TS 00103.1:1.0

Standard

25 kV AC Traction System

Part 1: Traction Power System

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Document history

Revision	Effective date	Summary of changes
1.0	10/04/2024	First issue as TS 00103.1

Preface

This Standard is the first issue as TS 00103.1:1.0 *25 kV AC Traction System – Part 1: Traction Power System*.

This document sets out requirements for 25 kV ac traction power systems, which apply to new classic installations as well as any upgrades or modifications to those systems.

This document forms part of the TS 00103 series of standards related to 25 kV ac traction systems. The series has been developed to establish a common approach for the development and installation of 25 kV ac traction power systems in NSW.

This document should be read in conjunction with TS 00103.2 and TS 00103.3.

Table of contents

1 Scope

This standard sets out design, functional and performance requirements for 25 kV ac traction power systems on TfNSW rail networks on a whole-of-system design basis.

This document also includes requirements on the functional interfaces with the NSP and the rolling stock.

This document excludes specific requirements associated with the following:

- bulk supply transformers at NSP substations
- TNSP or DNSP power systems, except where such matters are associated with the interface between the NSP and railway (for example, insulation coordination)
- non-traction power supplies
- DC traction power systems
- trackside installations
- train onboard 25 kV ac equipment
- telecoms and traction SCADA integration with human machine interface.

2 Application

This document applies to all new 25 kV ac classic feeding system installations and any upgrades or modifications to these systems. The requirements specified in this document do not apply beyond the point of supply connection to the NSP's network, other than for coordination purposes.

The specific subsystems to which the document applies or has a major interface with are shown in Figure 1.

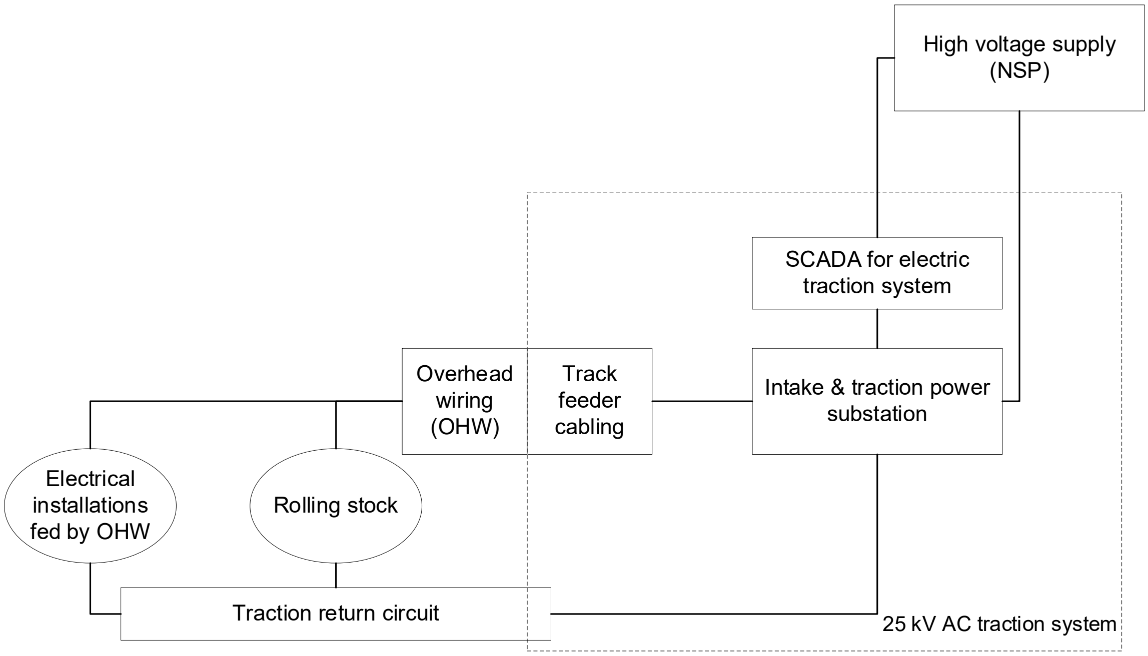

Figure 1 – Traction power system and associated interfaces

This document should be read in conjunction with TS 00103.2 and TS 00103.3.

3 Referenced documents

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

International standards

EN 15663:2017+A1:2018 *Railway applications – Vehicle reference masses*

EN 50121-1 *Railway applications – Electromagnetic compatibility – Part 1: General*

EN 50121-1:2017 *Railway applications – Electromagnetic compatibility – Part 1: General*

EN 50121-2 *Railway applications – Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world*

EN 50121-3-1 *Railway applications – Electromagnetic compatibility – Part 3-1: Rolling stock – Train and complete vehicle*

EN 50121-5 *Railway applications – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus*

EN 50122-1:2022 Version 3 *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*

EN 50124-1 *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

EN 50633:2016 *Railway applications – Fixed installations – Protection principles for AC and DC electric traction systems*

EN 50641:2020 *Railway applications – Fixed installations – Requirements for the validation of simulation tools used for the design of electric traction power supply systems*

IEC 60071-1:2019 *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 61850 (all parts) *Communication networks and systems for power utility automation*

IEC 62497-1 *Railway applications – Insulation coordination – Part 1 – Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

I.S. EN 50152-1 *Railway applications – Fixed installations – Particular requirements for alternating current switchgear – Part 1: Circuit-breakers with nominal voltage above 1 kV*

I.S. EN 50152-2:2012 *Railway applications – Fixed installations – Particular requirements for alternating current switchgear – Part 2: Disconnectors, earthing switches and switches with nominal voltage above 1 kV*

I.S. EN 50163:2004+A3:2022 *Railway applications – Supply voltages of traction systems*

I.S. EN 50388-1:2022 *Railway applications – Fixed installations and rolling stock – Technical criteria for the coordination between electric traction power supply systems and rolling stock to achieve interoperability – Part 1: General*

ISO 31000 *Risk Management – Principles and Guidelines*

PAS 2080: 2023 *Carbon management in buildings and infrastructure*

Australian standards

AS 1768 *Lightning protection*

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

AS 2067:2016 *Substations and high voltage installations exceeding 1 kV a.c.*

AS 2344 *Limits of electromagnetic interference from overhead a.c. powerlines and high voltage equipment installations in the frequency range 0.15 MHz to 3000 MHz*

AS 3996 *Access covers and grates*

AS 5577 *Electricity network safety management systems*

AS/NZS 60076.1 *Power transformers*

AS 60529 *Degrees of protection provided by enclosures (IP Code)*

AS 61000 (series) *Electromagnetic compatibility (EMC)*

AS 62271.1:2019 *High-voltage switchgear and controlgear, Part 1: Common specifications for alternating current switchgear and controlgear (IEC 62271-1:2017, MOD)*

AS 62271.200 *High-voltage switchgear and controlgear, Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV (IEC 62271-200:2011/COR1:2015, MOD)*

AS 62271.202 *High-voltage switchgear and controlgear, Part 202: High-voltage/low-voltage prefabricated substation (IEC 62271-202:2014, MOD)*

AS/NZS 1170.2:2021 *Structural design action, Part 2: Wind actions*

AS/NZS 3000 *Electrical installations (known as the Australian/New Zealand Wiring Rules)*

AS/RISSB 7722 *EMC Management*

AS/RISSB 7770 *Rail Cyber Security*

TR IEC 61000.3.6 *Electromagnetic compatibility (EMC), Part 3.6: Limits–Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

Transport for NSW standards

TS 00006 (ETN 11/02) *HV Earthing Design*

TS 00008 (all parts) *Fire Life Safety*

TS 00031.1 *OT10 Threat-Based Cyber Security Controls – Part 1: Controls and Implementation Requirements*

TS 00103.2 *25 kV AC Traction System – Part 2: Earthing and Bonding*

TS 00103.3 *25 kV AC Traction System – Part 3: Overhead Wiring System*

TS 00161 *Requirements for Software Tools used for Engineering Simulation and Modelling*

TS 01471 (T MU AM 06006 ST) *Systems Engineering*

TS 01506 (T MU AM 01003 ST) *Development of Technical Maintenance Plans*

TS 01517 (T MU AM 01002 MA) *Maintenance Requirements Analysis Manual*

TS 01722 (ESC 340) *Tunnels*

TS 02388 (T HR CI 12160 ST) *Boundary Fences*

TS 03736 (T HR EL 19002 ST) *Protection System Requirements for the High Voltage Network*

TS 03744 (EP 00 00 0013 SP) *Electrical Power Equipment – Design Ranges of Ambient Conditions*

TS 03754 (T HR EL 20007 ST) *Cable Pits*

TS 03866 (T HR EL 11002 SP) *Electrical SCADA System Remote Terminal Unit*

TS 03866:2023 (T HR EL 11002 SP) *Electrical SCADA System Remote Terminal Unit*

TS 03881 (T HR EL 99001 ST) *Substation and Sectioning Hut Commissioning Tests and Processes*

TS 03882 (T HR EL 99002 ST) *Substation Minimum Construction Standard*

TS 03882:2018 (T HR EL 99002 ST) *Substation Minimum Construction Standard*

TS 03883 (T HR EL 99004 ST) *Substation Fencing*

TS 04935 (T HR SS 80001 ST) *Infrastructure Lighting*

TS 04978 (T MU HF 00001 ST) *Human Factors Integration – General Requirements*

TS 04981 (T MU MD 20001 ST) *System Safety Standard for New or Altered Assets*

TS 04982 (T MU MD 20002 ST) *Risk criteria for Use by Organisations Providing Engineering Services*

