 34 (Eco Friendly design), the Designer must consider the substation energy efficiency. The energy efficiency is defined as the ratio of the 600V DC output power to the HV AC input power. The target substation energy efficiency, as a function of the DC output current of the substation rectifier(s), is given in Table 7.

Table 7: Target substation energy efficiency

DC OUTPUT CURRENT OF THE SUBSTATION RECTIFIERS (S) [A]	TARGET SUBSTATION EFFICIENCY, DURING TRACTION MODE	TARGET SUBSTATION EFFICIENCY DURING RECOVERY MODE (E.G., IF INVERTERS ARE INSTALLED)
$0.5 \times I_n$	> 0.95	> 0.95
I_n	> 0.95	> 0.95
$1.5 \times I_n$	> 0.95	> 0.95
I_n: Rated DC output current of the substation rectifier(s).		

28. Building and Equipment Layout

The layout of electrical equipment must consider:

- The equipment that is to be mounted or located within the substation building.
- Specific details of each equipment item (that is, rating, physical dimensions, weight, exact location of incoming/outgoing cables).
- Grouping arrangement of equipment (i.e., similar, or related items should be grouped together and ordered in a logical sequence from input to output with a minimum number of crossovers).
- Sufficient clearances from equipment to building walls, fences and other equipment for installation, maintenance, inspection, and removal requirements.
- Maintenance of consumable equipment and fittings should avoid the use of ladders or lifting devices; and
- Operation of all switchgear from ground level without the need to work off platforms.

29. Documentation

29.1. Drawings

- The Contractor must prepare or obtain from manufacturers and suppliers, all drawings and information necessary for fabrication, assembly, installation and commissioning of all plant, equipment, and systems.
- The Contractor must be responsible for obtaining all drawings and information necessary to enable work to be coordinated with the work of others on the site.

- All drawings are to be prepared in SI metric units.
- The Contractor must maintain a complete set of contract drawings on site during the Contract for the sole purpose of recording information relevant to the production of 'as-built' drawings. The Contractor must progressively mark up those drawings to accurately show the size, location, brand and model number of all plant and equipment, conduit and cable runs, cable trays and troughing and any changes to the contract drawings.
- 'As-built' drawings must be provided by the Contractor at the end of the project within the timeframes and in the formats stipulated by the CSTR.
- The Contractor must be responsible for updating the drawings as necessary for work carried out while under Defects Liability and for ensuring that a copy is available at site from the date of commissioning of the converter station.

29.2. Operating and Maintenance Manuals

- Operating and maintenance manuals must contain instructions for operating and maintaining the installed systems and plant, and a complete set of 'as built' drawings. Manuals must comprise separate binders for instructions and 'as built' drawings.
- O&M manuals must be provided within timeframes and with modality stipulated in the CSTR.
- Operating and maintenance instructions must be prepared in an approved format and submitted as a single copy draft for review before final issue.
- The maintenance instructions, including test and check sheets, must be presented as a step-by-step procedure for each system.

30. Construction Requirements

30.1. Substation Building Specifications

- The building must be of masonry, concrete, or other fire-resistant materials.
- Entry must be via a ramp to allow heavy loads (tools and equipment) to be trolleyed in and out. Stairs are not permissible.
- A bitumen or concrete hard-stand area must be provided outside of the door(s).
- Fencing must be provided to isolate the building from the tram corridor and pedestrian areas. Personnel entry to the building must be possible without having to enter the tram corridor. Where the building is exposed to vehicular traffic, bollards must be provided.
- A tram stop's LV isolation transformer must not be installed inside the building.
- Where possible, the building should be positioned to provide ready access for maintenance personnel and parking for a maintenance vehicle(s) should be provided.
- Light colours must be selected internally to promote uniformity of lighting levels around the room in support of tasks involving the correct identification of colour coded wiring. Ceilings must be painted white.
- External walls should be painted in a light colour.
- The paint seal to internal ceilings and walls must be applied before mounting frames, equipment and surface fittings are installed, so that unpainted surfaces will not be exposed if equipment or fixtures are changed or moved in the future.
- For temperature control, security and fire rating purposes, the building must not have any windows or skylights and no wall or door vents.
- Walls and ceiling on the outside of the building must be fully insulated to minimise the solar heat load during warm weather.
- Floors must be covered in a sheet 'vinyl' material, installed to the manufacturer's instructions and the finished surface must be smooth and washable. A continuous skirting must be formed by coving the vinyl 100 mm (minimum) up the face of all vertical surfaces. Joints must be made by welding or epoxy jointing.
- Internal hold-down bolts or plates on the floor must be avoided.