TS 04989 (T MU SY 10001 ST) *Public Transport Closed Circuit Television Functional Requirements Standard*

TS 04990 (T MU SY 10010 ST) *Cybersecurity for IACS – Overview*

TS 04991 (T MU SY 10012 ST) *Cybersecurity for IACS – Baseline Technical Cybersecurity System Requirements and Countermeasures*

TS 04992 (T MU SY 20001 ST) *Surface Transport Fixed Infrastructure Physical Security Standard* (This document is not publicly available. To obtain access email standards@transport.nsw.gov.au)

TS 04992 (T MU SY 20001 ST) Version 1.0 *Surface Transport Fixed Infrastructure Physical Security Standard* (This document is not publicly available. To obtain access email standards@transport.nsw.gov.au)

TS 04993 (T MU SY 10013 PR) *Cybersecurity for IACS – Cyber Risk Management Procedure*

TS 06305 (T MU SY 10014 GU) *Application Guide to NSW Cyber Security Policy for Operational Technology*

Legislation

Protection of the Environment Operations Act 1997 (NSW)

Waste Avoidance and Resource Recovery Act 2001 (NSW)

Other referenced documents

ENA DOC 015-2022 *National Guidelines for Protective Security of Electricity Networks*

ENA DOC 18-2015 *Guideline for the Fire Protection of Electricity Substations*

Reliability Panel of Australian Energy Market Commission, October 2023, *Frequency Operating Standard*

NSW Customer Service, 2022, *NSW Cyber Security Policy*

NSW EPA, 2014, *Waste Classification Guidelines – Part 1: Classifying waste*

NSW Rural Fire Service, 2019, *Planning for Bush Fire Protection – A guide for councils, planners, fire authorities and developers*

Transport for NSW, 2023, *Net Zero and Climate Change Policy*

The Australian Building Codes Board, *National Construction Code, volumes 1 and 2*

The Australian Energy Market Commission, *National Electricity Rules*

CISC, *General Guidance for Critical Infrastructure Assets Factsheet*

4 Terms, definitions and abbreviations

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

1ph single phase

25 kV ac classic feeding system railway electrical distribution network used to provide energy for rolling stock at 25 kV ac nominal voltage level without using booster transformers or auto-transformers

3ph three phase

ac alternating current

ACMA Australian Communications and Media Authority

A-FLR all sided, front, lateral, rear

AMB Asset Management Branch

asset custodian TfNSW division accountable for the end-to-end life cycle management and performance of assets (including asset condition, risk and reporting) on behalf of the asset owner to achieve agreed customer and community outcomes

asset steward – delivery entity responsible for:

- procuring assets from investment decision to commissioning
- delivering the benefits
- translating requirements from the client and managing delivery outcomes
- selecting the most appropriate supplier/s to meet project objectives

asset steward – **operate or maintain** entity responsible for the day-to-day operations and maintenance of assets once commissioned. May be a part of the asset custodian division or a separate entity. Operator and maintainer of the assets might be separate entities

DNSP distribution network service provider

EMC electromagnetic compatibility

EPA Environment Protection Authority

FED fixed earthing device

HV high voltage; voltage exceeding 1000 V ac or 1500 V dc

ICT information and communication technology

IED intelligent electronic device

ITPS intake and traction power substation

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

NCC *National Construction Code, volumes 1 and 2*

NER *National Electricity Rules*

network operator the entity authorised to operate an electricity network as per AS 5577

NPS negative phase sequence

NSP network service provider(includes both transmission network provider or distributed network provider)

N system operation normal feeding state of the traction power system

N-1 contingency system operation outage (planned or unplanned) of one system element out of two or more system elements such that the system element, under outage, is no longer a functioning part of the railway

N-2 contingency system operation outage (planned or unplanned) of two similar system elements out of three or more system elements such that the system elements, under outage, are no longer functioning parts of the railway

overhead contact line zone zone whose limits are in general not exceeded by a broken overhead contact line

OHW overhead wire

ODF optical distribution frame

PCS power control system

RMS root mean square

RTU remote terminal unit

SCADA supervisory control and data acquisition; networked system of master stations, remote terminal units, IEDs, network switches and the like used to control and monitor remote power assets (for example, switchgear, transformers, SFCs)

SF_6 sulphur hexafluoride

SFC static frequency converter

substation a place (including substations, traction substations, transformer rooms, switch rooms, sectioning huts, pole-mounted or pad-mounted transformers) containing high-voltage electrical equipment

synchronous connection connection to public electricity network (for example, to the NSP directly or by means of a conventional transformer)

TCP/IP transmission control protocol / internet protocol

TSC track sectioning cabin

TfNSW Transport for New South Wales

TNSP transmission network service provider

5 General requirements

5.1 System safety and systems engineering approach

The safe and efficient operation of the 25 kV ac traction power system involves applying the principles and concepts of a system safety and systems engineering approach.

the 25 kV ac traction power system is a highly complex system that functions due to the systematic integration of many different parameters. Consequently, HV traction power supply systems for 25 kV ac rolling stock shall apply a systems engineering approach to all parts of the project lifecycle.

The approach in the following system safety and systems engineering standards shall be applied:

- TS 01471
- TS 04981.

5.2 Safety

The design of the 25 kV ac traction power system shall take into account the safety of construction and maintenance personnel, operations personnel, and general public (in publicly accessible areas) who may directly or indirectly interact with the traction power system.

5.3 Human factors

The design of the 25 kV ac traction power system shall incorporate a human factors integration process, in accordance with TS 04978.

All design reports shall describe how human factors are considered for each stage of the project life cycle.

5.4 Maintainability

The design of the 25 kV ac traction power system shall account for the ability to access components for inspection, maintenance purposes and end of life cycle replacement. Safety and availability requirements should be considered if planning to undertake inspection and maintenance works during operation.

The asset steward delivery shall ensure that training is provided to the asset steward operate or maintain.

Components, materials and finishes shall be chosen to minimise future maintenance, taking into account the design life and the whole-of-life costs.

Maintenance requirements shall be specified for the traction power system in accordance with TS 01517. Requirements shall include the following:

- examination tasks and frequencies
- work involved
- special tools
- repair standards.

The maintenance requirements shall be supported by documentation demonstrating the basis for these requirements.

Traction power equipment shall be maintained in accordance with manufacturers' recommendations and the applicable standards, including TS 01506. The traction power system shall be designed to take account of RAMS targets inclusive of spares analysis conducted in consultation with the asset steward – delivery and asset steward – operate or maintain.

All HV and traction power system equipment shall be accessible for maintenance in a safe manner with minimal impact to the operation of the electrical network.

5.5 Equipment procurement

All HV equipment procured in accordance with this document shall be endorsed by the asset steward – delivery before being procured.

5.6 Resilience

The design of the 25 kV ac traction power system shall account for resilience throughout the asset lifecycle, in compliance to TS 04982.

The TAO shall take into account, in consultation with the asset steward – delivery and asset steward – operate or maintain, the following components as a minimum to ensure system resilience:

- climate change
- cost to recover
- time duration of recovery
- performance before and after – full recovery of the 25 kV ac traction power system after an event or degraded operation
- maximum brownout period
- maximum outage period
- ratio of performance recovery to loss – recovery time/down time

- time duration of failure
- resource resiliency – degradation of capability that occurs after successive contributing assets are lost.

6 25 kV AC traction power system design

6.1 Traction feeding system

The traction power feeding system shall be a 25 kV ac classic feeding system, supplied via SFCs. A typical feeding arrangement is shown in Figure 2.

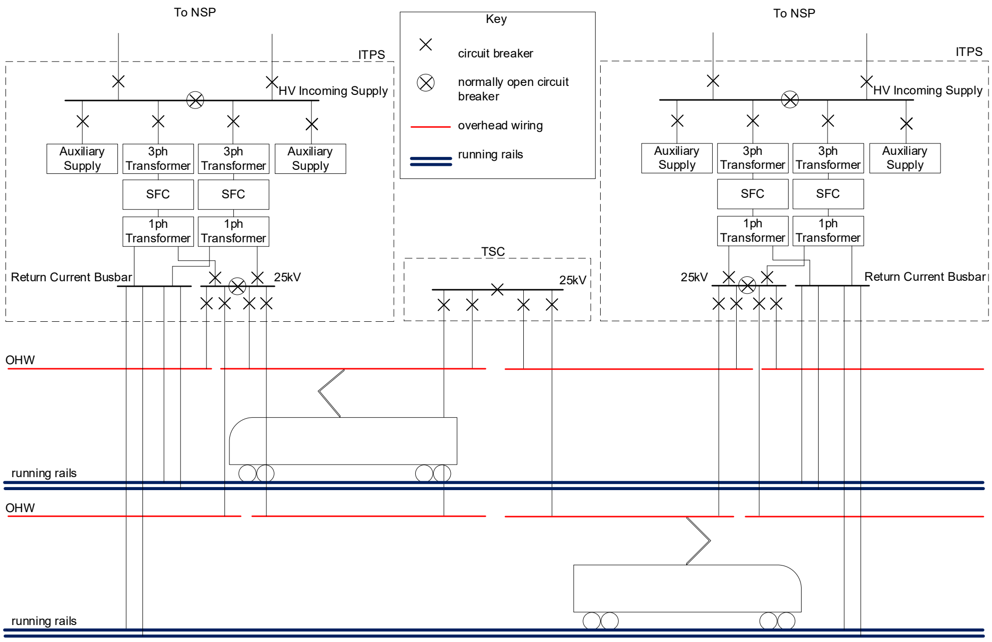

Figure 2 – 25kV ac classic feeding system supplied via SFCs

6.2 Traction return system

The traction current return to the source shall be based on a 25 kV ac classic feeding system. Refer to TS 00103.2 for detailed information on earthing and bonding.

6.3 Traction voltage

The characteristics of the main voltage systems (for over voltages, see Section 6.10 in this document) are specified in Table 1. The voltage limits shall apply to the potential measured between the train's pantograph and the return circuit.

Table 1 – Nominal voltages and their permissible limits in values and duration

Electrification system	Lowest non-permanent voltage U_{min2} V	Lowest permanent voltage U_{min1} V	Nominal voltage U_n V	Highest permanent voltage U_{max1} V	Highest non-permanent voltage U_{max2} V	Highest momentary voltage U_{max3} V
AC (r.m.s values)	17,500	19,000	25,000	27,500	29,000	38,750

(Source: I.S. EN 50163:2004+A3:2022, Table 1. Reproduced and modified with permission.)

The following requirements shall be fulfilled:

- the duration of voltages between U_{min1} and U_{min2} shall not exceed 2 minutes
- the duration of voltages between U_{max1} and U_{max2} shall not exceed 5 minutes
- the duration of voltages between U_{max2} and U_{max3} shall not exceed 1 second
- the duration of voltage U_{max3} shall not exceed 20 ms
- the voltage of the busbar at the substation at no load conditions shall be less than or equal to U_{max1}
- under normal operating conditions, voltages shall lie within the range $U_{min1} \leq U \leq U_{max2}$
- under abnormal operating conditions, the voltages in the range $U_{min2} \leq U \leq U_{min1}$ given in Table 1 shall not cause any damages or failures
- if voltages between U_{max1} and U_{max2} are reached, it shall be followed by a level below or equal to U_{max1}
- voltages between U_{max1} and U_{max2} shall only be reached for non-permanent conditions such as:
    - regenerative braking
    - movement of voltage regulation systems such as mechanical tap changer
    - switching in the network
- lowest operational voltage: under abnormal operating conditions U_{min2} is the lowest limit of the OHW voltage for which the rolling stock is intended to operate.

(Source: I.S. EN 50163:2004+A3:2022, Section 4.1. Reproduced and modified with permission.)

In addition to the characteristics specified in Table 1, the no-load voltage of the SFCs may be set above the nominal voltage, typically 26.5 kV. This is to enable the system to perform more favourably during N-1 and N-2 contingency conditions.

6.4 System frequency

For systems with synchronous connection to an interconnected system or traction power frequency derived from an NSP output, the Reliability Panel's *Frequency Operating Standard* shall be followed.

The frequency range for traction systems fed by SFCs in frequency elastic control mode (that is, with the SFC control system determining the frequency of the SFC output) shall be 50 Hz ± 1%.

6.5 Mean useful voltage

The requirements of Annex B of I.S. EN 50388-1:2022 shall apply for the calculation of mean useful voltages.

6.6 Continuous current

The maximum continuous current rating of equipment shall be determined by the system design process (that is, by modelling and calculation and verified by cross-checking with standard equipment ratings under the ambient conditions described in Section 8.3.3). The continuous current at any location in the network shall be within the continuous current rating of the associated equipment.

6.7 Fault current

6.7.1 Short circuit current maximum and minimum values

The maximum value for short circuit faults between the OHW (including other 25 kV ac conductors) and infrastructure or vehicles connected to the traction return rail, and falling within the overhead contact line zone, shall be 6 kA for traction supplies derived from SFCs.

The minimum value of short circuit current resulting from a fault between the OHW (including other 25 kV ac conductors) and infrastructure or vehicles connected to the traction return rail, and falling within the contact line zone, shall be provided and defined to enable faults to be cleared by the traction protection system.

6.7.2 Short circuit current duration

For the maximum short circuit fault currents, immediate tripping of the relevant circuit breaker shall be provided without intentional delay from the protective scheme.

The main protection shall operate within a maximum of 120 ms.

If the main protection does not act, the secondary (backup) protection should operate within a maximum of 500 ms. However, the backup protection time grading shall be aimed to minimise the fault clearance time. The protection settings shall be agreed between the TAO designer and both the asset steward – delivery and asset steward – operate or maintain.

Note: Some protection schemes, including standby earth fault and circuit breaker fail, may take longer to operate than 500 ms due to these protection schemes being designed to provide a ‘last line of defence’ to the network.

6.7.3 SFC fault current limitation

To ensure correct operation of downstream 1ph 25 kV ac traction protection systems (outside of the SFCs), all SFC 1ph converters shall behave as follows under 25 kV ac OHW fault conditions:

- The fault current angle is not controlled by the SFCs and shall be dictated by the impedance of the downstream fault or load.
- Each SFC shall maintain the pre-fault phase angle on the 1ph 25 kV ac side to within a tolerance of ± 20°.
- Where the current delivered during the fault is limited by an SFC, the current limit shall be greater than or equal to the peak apparent power rating of the SFC divided by 25 kV.
- Each SFC shall sustain both its voltage angle and current limit for a minimum of 2 seconds.
- Each SFC shall provide a signal to the protection systems in the downstream 25 kV ac feeder station to indicate that the SFC is limiting the fault current.

Note: Each SFC may alter the magnitude on the (nominally) 1ph 25kV ac side.

Each SFC supplier shall describe the behaviour of its 1ph converters under fault conditions as a key input into the development of the design and safety case for the downstream 25 kV ac traction protection systems.

6.8 Design life

Unless otherwise specified by the asset steward – delivery, the minimum design life of traction power system equipment shall be in accordance with Table 2.

Table 2 – Design life of traction power system equipment

TPS equipment	Design life (years)
HV switchgear and HV electrical subsystems	30
25 kV ac switchgear	30
LV switchgear, lighting fixtures and electrical systems	30
SFC	40

TPS equipment	Design life (years)
SFC subsystem equipment	40
Transformers	30
HV cables	30
Battery and battery charger	15
Earthing, bonding and electrolysis protection systems (accessible)	30
Earthing, bonding and electrolysis protection systems (inaccessible)	120
Fire protection, mechanical and electrical control systems (inaccessible)	50
Substation building (including track sectioning cabins)	120
Prefabricated (or modular) traction substation (including track sectioning cabins)	30 (subject to agreement with asset steward delivery)

Note: The design life of consumables and subsystem equipment requiring periodic replacements are not included in the table.

The system designer and manufacturer shall provide details of:

- maintenance activities necessary to achieve this design life
- all components of the system that will require replacement during this design life.

6.9 EMI mitigation measures

The equipment (including LV components) shall be designed and manufactured to meet electromagnetic compliance and installed to meet electromagnetic compatibility. For further details about electromagnetic compatibility and compliance requirements, see Section 13 and Section 22.

6.10 Insulation coordination

The requirements of EN 50124-1 shall apply for insulation coordination. The rated lightning and short duration power frequency withstand values in Table 3 are based on Table 1 of I.S EN 50152-2:2012. The over voltage category 4 shall be applied when equipment and cables are connected directly to the overhead wiring system and can be endangered by lightning or switching over voltages.

Table 3 – Rated voltages for equipment connected to 25 kV ac traction systems

Nominal voltage U_N kV (RMS value)	Rated maximum voltage U_{Ne} kV (RMS value)	Rated short-duration power-frequency withstand voltage U_d kV (RMS value)		Rated lightning impulse withstand voltage U_{Ni} kV (peak value)		Over voltage category[1]	Pollution degree (fixed installations)[1]	
		Common value	Across the isolating distance	Common value	Across the isolating distance		Non-trackside locations	Trackside locations
25	27.5	70	95	170	200	3	PD4	PD4A
		95	110	200	220	4		

Note 1: Refer to EN 50124-1.

6.11 System stability (abnormal conditions)

So far as is reasonably practicable, the stability of the power distribution system and the power supply to the trains shall be maintained. If there is a fault condition or loss of equipment on the NSP's network, or 3ph part of the traction power distribution network, or 1ph 25 kV ac part of the traction power distribution network, this shall not cascade to and destabilise either of the other two networks.

Note: 'Reasonably practicable' in this context refers to that which is reasonably able to be done to ensure safety, taking into account and weighing up all relevant matters.

6.12 Earthing and bonding

For requirements regarding traction substation and trackside earthing and bonding design, refer to TS 00103.2.

7 Electrical protection

7.1 Description of protection system

A protection system applied to an electric traction system is formed from a combination of devices and equipment that each fulfil a required protection function. The protection system shall comprise of:

- protection devices (IEDs)
- different sensing devices (for example, instrument transformers, temperature sensors, position indicators)
- dedicated communication for protection
- auxiliary supplies.

7.2 Interface with 3ph network

The requirements stipulated in the customer connection agreement with the relevant NSP shall apply for interfacing with the incomer 3ph network.