- Lighting must comprise LED batten fittings with diffusers selected to provide even illumination around equipment racks and walls, and inside racks when the doors are opened.
- Ceiling mounted light fittings must be provided both behind and in front of equipment. Light fittings must not encroach upon the space above equipment.
- The lights must be automatically switched on by a movement detector targeted at the door and remain illuminated for a dwell time of 15 minutes after last movement was detected. A high-level (typically 2.1 m AFFL) parallel manual start switch must be provided inside the door to override the movement detector if necessary.
- Emergency lighting must be provided.
- The lighting level must meet the requirements of AS 3084 at equipment, on walls and at the front and rear of cabinets.
- The lighting level in access and circulation spaces within the room (such as the aisle providing access between the front and rear of equipment may be lower but must exceed 150 lux at the centre of the aisle.
- Two independent air conditioning units must be provided, and capacity must be based on cooling of the projected ultimate equipment load. The peak building thermal load (from sun exposure at high outdoor temperatures) based on the AIRAH code for Adelaide must be considered.
- The units selected must be suitable for continuous 24×7 operation with an expected service life of 5 years.
- The building's rooms must be fitted with a pressurization air supply, rated for continuous 24×7 operation. It must be fitted with an inlet louvre rated to IP54 (minimum) and filters rated as 'F7' to AS1324.1 in order to ensure protection against the entry of pantograph dust. At least 2% of the total air moved must be fresh air. A positive internal air pressure must be maintained at 10 Pascals.
- The outdoor units must be fitted with a vandal resistant steel guard fixed to the building or mounting concrete pad using anti-tamper fasteners and provided with a padlocking facility. Outdoor unit noise levels must comply with local authority requirements.
- The outdoor units must not be placed in the tram corridor (unless suitable "safe zone" fencing is provided).
- In the event of power failure, the units must automatically restart when power is restored.
- Notwithstanding AS 4755.1, the air conditioners must have any Demand Response Enabling Device (DRED) functionality disabled.
- Air conditioners must be fitted with alarms to report the following conditions:
  - Air conditioner switched off manually or power fail; and
  - Air conditioner fault.
- The two air conditioners must be controlled by a PLC or similar control system. This must provide staged control utilising both 'Fan' and 'Cool' modes and start-up sequencing so that both units are used at a similar rate. The system may also generate the alarms as per 27. above, a PLC fault must generate an Air Conditioner Fault alarm.
- Wall convenience general power outlets must be provided (a minimum of two circuits).
- The building's walls and doors must be of a construction capable of withstanding malicious vandal attack. Access must not be readily gained by removing panels or in-wall air conditioners. The door(s) must be of solid timber construction, steel clad with four heavy-duty hinges.
- The external door(s) must be fitted with weather and dust seals to prevent ingress of water or contaminants into the building. (However, some filtered ventilation near roof level must be provided if necessary to meet the minimum air change requirements of referenced battery accommodation standards and the 2% fresh air criterion of 22. above. The door(s) must have a self-closing mechanism and must

automatically lock from the outside but must still be able to be opened without the use of a key from the inside.

30.2. Quality and Workmanship

- All materials, equipment and systems must be new.
- The designer must implement Quality Control systems and procedures in accordance with the relevant AS/NZ/ISO 9000 Quality Management Systems Standard, to ensure all design, workmanship, equipment, and materials comply with the requirements of this Specification.
- The Designer must develop a comprehensive project specific quality assurance plan in accordance with recommendations provided in Standards Australia Quality Systems publications.

30.3. Noise

The Designer must comply with all requirements of the South Australian EPA.

30.4. Residents

The Project must notify residents of all work to occur during construction and potential impacts including, but not limited to:

- Noise level during construction.
- Impact on traffic flow
- Safety of commuters.
- Councils in the case of council trees or trees under environmental protection schemes; and
- Impact on any bushes/trees in the vicinity.