The interface between the electric traction system and the transmission and distribution systems is generally the bulk supply point feeder (the HV feeder originating from the NSP) circuit breaker at the ITPS. The upstream installation that covers the upstream bulk supply point should be as agreed between the asset steward – delivery, TAO designer and the NSP. The HV connection agreement with the NSP typically covers the following areas:

- protection settings
- communication
- automatic reclosure
- direction of power flow (consumption and regeneration)
- power quality
- HV installation safety management plan.

7.3 Interface with rolling stock

The operational parameters of the protection on the rolling stock are not within the scope of this document.

The requirements in Clause 4.2.2 of EN 50633:2016 shall apply for interfacing with rolling stock. In accordance with those requirements, the traction unit main circuit breaker shall be the interface between the electric rolling stock and the electric traction system (that is, the OHW as part of the traction system).

When internal faults occur downstream of the interface, they shall be cleared by the protection on the rolling stock. They also shall not affect the operation of the traction power system. However, the traction power protection system shall have the ability to provide some degree of remote backup protection against faults downstream of the interface.

7.4 Protection system requirements

7.4.1 Protection reliability

The protection system shall meet reliability, availability and maintainability targets specified by the asset steward – delivery. Identical relays shall not be used for primary and backup protection schemes to avoid common mode failure events.

7.4.2 General protection requirements

The general protection philosophy shall be in accordance with TS 03736.

7.4.3 LV auxiliary supply and control

For details on the following, refer to the relevant sections of TS 03736:

- trip coil requirements
- trip circuit supervision requirements
- auxiliary supply arrangements
- test block wiring requirements and labelling requirements
- IED (protection relay) alarm requirements.

7.5 Lightning protection

The assessment and management of risk due to lightning shall be in accordance with AS 1768.

Lightning protection shall comply with the requirements of TS 00103.2.

8 Computer modelling of 25 kV AC traction systems

8.1 General requirements

A 25 kV ac railway computer model shall be built and maintained throughout a project lifecycle. The model shall be submitted to the asset steward – operate or maintain and asset steward – delivery and updated and verified at the following project stages (as a minimum):

- feasibility design
- detailed design
- approved for construction design
- as-built validation.

8.2 System loads and 3ph network supply point demand

The 25 kV ac railway computer model shall be used to verify that the maximum half-hour demand is at or below the continuous rating for each 3ph network supply point. The N, N-1 and N-2 conditions shall be taken into account during such verification. The 3ph network supply points shall also provide spare capacity for future demand in train service. A percentage spare capacity shall be agreed by the system designer, asset steward – delivery and NSP.

8.3 System data model

8.3.1 Infrastructure data model

8.3.1.1 Route topographical data

Route topographical data shall be loaded as input data into the computer. The data shall comprise locations of junction layouts and locations, locations of stations, and the number of tracks. The location data and route lengths shall be checked by the system designer using the applicable documentation for conducting the required checks and calculations.

8.3.1.2 Gradient data

Gradient data about the area under study shall be obtained from relevant diagrams and databases and inputted into the 25 kV ac railway computer model.

8.3.1.3 Horizontal alignment data

Horizontal alignment data about the area under study shall be obtained from relevant diagrams and databases and inputted into the 25 kV ac railway computer model.

8.3.1.4 Line speed data

Line speed data shall be obtained for the routes being considered. The line speed data shall be used as input data for the 25 kV ac railway computer model.

8.3.1.5 Signalling data

The stopping pattern of trains at stations and operational stopping locations shall inform the model of the signalling data. The signalling data shall be loaded as an input into the 25 kV ac railway computer model. In the initial stages of a project, headways shall be used. As signalling data becomes available, the model shall incorporate this data.

8.3.1.6 Electrical data

8.3.1.6.1 Electrical data model characteristics

For each route, the electrification system characteristics shall be loaded into the 25 kV ac railway model as input data. The assessment of feeder and return cable size, overhead cable types and size, the use and configuration of single or double rail traction return shall be included as part of the electrical characteristics. Generic assumptions shall be made when specific data are not available. The worst-case scenario shall be used for the basis of the generic assumptions without adversely affecting the accuracy of the modelling.

8.3.1.6.2 3ph network supply point data

The 3ph network supply point data shall be confirmed by the system designer with the NSP. The 3ph network supply point data shall include the nominal voltage and spare capacity as a minimum. The 3ph network supply point data shall be used as an input into the computer model.

8.3.1.6.3 3ph network supply point transformers

The 3ph network supply transformers that have been assumed shall be identified with the following associated characteristics as a minimum:

- thermal rating (continuous rating, duty cycle rating and overload rating)
- impedance data
- primary and secondary nominal voltage.

The transformer characteristics shall be in accordance with AS/NZS 60076.1. The transformer characteristics shall be loaded into the model as input data.

8.3.1.6.4 System voltage

The system designer shall identify the fixed no-load voltage used for the 25 kV ac railway computer model. The 1ph 25 kV ac SFC output no-load voltage for incoming connections at 132 kV, 66 kV and 33 kV for use in simulations should fall within the range of 25 kV and 26.5 kV. Chapter 5 of the NER sets out data for determining the 3ph network supply point voltage variations for each network supply point nominal voltage level. The traction system voltage limits shall follow the requirements in Section 6.3 of this document.

8.3.1.6.5 Soil resistivity

In the early stages of a project (i.e. feasibility design) typical soil resistivity data can be used. Once soil resistivity studies have been undertaken, the data from these studies shall be incorporated as input data for the 25 kV ac railway model. The methodology and further requirements on soil resistivity from TS 00103.2 and TS 00006 shall be followed.

8.3.2 Train service data model

8.3.2.1 Service pattern

The service patterns and frequencies of all trains shall be loaded into the 25 kV ac railway model as input data. The system designer shall size and design the traction energy system on the agreed parameters which include as minimum:

- volume of electric traffic – including mixing of different rolling stock types
- headway or timetable
- line speed and signalling requirements
- perturbation recovery
- future load growth and spare capacity
- dwell times
- end to end and point to point run times
- operating modes for strategic sidings.

8.3.2.2 Rolling stock characteristics

The mass (with passengers) and speed of each vehicle under study shall be used as input data for the 25 kV ac railway computer simulation. The tractive effort, braking effort, mass of the traction unit vehicles and vehicle speed shall be determined in accordance with data from the rolling stock manufacturer. If the mass data are not available, the mass of vehicles and passengers may be determined by referring to Tables 7 to 9 in EN 15663:2017+A1:2018.

8.3.2.3 Depots

Depot and stabling requirements shall be agreed with the asset steward – operate or maintain. The requirements shall include, as a minimum, electrified vehicle stabling tracks and any electrified test tracks connected to the electric traction system, as well as knowledge of operating modes for the rolling stock (while berthed). This shall include data about the auxiliary power load associated with such modes.

8.3.3 Environmental data

The traction power system (including all SFCs) shall be capable of operating at full power, without any limitation or restriction of performance or functionality across the full range of ambient conditions that are specified for each project. During extreme environmental events outside the specified ambient conditions, the traction power system, including all SFCs, shall continue to operate where it is safe to do, although with reduced performance.

The environmental data in Table 4 is in accordance with the conditions set out in TS 03744 and shall be used in environmental assessments and traction system design. The requirements in TS 03744 shall also be taken into account. See also Section 13.

Table 4 – Environmental parameters for rating calculations of fixed equipment (located in non-weather protected locations)

Environmental parameter	Value
Altitude	–32 to 1000 m
Ambient air temperature	–5 to 50 °C
Maximum wind speed	35 $m \cdot s^{-1}$ For maximum temperature condition assume 0 km/h
Probable maximum precipitation (duration 0.25 hours for 1 km^2) Probable maximum precipitation (duration 1 hours for 1 km^2)	13 mm/min 7 mm/min
Annual mean daily global solar exposure Maximum level of solar radiation	4.5 $kWh \cdot m^{-2}$ 1000 $W \cdot m^{-2}$

Environmental data applicable to the geographic area under study shall be fed into the computer model. The system designer may use bespoke data from a significant weather authority from the area under study that is agreed and approved by the client. Table 4.1 of AS/NZS 1170.2:2021 shall be used to provide additional environmental data regarding wind velocities depending on terrain and height.

8.4 Assessment procedure

8.4.1 Simulation tools

The requirements of EN 50641:2020 and TS 00161 shall be followed to assess the traction power system simulation tool.

8.4.2 Operational and verification requirements

8.4.2.1 Simulation operation

The outputs and results from the simulation tool shall be used to determine if the required performance of the traction system in normal (N) and abnormal (N-1 and or N-2) conditions is met. The safety requirements shall be met under all operational conditions (for example, rail to earth potential).

Note: The assessment of lineside cables includes the determination of induced voltages on signalling and telecommunication cables.

8.4.2.2 N condition

The compliant operation under N conditions shall be verified with and without regenerative braking on all trains simultaneously during the design stage.

8.4.2.3 N-1 contingency condition

While operating under N-1 contingency conditions, the traction power system shall maintain the train service without detriment to the train services.

8.4.2.4 N-2 contingency condition

While operating under N-2 contingency conditions, the traction power system shall maintain at least a minimum train service timetable. For N-2 operational conditions, U_{min2} is the lower limit.

8.4.2.5 Verification requirements

The normal and contingency operating conditions that the traction power system is expected to reliably provide power to shall be verified.

8.4.3 Time period for averaging and integrating

To determine the equipment ratings, system loads, and supply point demands, the time periods required to calculate averages or integrate over shall be as specified in Table 5, which have been determined with reference to Table A.1 of I.S. EN 50388-1:2022.

Table 5 – Averaging or integration periods

Function	Component	Averaging or integration duration
Thermal loading	Track feeder (cable)	15 to 20 minutes (Note 1)
Thermal loading	Contact wire system	15 to 20 minutes (Note 1)
Thermal loading	Earth wire	15 to 20 minutes (Note 1)

Thermal loading	3ph network supply point, Feeder station	30 minutes
Thermal loading	Load-break switch	15 to 20 minutes (Note 1)
Thermal loading	Switchgear (circuit breakers and disconnectors)	15 to 20 minutes (Note 1)
Phase (voltage) unbalance	3ph network supply point (point of common coupling)	1 minute, 10 minutes, 30 minutes and 24 hours (Note 2)
Protection		120 ms to 3 s

Notes:

1. The 20-minute duration has been selected to align with the upper value given in Table A.1 of I.S. EN 50388-1:2022. A longer averaging period may be used where this is supported by data provided by the manufacturer.
2. The averaging periods depend on the connection voltage and operating condition. The system designer may, with appropriate justification, extrapolate or interpolate data from a shorter time period to achieve a 24-hour value. An over-pessimistic or over-optimistic outcome should be avoided.

8.4.4 Mean useful voltage

The normal service shall be used to assess the performance of the trains and the electric traction system on a quantitative basis. The mean useful voltage shall remain above the minimum as specified in Section 6.5 under N and N-1 contingency operations. The mean useful voltage shall be calculated using the methods in Clause 8 of I.S. EN 50388-1:2022.

8.4.5 Electrical safety, earthing and the return circuit

The step and touch voltages as well as the induced voltage in the rail, lineside cables and connections to earthed metal work shall be in accordance with TS 00103.2. The three conditions that shall be assessed are short-term short circuit fault conditions, normal and abnormal load operation.

When there is a fault within or to a vehicle, if the vehicle is touched then the impedance values between the vehicle body and rail shall be as provided in Clause 9 of EN 50122-1:2022.

8.4.6 Energy losses

The energy losses shall be calculated when the energy system is being designed or assessed with the following three criteria applied:

- normal operation with all equipment in-service
- with the proposed normal level of train service

- over a complete geographic zone.

The temperature to be used to calculate energy losses shall be within the range given in TS 03744. For more information on ambient temperature, see Section 13.

Energy losses are defined as the integral of percentage active power loss. The proportion of active power provided at the 3ph network supply point that is not transferred to the pantograph of the train defines the system power loss. The energy losses include all losses on the electric traction system but do not include the losses from the 3ph supply network. See also Section 21.1.

8.4.7 System demand

The predicted peak 30-minute RMS demand of the electric traction system shall be maintained at or below the continuous rating of the 3ph network supply point that is the nominal continuous circuit rating. The electric traction system shall maintain the nominal continuous circuit rating under N-1 and N-2 conditions.

The predicted demand shall include the provision for capacity to meet future power demands, such as for future train service increases.

9 Traction power SCADA and telecoms

9.1 Telecommunications architecture

A typical traction power SCADA telecommunications architecture is shown in Figure 3.

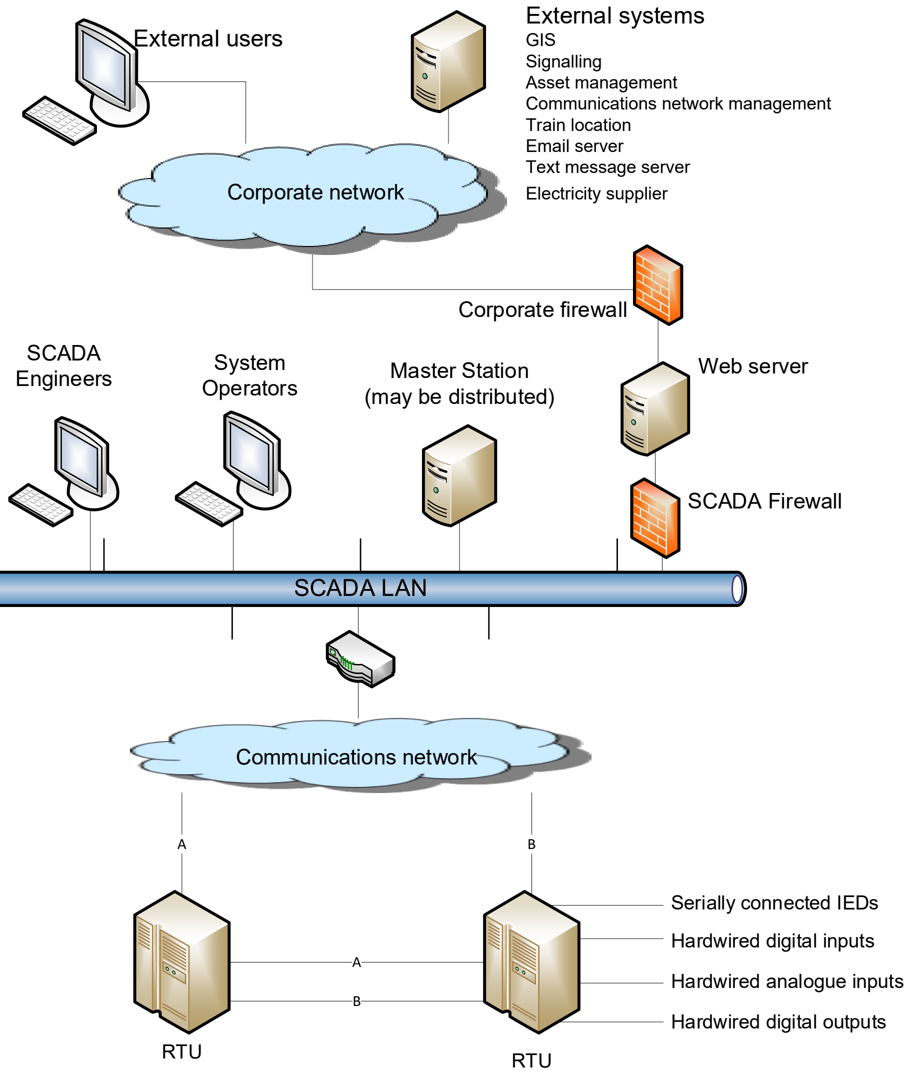

Figure 3 – Typical SCADA architecture

The asset custodian shall be consulted for SCADA telecommunication requirements.

9.2 Master station requirements

The master station consists of hardware and software components. These components may be co-located, or geographically distributed to meet other requirements, such as availability or business needs.

The master station hardware shall comprise commercial off-the-shelf ICT parts and technology. If hosted in an ICT data centre, it shall meet Australian government requirements for critical infrastructure, where dedicated contracts already exist for the environment, maintenance, reliability and change management. For further information, refer to CISC*, General Guidance for Critical Infrastructure Assets Factsheet*.

The hardware shall support and meet the integrity, availability, security, maintenance and performance requirements detailed in this document and in TS 03866. All hardware used to run the master station software shall be located in New South Wales. The application software shall be able to run on virtual machines on the hardware described in this section. It may be part of a railway software application that performs other functions. For more information on cyber security, see Section 14.

9.3 Layer requirements

9.3.1 Top layer requirements

A telecommunications network shall be used to connect the SCADA master station with the RTUs located in substations and other locations. The telecommunications network shall comprise an ethernet wide area network using TCP/IP. It may use links and hardware provided by external suppliers. The communications network shall have duplicate fibre-optic connections at each HV substation. Locations where SCADA is required shall use fibre optic cables for SCADA communications. No copper communication cables shall cross a substation boundary, as defined by the earth grid. A risk assessment shall determine the communication requirements for other locations. The protocols used on the SCADA system shall not be proprietary. The master station and RTUs shall be able to use at least two common SCADA protocols. Secure distributed network protocol or an IEC protocol (for example, IEC 61850 (all parts) or IEC 60870-5) shall be used.

9.3.2 Layer 3 requirements

Layer 3 is an extended station bus that provides a virtual encrypted network between the substations. It shall be used for protection, control and wide area monitoring.

SFC controllers shall exchange signals and measurements over this layer, thus establishing parallel operation. Exchange of protection signals enables in-zone fault clearance times of as low as 80 ms with normal feeding arrangements, and 100 ms for alternative feeding arrangements.

9.3.3 Layer 2 requirements

Layer 2 shall be made up of a station bus, protection and control IEDs, an RTU and a local SCADA system.

10 NSP interface

10.1 Rated voltages and insulation coordination

3ph network connections between 33 kV and 132 kV voltages shall follow the insulation levels in Table 6, which have been adopted with reference to Table 1 in AS 62271.1:2019, Table 2 in IEC 60071-1:2019 and IEC 62497-1.

Clause S5.1a.4 of the NER sets out requirements that apply to the normal voltage range (i.e. the power frequency voltage of supply at a connection point).

All equipment, cables and conductors connected at these voltages shall comply with the insulation levels in Table 6 and compliance demonstrated through type tests and route tests as stated in the applicable standard.