31. Testing and Commissioning

31.1. Checking and Inspection

- The Contractor must be responsible for the detailed checking of all work to ensure compliance with the requirements of the Specification and the detailed design carried out by the Contractor.
- The Contractor must prepare a testing schedule which will list all appropriate off site and on-site testing of equipment. The list must include but not be limited to:
  - Factory tests.
  - Functional, Control logic / function tests to ensure correct and safe operation.
  - Protection operation tests.
  - Supervisory operation tests.
  - Instrumentation, relays, and transducer calibration tests.
  - Insulation resistance of all power and control circuits.
  - Earth grid continuity tests.
  - High voltage tests; and
  - Primary and secondary injection tests for ac and dc protection equipment.

FAT plans to be supplied to the Department in advance, with proposed ‘ready’ dates for engineering to schedule personnel for hold point witnessing.

31.2. Testing and Commissioning

- The Contractor must carry out all tests as listed on the approved testing schedules.
- The Contractor must be responsible for making any arrangements with SAPN for inspection of the station and energisation of the station.
- Acceptance Test and Commissioning at site will involve:
  - Checking the operation of principal equipment such as AC and DC circuit breakers.
  - Injection testing of all protective relays. (Results to be supplied in raw test equipment format (e.g., CMC, CPC test plans for protection, CT, VT testing).
  - Mitigation of harmonic currents injected into the SAPN.
  - Load testing of the Converter Station.

- All test results must be recorded and supplied within one week of testing being completed.
- SAT plans to be supplied to DIT in advance, with proposed ‘ready’ dates for engineering to schedule personnel for commissioning witnessing.

31.3. Inspection of Works

- Prior to commencement of any site works, a site inspection involving the Designer and SAPTA must be held to gain familiarisation with the tramway environment, principles of the design and site-specific considerations.
- The project/main contractor is responsible for the totality of all works on site.
- During the performance of works, inspections must be carried out by SAPTA to ensure compliance with this standard and equipment specifications. Additional random safety inspections must also be carried out by SAPTA at its discretion.
- General inspections will be carried out by SAPTA prior to and after commissioning. SAPTA must also attend the commissioning. The Project must comply with hold points and must ensure reasonable notification for SAPTA representatives to attend.
- The Designer must maintain, on an ongoing basis, a set of marked up construction drawings on site. SAPTA must have access to these drawings to monitor the progress of the construction. Particularly at brownfield sites, the construction drawings must be adequate to enable emergency operation and reactive maintenance of any in service equipment while the construction is occurring. Construction plans are to be maintained on site and kept up to date on progress.

31.4. The Earth Grid

- The earth grid must be installed and tested and the earthing report and must be approved by SAPTA before the concrete base is laid.
- Further construction work must not proceed until SAPTA evaluates the earth grid test results, reviews the earthing report, and confirms that the results are satisfactory.

31.5. Training

- The Designer must train allocated Departmental and contractors’ representatives in all aspects of the new electrical installation. All operational, technical, safety and environmental aspects of the new installation must be covered during the training. The technical training must involve going through the as constructed drawings, operator instructions and a site visit.
- The Designer must run two training sessions on different days (per substation), to accommodate the availability of SAPTA representatives.
- Training must be completed before the substation is placed into service.
- Wherever possible, the equipment operation will be aligned to existing operating systems within SAPTA.

31.6. RAMS

Reliability, Availability, Maintainability and Supportability (RAMS) requirements please refer to *RW RAMS D1 – Reliability Availability Maintainability and Supportability and PC RW20.*

The Designer must comply with SAPTA’s Engineering Management System.

The substation must comply with the general requirements in Table 8.

Table 8: RAMS – General requirements

DESCRIPTION	REQUIREMENT
Operational availability[1], A_o	≥99.99%
Design life[2]	≥ 30 years

[1] Operational availability is the probability that an item will operate satisfactorily at a given point in time when used in an actual or realistic operating and support environment. It includes, but is not limited to:

- Undetected fault down time.
- Administrative down time.
- Logistics down time.
- Preventive maintenance down time; and
- Corrective maintenance down time.

Operational availability is a measure which extends the definition of availability to elements controlled by project managers, manufacturers, and logistics companies. Elements may include the quantity and proximity of spares, tools, and maintenance staff availability. In accordance with EN 61703, operational availability must be defined by the expression:

$A_o = MUT / (MUT + MDT)$

[2] The design life of electronic devices must be ≥ 15 years.

Information: Definition and detailed guidance on mathematical treatment of RAMS terms is given in EN 61703.