Table 6 – Rated voltages for equipment connected to NSP supplies

Nominal voltage U_N kV (RMS value)	Normal voltage range kV (RMS value)		Rated maximum voltage U_m kV (RMS value)	Rated short-duration power-frequency withstand voltage U_d kV (RMS value)		Rated lightning impulse withstand voltage U_p kV (peak value)		Rated switching impulse withstand voltage U_s kV (peak value)			Pollution degree (fixed installations)[1]	
	Minimum	Maximum		Common value	Across isolating distance	Common value	Across isolating distance	Phase-to-earth and across open switching device	Between phases	Across isolating distance	Non-trackside locations	Trackside locations
33	29.7	36.3	36	70	80			–	–	–	PD4	PD4A
						170	195					
66	59.4	72.6	72.5	140	160	325	375	–	–	–	PD4	PD4A
132	118.8	145.2	145					–	–	–	PD4	PD4A
				275	315	650	750					

Note 1: Refer to IEC 62497-1

10.2 Power factor

For loads equal to or greater than 30% of the maximum demand at the connection point, the power factors for the railway electrical network are set out in in Table 7, which have been adopted with reference to Table S5.3.1 of the NER.

Table 7 – Permissible power factor ranges for different supply voltages

Supply voltage (nominal)	Power factor range
66 kV and 132 kV	0.95 lagging to unity
11 kV and 33 kV	0.90 lagging to 0.90 leading

10.3 Load

The HV ac supply shall be sized to meet the requirements of the worst-case contingency as determined by the traction modelling and system-wide LV loads calculation. See Section 8.4.7 for the modelled system demand.

10.4 Reliability and availability

The reliability and availability of the NSP HV bulk supply points shall be maximised by feeding both individual ITPSs and adjacent ITPSs from different zone substations via diversified routes.

The intake feeders to the ITPS shall be via diversified routes from either different zone substations or different busses from the same zone substation.

10.5 Load currents balancing

Clause S5.3.6 of the NER sets out requirements that apply to 3ph network connection balancing of load currents. The NER requirements include the limits given in Table 8 for currents in any phase, where the percentage shown corresponds with the average currents in the three phases.

Table 8 – Maximum and minimum percentage currents of 3ph average current for corresponding network connection voltage

Supply voltage (nominal)	Maximum current	Minimum current
33kV, 66 kV and 132 kV	102%	98%
11 kV	105%	95%

10.6 Voltage fluctuations

Clause S5.1a.5 of the NER sets out requirements that apply to variations in loading level at the connection point, including those arising from energisation, de-energisation or other operation of plant causing voltage fluctuations.

10.7 ITPS points of interface

At the NSP interface, the points of interface for the ITPS shall be:

- NSP HV cable ducts – the boundary of the ITPS site
- NSP HV control and protection cable ducts – the boundary of the ITPS site
- telecommunications cable ducts – the boundary of the ITPS site
- DNSP HV cables – as agreed with the NSP
- SCADA – the telecommunications network ODF in the ITPS control room to which the RTU and the ITPS protection and control system shall be connected
- telecommunications – the network ODF in the ITPS control room to which the RTU and the ITPS protection and control system shall be connected
- NSP HV control and protection interfaces – terminals in control panels in the ITPS control room
- civil systems – the boundary of the ITPS site.

11 Power quality

11.1 Voltage waveform quality

11.1.1 Harmonic voltage distortion

The harmonic voltage distortion shall be less than the “Planning Levels” stated in Clause S5.1a.6 of Section 5 of the NER. Background harmonic voltage measurements of the NSP’s network shall be undertaken by the NSP. The systems designer shall supply the predicted harmonic distortion that will be connected to the supply.

The system designer shall comply with the harmonic limits at the relevant frequencies as per the connection agreement with the NSP.

The harmonic compatibility study shall be carried out in accordance with TR IEC 61000.3.6 and I.S. EN 50388-1.

11.1.2 Phase (voltage) unbalance

Clauses S5.1a.7 and S5.1.7 of the NER set out requirements that apply to the phase voltage unbalance. The voltage unbalance is measured as negative sequence voltage and Table 9 shows the NPS voltage depending on the nominal supply voltage under different conditions, which have been adopted with reference to table S5.1a.1 of the NER.

Table 9 – Maximum NPS voltage (% of nominal voltage)

Supply voltage (nominal) (kV)	No contingency event (30-minute average)	Credible contingency event or protected event (30-minute average)	General (10-minute average)	Once per hour (1 minute average)
More than 100	0.5	0.7	1.0	2.0
More than 10 but not more than 100	1.3	1.3	2.0	2.5

11.2 Power factor of the SFC

The power factor of the SFC shall be as close as possible to unity (1.0) and always within the range of 0.98 (lagging) and 0.98 (leading).

11.3 Voltage fluctuations caused by the SFC

For requirements to apply to voltage fluctuations, see Section 10.6.

11.4 Voltage unbalance caused by the SFC

For requirement to apply to voltage unbalance, see section 11.1.2.

11.5 Primary side harmonic emissions from the SFC

For requirements that apply to harmonic voltages, see Section 11.1.1.

11.6 25 kV AC harmonics

The SFC shall comply with the requirements of EN 50121-1, EN 50121-2 and EN 50121-5.

The SFC shall operate correctly when subjected to harmonic voltages and harmonic currents from rolling stock. A harmonic emissions study shall be conducted to determine the combined behaviour between the SFC, 25 kV ac network and the 25 kV ac rolling stock loads. The study shall show that the SFC shall not cause maloperation of each type of equipment. The results of the study and the correct operation of the signalling and telecommunications equipment and the 25 kV rolling stock, shall be validated by testing at the commissioning stage. The harmonic emissions study shall be conducted in line with EN 50121 (series).

11.7 25 kV AC harmonic overvoltage

The SFC shall not excite or create natural frequencies:

- that lead to harmonic over-voltages determined in accordance with I.S. EN 50388-1

- that create adverse effects on train detection and signalling systems within the feeding limits under alternate feeding.

Table 10 shows the maximum repetitive peak voltage on the traction power supply when the line voltage, U_n is below or equal to U_{max2} in I.S. EN 50163:2004+A3:2022.

Table 10 – Maximum repetitive peak voltage on the traction power system

Traction power supply system	Maximum (kV)	Maximum for more than 30 s (kV)
AC 25 kV 50Hz	50	47

12 Isolation and earthing

12.1 Safety

All HV apparatus shall have provision for proof of de-energisation. HV switchgear shall be equipped with viewing windows to verify the position of the earth switch.

12.2 Switching – isolation and earthing

12.2.1 OHW trackside switching philosophy

OHW sectioning shall be achieved via motorised switches with voltage presence indication systems.

Track switches including disconnectors, isolators and earthing switches shall be remotely operable by the asset steward – operate or maintain. Track switches shall have the provision for local isolation and earthing. Remote operation rather than local switching should be enabled. Remote operation shall be inhibited when the switch is in local control.

The remote motorised bypass switches and OHW feed switches shall be operable via the PCS to enable alternative feeding arrangements. The switches shall have the capability of being automatically reconfigured in the event of power loss, should the PCS be programmed with this functionality.

Track side isolation points shall be at fixed points. The isolation points shall have the provision to effectively implement an isolation at the track side. Access requirements and adjacent live sections at the track side shall be taken into account.

FEDs are earthing switches that shall be permanently secured to OHW structures. A double point indication via the PCS shall be provided for indication of the FED when in either open or earthed position.

Remote operation shall be inhibited when the equipment is under local control. FEDs shall have the provision to be locally secured in the earthed position by means of a unique key or padlock facility.

Visible direct indication of the FED position shall be provided. FEDs shall have the provision for proof of de-energisation. FEDs may be combined with an OHW isolation point.

12.2.2 HV switchgear

Non-withdrawable HV switchgear should be used instead of withdrawable switchgear. Withdrawable switchgear may only be used if endorsed by AMB. HV switchgear shall have the provision to securely isolate and earth each individual circuit.

The HV switchgear shall be capable for remote and local operation of the isolation and earthing switches. Double point indication via the PCS shall be provided for indication of the switchgear when in any of the open, closed, isolated or earthed positions. Remote operation shall be inhibited when the equipment is under local control. HV switchgear shall have the provision to be locally secured in the isolated, earthed position by means of a unique key or padlock facility.

12.2.3 LV switchgear

LV switchgear shall have the provision to securely isolate each circuit and busbar. LV switchgear that has the capability of being withdrawn shall not leave any live parts accessible when in the withdrawn position. The LV switchgear that can be operated remotely shall have the capability of having remote operation inhibited when under local control.

For remote isolation, double point indication via the PCS shall be provided for indication of the switchgear status.

13 Operational environment

Built and natural environmental parameters (relevant to the design of the traction power system) shall be based on TS 03744 (see Section 8.3.3 in this document).

Provision for climate change projections shall take account of the requirements in Section 21.3.

All traction power equipment (for example, SCADA systems, protection relays, switchgear, auxiliary power supplies, SFCs) shall not suffer or cause any deleterious effects while operating in the foreseeable electromagnetic environment. The traction power equipment and the railway as a whole shall operate to the defined design parameters and requirements while operating in the electromagnetic environment.

EMC requirements within the operating environment shall comply with the following standards:

- AS/RISSB 7722
- AS 61000 (series)

- EN 50121 (series)
- ACMA mandated EMC standards for equipment

For detailed EMC requirements, see Section 22.

14 Cyber security

TfNSW has produced cybersecurity requirements for operational technology in line with the *NSW Cyber Security Policy*.

The standards that an operational technology system shall comply with include, as a minimum, the following:

- TS 00031.1
- TS 04990
- TS 04991
- TS 04993.

Additional guidance is available from the following standards, with the TfNSW standard taking precedence in the event of any conflict:

- TS 06305
- AS/RISSB 7770.

15 Physical security

15.1 Unauthorised access

Unauthorised access to traction power infrastructure may take the form of trespass (for example, to premises) or theft (for example, of cabling). Measures to prevent unauthorised access shall be based on a deter, detect and delay approach.

Each of the following techniques shall be taken into account to determine the measures to be taken:

- Deterrence such as:
    - warning signage (for example, indicating that the area is restricted)
    - personnel and vehicle barriers
    - sufficient lighting and secure fencing
    - sheath colours (for example, black) that are less obvious indicators of the presence of earthing cables

    - indelible custodianship marking of assets.
- Detection such as:
    - CCTV
    - perimeter detection systems and intruder alarms for buildings
    - security patrolling.
- Delay such as:
    - fencing
    - use of space
    - anti-climb features
    - tamper proof containment (for example, troughing with secure lid fastenings).

15.2 Security design

Security arrangements for substations and sectioning huts shall be designed in accordance with TS 04992. Where key entry systems are used, the procedures shall be in accordance with section 9.14 of TS 04992.1.0 for the control of the issue of keys to personnel.

Designs related to the security of premises shall take into account interfaces with public footpaths such that they are sufficiently illuminated and signposted. In addition, access and egress to the premises for the asset steward – operate or maintain shall be taken into account as part of any holistic security design (for example, dedicated and illuminated pathways, elimination of trip hazards).

A staff alarm shall be fitted at each ITPS, such that each external door is alarmed over SCADA in accordance with the requirements of Section 16.3 of TS 03866.

Additional guidance is available from the following documents:

- TS 04992
- ENA DOC 015-2022
- ISO 31000
- TS 02388
- TS 03883
- TS 04989.

16 Switchgear

AC switchgear are switching devices combined with their associated control, measuring, protective and regulating equipment to detect and clear fault conditions, and to support autonomous reconfiguration of the railways. The 3ph ac switchgear are the interface between the ITPS and NSP supply boundary. The 1ph ac switchgear are the primary equipment to feed and section the 25 kV ac electrified OHW. All ac switchgear and control gear shall be in accordance with AS 62271 (series).

I.S. EN 50152-1 details the single-phase ac one-pole circuit breakers designed for indoor and outdoor fixed installations for operation at a frequency of 50 Hz on traction systems, having a rated insulation level above 1 kV up to 50 kV. Such circuit breakers shall comply with the requirements in I.S. EN 50152-1.

HV ac switchgear shall:

- comply with manufacturers' recommendations for minimum clearances required for maintenance
- Internal arc classification rating to A-FLR (All sided, Front, Lateral and Rear) in accordance with AS 62271.200
- include condition-based monitoring equipment to assist the asset steward – operate or maintain in planning maintenance activities
- not contain SF6 as an insulating or interrupting medium. SF6 as an insulating or interrupting medium may only be used if endorsed by AMB.
- be ingress protected to IP54 for outdoor switchgear in accordance with AS 60529
- be ingress protected to IP42 for indoor switchgear in accordance with AS 60529.

Switchgear shall be suitably rated for short-circuit currents so as to be capable of withstanding the fault levels (including future expected fault levels) well beyond the time for protection systems to operate. The specified duration shall be above the protection systems clearing time. This shall be supported by a protection study.

17 Cable management

17.1 General requirements

Cables shall be installed in accordance with AS/NZS 3000 and AS 2067.

Cable entries or ducts shall be sealed to prevent the ingress of soil, water and vermin.

The design of cable management systems shall take into account access and egress measures in consultation with the asset steward – operate or maintain and asset steward – delivery.

Provision for EMC management shall incorporate the requirements in Section 22.

The risk of cable theft in the substation environment and deterrence techniques are detailed in Section 15.

17.2 Within buildings

Cable pits for HV cables shall comply with the requirements specified in TS 03754 and the requirements in TS 03882. Where there is a conflict between this document and TS 03754, the requirements in TS 03882 take precedence.

17.3 Outside buildings

Access for outside buildings and cable containment shall be taken into account at the design stage. This shall involve taking into account the location and access covers of the containment, so that the asset steward – operate and maintain has sufficient access and egress for general maintenance and responding to failures and faults.

Cable pits, trenches and cable basements shall be sealed by an approved method to prevent the ingress of debris, water, vermin and dangerous gases via cable ducts. External cable pits shall be designed and constructed so that build-up of water cannot occur to the extent that cables are compromised, or access and egress to and from the pit is hindered (for example, graded floors, drainage, sump pumps). Refer to TS 03754 for guidance on cable pits. Lids shall be provided in accordance with AS 3996.

Cable locations shall be recorded in the Asset Steward Operate or Maintain records management system (geographic information system) and Before You Dig Australia as applicable.

Additionally, cable routes shall be designed taking into account the following:

- cable bend radius
- cable installation methodology
- EMC (see Section 22)
- segregation and diversity of routes
- protection against vermin
- protection from theft (see Section 15).

18 Substation building

18.1 Civil design

Traction power electrical installations usually consist of one or more types of physical buildings, in addition to outdoor switchgear yards, transformer bays and maintenance vehicle parking areas. TS 03882 shall be followed to ensure substations and sectioning huts are built to a minimum standard, inclusive of lighting (luminosity) requirements.

External surfaces and finishes shall be designed to minimise or reduce heat island impacts. Heat absorption planting should be used if there is sufficient space available.

External surfaces for vehicle access, turning and parking shall be designed to maximise permeability. Building roof drainage shall be designed to avoid increasing runoff to existing sewerage systems.

The advantage of offsite construction and standardisation of substation modules shall be taken into account and adopted where possible. These shall be designed within the size constraints of the delivery methodology. The building and equipment shall not suffer any deleterious effects during storage, transportation or delivery. Equipment modules and components shall be designed to be cost-effective for ongoing maintenance, replacement and decommissioning. Substation buildings constructed offsite shall comply with AS 62271.202.

18.2 Site location considerations

The following shall be taken into account when determining the location of a substation:

- security (see Section 15)
- HV cable or transmission line route
- space availability and site topography
- site access – all weather heavy vehicle access shall be provided for construction and future maintenance requirements
- crane and float access
- easement requirements
- location from and orientation to track
- utilities – required for stormwater and sewerage connections
- neighbouring land use and separation – current and future industrial and residential
- sound – construction and operational sound
- planned surrounding future infrastructure

- proximity to signalling and communication locations
- availability of suitable auxiliary electricity supply
- susceptibility of the site to adverse weather conditions (see Section 21)
- site specific environmental requirements (see Section 21)
- flood immunity – the substation shall not be subject to flooding (whether natural or due to surrounding infrastructure such as stormwater canals). If it is not possible to avoid such a location, then the switch room floor level shall be not less than 500 mm above the 100-year average recurrence interval flood level (see Section 21)
- bushfire susceptibility (see Section 21)
- proximity to facilities that have hazardous areas
- sites located on sloped ground – such sites shall have the following:
    - a level area provided in front of all equipment doors that is accessible by construction and maintenance vehicles
    - hand railing and guardrails provided with walkways

  Note: The NCC sets out requirements that apply to hand railing, guardrails and walkways.

    - where the site is cut into a slope, provision for retention of the bank
- oil-filled transformers – the risk of any environmental contamination from oil-filled transformers during installation, operation and maintenance shall be controlled by the provision of secondary oil containment. This containment shall not become inoperable during the lifetime of the equipment.

18.3 Substation fencing

For substation fencing requirements, see Section 15.

18.4 Separate spaces

Adequate access and egress shall be provided within the traction substation, specifically to allow maintenance activities to be undertaken, and equipment to be accessed, installed and removed.

The interconnection of rooms and the access routes within the substation shall be consistent with the access and control requirements, so that the asset steward – operate and maintain is able to reach all areas they are authorised to enter without having to pass through any areas that they are not authorised to enter.

HV ac indoor switchgear shall be A-FLR rated to ensure compliance with the manufacturers' recommendations for minimum clearances required for maintenance.

The substation shall be designed so that there are separate areas for the following:

- 25 kV ac equipment room
- HV equipment to be demarcated by voltage
- auxiliary transformer room
- bays for oil-filled equipment
- administration area.

The administration area shall be able to house the following furniture as a minimum:

- a desk suitable for report writing, updating maintenance records, the completion of procedural documentation and meals
- chairs
- a wall mounted bookcase suitable for equipment operation and maintenance manuals
- a suitable storage unit for copies of all as-built drawings of the substation
- a key locker for storing equipment cabinet keys.

18.5 Tunnels

ITPSs shall not be located in tunnels.

Where TSCs or switchgear are located in tunnels, they shall comply with TS 01722. The following also apply:

- The routes shall be designed taking into account obstruction-free delivery and allow for replacement of equipment.
- Access corridors and passageways shall be designed taking into account the requirements for equipment transport.
- HV cable routes shall be designed with suitable physical segregation as specified in Section 17.
- The design shall take account of the ventilation provision of arc gases, management of explosion in catastrophic failure, heat dissipation, and fire requirements of materials used.
- Fire compartmentation between equipment rooms and other operational spaces and general public areas shall be taken into account.
- Separate access requirements for HV rooms/compartments shall be taken into account.