- Unless stated otherwise, the Designer must submit a RAMS Report which provides evidence of compliance. The report must at least include the following:
  - Consideration of how the operating conditions affect the RAMS of the substation.
  - Details of the maintenance regimes required to achieve the reliability requirements stated, and
  - Consideration of how electronic devices will be replaced at the end of their design life (e.g., 15 years) to ensure the design life of the substation (e.g., 30 years).
- The following substation specific definitions must apply:
  - For a dual rectifier substation, the substation is only considered to be in down time when both rectifiers are at fault.
  - The design must nominate and ensure maximum reliability for redundant systems. The design phase must consider the following reliability objectives:
    - MTBF higher than 12,000 hours for the substation.
    - MTBF higher than 50,000 hours for each cubicle/panel.
- The types of maintenance to support the substation are:
  - Preventive maintenance; and
  - Corrective maintenance.
- Preventive maintenance tasks must be detailed in the Operational and Maintenance Plan of the substation.
- The Designer must request information from SAPTA as necessary to calculate the substation operational availability. Information requests may include:

- MTR values for equipment.
- MAD values for maintenance; or
- Maintenance staff availability

31.7. Tools, Fault Diagnostic Equipment and Spare Parts

- The Designer must provide a recommended list of tools, fault diagnostic equipment and spare parts, which the Designer considers will be required to install and maintain the substation and its equipment.
- The Designer should use standard products (or products accepting standard stock lines) to allow for minimum spare parts to be carried into stock. Where superior performing products or equipment are available, they must be referred to SAPTA for prior approval.

32. Documentation Requirements

32.1. General

Unless stated otherwise, submitted documentation for the DC traction substation must at least comprise the items outlined in Table 9. This documentation must be provided for the substation throughout the procedure outlined in the Manage Design Procedure. Additional documentation requirements are defined in each equipment specification.

Table 9: Documentation

DOCUMENTATION	SYSTEMS DESIGN	PRELIMINARY DESIGN	DETAILED DESIGN	COMMISSIONING (PRIOR TO ENERGISATION)	PROJECT COMPLETION
Statement of compliance				✓	
Substation single-line diagram	✓		✓		✓
Substation equipment layout and schedule layout	✓		✓		✓
The detailed configuration of electrical equipment to be installed (e.g., number of rectifiers, transformers, circuit breakers, feeder panels, battery charger, etc.)	✓		✓		✓
Electrolysis mitigation requirements	✓		✓		✓
Full details of equipment selection and bill of materials			✓		✓
Main and auxiliary circuit diagrams	✓		✓		✓
Equipment interconnection design and drawings	✓		✓		✓

SCADA and communications system overview drawing	✓		✓		✓
SCADA equipment interconnection design and drawings	✓		✓		✓
SCADA points description excel sheet		✓	✓		✓
Equipment earthing and bonding connections, design, and drawings	✓		✓		✓
Negative, earthing and electrolysis busbars design and drawings	✓		✓		✓
Protection and control system design and drawings	✓		✓		✓
Interlocking system design and drawings	✓		✓		✓
Cable and wiring schedules		✓	✓		✓
Design reports			✓		✓
General report (including Equipment rating calculations, technical specifications for the substation and each individual item of equipment)		✓	✓		✓
Protection report (including fault calculations, protection coordination)			✓		✓
Noise report					✓
EMC report					✓
Earthing report			✓		✓
RAMS report			✓		✓

Table 10: Testing and Commissioning

DOCUMENTATION	SYSTEMS DESIGN	PRELIMINARY DESIGN	DETAILED DESIGN	COMMISSIONING (PRIOR TO ENERGISATION)	PROJECT COMPLETION
Test and commissioning plans			✓	✓	✓
Application for approval to place electrical installation into service				✓	✓
Certificate of electrical safety				✓	✓
Installation, operation, and maintenance manual(s)			✓		✓
Operation manual(s)			✓		✓
Maintenance manual(s)			✓		✓
Technical maintenance plan			✓		✓
Calibration certificates (type test certificates, NATA certification of metering equipment, factory, and commissioning test overcurrent calibration charts for the full range of all settings for each DC circuit breaker supplied);					✓

- The Designer must be solely responsible for the creation, supply and certification of all new drawings and modifications to existing drawings where necessary.
- All drawings must be technically and functionally corrected, accurately reflecting the installed equipment and associated circuits.
- Documentation of the design of equipment, assemblies or installations must be supplied to SAPTA at each design step for review and approval, as part of the gate process. The main purpose of the review and approval gate processes is to determine that the design is compliant with the technical standards and specifications.

32.2. Installation, Operation and Maintenance Manuals

The Designer must provide installation, operation, and maintenance manuals for all substation equipment. The manuals must at least include a description of all the servicing activities, the overhaul instructions, adjustments procedures, changing components for repairs, fault finding procedures, any software programs (where a PLC/IED is utilised), a complete set of as-built drawings and a comprehensible spare parts list for the electrical equipment.

32.3. Technical Maintenance Plan

The Designer must be solely responsible for the creation, supply, and certification of the technical maintenance plan for a new substation and the modifications to existing substation technical maintenance plans where necessary (e.g., replacing a single piece of equipment in a substation). The technical maintenance plan must at least include:

- A summarised maintenance policy for the equipment.
- Summarised preventive maintenance schedules for the equipment; and
- Summarised corrective maintenance instructions for the most commonly replaced parts of the supplied equipment.

Information: The technical maintenance plan is a useful summary document of relevant parts of the equipment installation, operation and maintenance manuals for all equipment supplied.

32.4. As-built documentation

Once the substation has been built and commissioned, it is the responsibility of the Designer to produce as-built documentation, which includes mark-ups and any minor design changes due to unforeseen site constraints. Mark-ups and/or minor design changes must be approved by SAPTA.

32.5. Documentation Requirements and Formatting

- Reports and other non-CAD documentation must be submitted in .pdf and .docx formats.
- All documentation must be provided in English.
- Technical drawings must comply with AS 1100 series.

33. Spares and Special Tools

- The Contractor must supply special tools that are necessary for normal maintenance and operation of the station. This must include any programming tools that are necessary for operation and maintenance of micro-computers or programmable controllers.
- The Contractor must nominate any spares that are considered necessary for the ongoing maintenance of the equipment supplied under this contract. The Contractor must also identify:
  - Which spares are critical, and which are for routine maintenance.
  - Where the spares are available to be purchased.
  - Cost.
  - Availability.
  - Delivery lead time

34. Training

- The Contractor must develop training materials for use by the principal for two separate training courses. The training must include:
  - Course 1: Short course covering daily operations including switching, alarms, inspections, basic faults, available documentation, emergencies for general operations and maintenance staff.
  - Course 2: Detailed routine and preventative maintenance and operations, fault finding, replacement of key components aimed at trade qualified maintenance staff.
- Each person trained must be provided with a full and comprehensive manual covering the details of the training course as appropriate to the course content.
- In addition, the Contractor to provide course training materials suitable for on-going staff training.
  - The Rail Regulator requires where possible training in accordance with Australian Skills Quality Authority (ASQA).
  - Where not possible it should be competency-based training.
- Depending on the product or subject, there may be a requirement for the training to be conducted in accordance with an Australian Standard, Technical Regulation, WHS Legislation or Licensing arrangements.

35. Innovation

Innovative solutions and energy efficiency solutions should be highly considered. Examples of innovative solutions are:

- Integration of solar and battery storage to substation auxiliary power system:
- Integrated transformer rectifier (rectifier transformer and rectifier converter combined into a single unit).
- Controlled rectifier(s).
- Wayside energy storage system(s).
- Inverter(s) connected in parallel with the rectifier(s).
- 4-quadrant rectifier(s) entirely controlled.

If such solutions are used, they must be compliant with the relevant reference documents listed above. These solutions must be proven in-service, rather than untried principles or equipment.

36. Eco-Friendly Design

Due to the environmental stakes at a worldwide level, and to promote SAPTA's environmental engagement, it is desirable that each new substation be labelled ISO 14025. The output of this label is an Environmental Product Declaration (EPD). To reach this objective, the following criteria must be considered when designing equipment:

- Use of low-impact materials (non-toxic, sustainably produced, or recycled materials that require little energy to process).
- Ban of hazardous substances such as Lead, Mercury, Asbestos, PCB, Cadmium and SF6.
- Energy efficiency.
- Quality and durability.
- Reuse and recycling.
- Total carbon footprint; and
- Renewability.

A Life-Cycle Assessment (LCA) of the whole substation should be performed. The purpose of an LCA is to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. The procedures for LCA are detailed in ISO 14040 and ISO 14044 standards.