- Tunnel specific ambient conditions shall be taken into account and that they may deviate from the requirements of Section 8.3.3.
- The ingress protection rating for the TSC rooms and compartments as a whole shall be determined in accordance with the risk of airborne dust in tunnel environments and in compliance with AS 60529.

18.6 Civil building requirements prior to installation of equipment

Before the installation of electrical equipment in a building, certain civil aspects of the construction are mandatory. Further information can be found in TS 03882.

The following general building requirements shall be met before all equipment is installed:

- Equipment shall be protected from meteorological events. That is, the structure of building shall be watertight with roofing and associated stormwater systems complete to ensure no stormwater ingress.
- Security arrangements shall be in place, either temporary or permanent, to prevent unauthorised access and protect the equipment from tampering, vandalism and theft.
- The site and interior spaces shall be free of dust at the earliest possible time before installation of electrical equipment (that is, lock-up time), with all construction activities that would create dust completed and the interior of the building protected from environmental events (that is wind). This is particularly important as the majority of equipment to be installed is sensitive to dust (for example, switchgear).
- The oil containment system shall be installed and commissioned before the installation of oil filled equipment (for example, power transformers and reactors).
- Anti-condensation measures shall be in place.

TS 03881 contains additional requirements that shall be met before the energisation and commissioning of equipment where applicable.

18.7 LV services

Auxiliary low voltage supply shall be provided for HV substations such that failure of LV equipment will not affect the redundancy philosophy of the HV supply arrangement. The auxiliary low voltage supply shall be designed to achieve N-1 redundancy without intervention by an operator (for example, via the use of an automatic transfer switch). Design and installation of low voltage system shall be in accordance with AS/NZS 3000.

Low voltage lighting shall be in accordance with TS 04935.

The main low voltage distribution switchboard shall have provision for connection of a generator supply. A generator connection box shall be mounted to the external of the building.

19 Fire protection

Fire life safety systems within a traction substation shall be in accordance with the requirements of TS 00008 (all parts).

Note: The NCC sets out requirements that apply to fire protection.

In addition, the following documents shall be followed:

- ENA DOC 18-2015
- AS 2067:2016 Section 6.7
- *Planning for Bush Fire Protection – A guide for councils, planners, fire authorities and developers*.

20 Commissioning and energisation

20.1 Designer endorsement

The designer is required to endorse the completed inspection and test plans and inspection and test checklists in the following circumstances:

- where the designer specifically requires test data to verify theoretical modelling completed during the design phase (for example, earthing design,) or
- a test failed to meet the initial pass/fail criteria, or a design configuration change was required.

20.2 Testing requirements

All testing shall be successfully performed before energisation in accordance with relevant standards and TfNSW requirements (for example, internal NSP rules). The order of precedence of relevant standards shall be:

1. TfNSW standards
2. Australian standards
3. international standards
4. manufacturer’s specifications.

If there is no applicable standard, testing shall be conducted in such a way as agreed with the TfNSW asset steward – delivery, asset steward – operate or maintain, and the designer.

20.3 Identification of test equipment

All test equipment shall be identifiable by the following:

- serial number or unique asset number
- date of calibration
- person responsible for the calibration
- test method used for calibration.

20.4 Documentation for equipment commissioning

Documentation for equipment commissioning shall have the following details:

- Each test shall have a unique identifier.
- Each test shall identify the test method in use and pass criteria.
- Each test method will identify all test equipment used by its unique asset number.
- Each test shall show time and date of execution.
- Each test shall identify the tester and final approver.
- Each test shall clearly show all recorded results.
- If a test fails, it shall be re-executed and the failure noted.
- Each test shall provide ambient conditions at the time of execution, including humidity and temperature.
- Each test shall identify the piece of equipment being tested.

The network operator (electrical) shall have an electrical network safety management system in place in accordance with the requirements of AS 5577 prior to the energisation of any HV assets.

All documentation required for electrical network configuration changes shall be provided in accordance with the requirements of AS 5577 and in consultation with the network operator (electrical).

21 Sustainability and environment

21.1 Energy efficiency

21.1.1 Services

Electrical services infrastructure (for example, lighting, cooling and de-humidification) in substations shall be optimised for energy efficient operation.

21.1.2 Traction

Traction system modelling shall be optimised for energy efficient operation.

To optimise energy efficiency, opportunities shall be sought for energy efficiency and consumption reductions through modifications to service patterns, stabling and driver behaviour.

The energy efficiency and loss characteristics of the electrical infrastructure shall be assessed and optimised.

21.2 Environmental impact

Materials shall be selected to minimise their environmental impact such as through the use of:

- low volatile organic compounds paints, finishes, sealants and adhesives
- zero or low formaldehyde emission composite wood products
- ester oil for the insulating and cooling mediums for power transformers, where mineral oil would have otherwise been used.

Waste (be it generated during construction or as part of ongoing operations) shall be kept to a minimum with recycled materials used where it is practicable to do so. In any event, all waste (for example, transformer insulating oil, lead acid batteries) shall be assessed, classified and managed in accordance with the *Waste Classification Guidelines – Part 1: Classifying Waste* and disposed of to an appropriately licensed facility.

> Note: The *Protection of the Environment Operations Act 1997* (NSW) and the *Waste Avoidance and Resource Recovery Act 2001* (NSW) set out requirements applying to the disposal of waste.

The system designer shall provide carbon calculations for the whole-life carbon of a project and implement carbon reduction measures in accordance with applicable Australian standards. For further guidance on carbon management, refer to PAS 2080, the *Net Zero and Climate Change Policy* and applicable legislation.

Dry type transformers are preferred. Where oil is used in transformers, the environmental impact of any leak or spill shall be assessed and containment measures applied. The monitoring, inspection and maintenance regime of any containment measures shall be defined. The assessment shall include the storage and transport of any transformer oil.

Finishes and facades shall be complimentary to the surrounding environment while also meeting any security and functional requirements relevant to the premises. See also Section 18 for other civil information.

21.3 Resilience to climate change

Climate change projections for increase in average conditions and increased probability of extreme events shall be factored into the design processes to ensure that the traction power system is resilient to these projections.

22 Principles for electromagnetic compatibility

22.1 Characteristics

EMC management shall take into account the sources and victims of electromagnetic disturbance, with their characteristics in both contexts (that is, as both source and victim) and the coupling mechanisms available to link these sources and victims. AS/RISSB 7722 shall be followed for the framework to ensure EMC management is adequately implemented and assurance evidence is available to demonstrate that it has been adequately implemented.

The characteristics that affect EMC shall be identified. They shall include, as a minimum, the following:

- frequencies at which equipment operate
- magnitude of currents and voltages
- harmonic content of currents and voltages
- selectivity of a receiving circuit to the intentional transmitted signals (that is, its capacity to reject noise)
- electromagnetic interferences caused by adjacent operations (rail and non-rail) to the rail line (threats). The coupling mechanisms include:
  - conducted
  - inductive and capacitive
  - radiated.

Once identified and characterised, management techniques shall be applied to ensure compatibility.

A general summary of EMC-related factors relevant to railways, including those equipped with 25 kV ac electrification, is provided in Annex A of EN 50121-1:2017.

22.2 Management techniques

The EMC management techniques that apply in the context of 25 kV ac electrified railways shall include the following:

- To avoid conducted electromagnetic interference, especially due to bonding of metallic components, earthing and bonding connections shall avoid paralleling of traction return paths. Mitigation requirements in TS 00103.2 shall be followed.
- EMC management shall take account of harmonics and resonance, especially in the design of power conversion equipment. Where mitigation of high harmonic levels is required, filters shall be applied to the source. The application of filters shall also be taken into account so that only the harmonics of the source are absorbed and that the filter does not become a sink for other sources.
- Sensitive electrical equipment shall have a high level of immunity to electromagnetic interference. Compliance and compatibility shall be demonstrated in accordance with AS 61000, EN 50121 (series) and ACMA mandated standards for all electrical equipment including sensitive receivers.
- The inductive and capacitive interferences due to the traction feeding and return circuits shall be taken into account. Mitigation techniques for the inductive coupling along the lengths of parallel cables and metallic components shall be taken into account, including' the following, as a minimum:
    - Inductive effects on 'victim' cables shall be mitigated through the limitation of cable length, and through use of cable types that are designed to minimise interference.
    - Fibre optics shall be adopted where practical due to their inherent immunity to inductive interference. Metallic parts of the fibre optic cable are still vulnerable to interference and shall be managed.
    - Screening conductors shall be used on victim cables where practical.
    - Earthing and bonding mitigation methods shall be used to manage inductive interference.

  Note: Refer to TS 00103.2 for further information on earthing and bonding mitigation methods and the use of screening conductors.
- Radiated emissions can be caused by arcing between the pantograph and the OHW. This shall be mitigated and managed by coordination of their specification and mechanical design where applicable.

  Note: Refer to TS 00103.3 for further information on OHW.
- Radiated emissions caused by distributed conductors acting as antennae for the conducted emissions of the connected power equipment shall be managed through the specification and design of the connected power equipment. The equipment shall meet the following standards:
    - EN 50121-3-1, which limits such emissions and EN 50121-2, which limits the radiated emissions of the railway to the outside world.

  - AS 2344, which assures adequate prevention of interference to sensitive radio-frequency receivers.

Time-varying radiated emission limits to members of the public in publicly accessible areas should be taken into account. The designer should seek guidance from AMB on acceptable public exposure limits.