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Preface

This standard was prepared by the 25 kV AC Rail Traction Systems – Part 1: General Requirements Development Group, overseen by the RISSB Infrastructure Standing Committee.

Objective

The objective of this Standard is to provide the Australian rail industry with a set of mandatory and recommended requirements for the traction power system and includes the interface requirements with other rail systems.

The Standard addresses the requirements of a traction power system for the use of designers, contractors and rail infrastructure managers (RIMs). This Standard is Part 1 of a three-part series and shows the general requirements for a traction power system. Part 2 and Part 3 address the specific requirements of the overhead contact line and earthing and bonding respectively.

The use of this Standard allows for a uniform approach to be applied to the design, installation, testing and commissioning, operation and asset management of traction power supply systems.

Compliance

There are four types of provisions contained within Australian Standards developed by RISSB:

(a) Requirements.

(b) Recommendations.

(c) Permissions.

(d) Constraints.

Requirements – it is mandatory to follow all requirements to claim full compliance with the Standard. Requirements are identified within the text by the term 'shall'.

Recommendations – do not mention or exclude other possibilities but do offer the one that is preferred. Recommendations are identified within the text by the term 'should'.

Recommendations recognize that there could be limitations to the universal application of the control, i.e. the identified control is not able to be applied or other controls are more appropriate or better.

Permissions – conveys consent by providing an allowable option. Permissions are identified within the text by the term 'may'.

Constraints – provided by an external source such as legislation. Constraints are identified within the text by the term 'must'.

For compliance purposes, where a recommended control is not applied as written in the standard it could be incumbent on the adopter of the standard to demonstrate their actual method of controlling the risk as part of their WHS or Rail Safety National Law obligations. Similarly, it could also be incumbent on an adopter of the standard to demonstrate their method of controlling the risk to contracting entities or interfacing organisations where the risk may be shared.

RISSB Standards address known hazards within the railway industry. Hazards, and clauses within this Standard that address those hazards, are listed in Appendix A.

Appendices in RISSB Standards may be designated either "normative" or "informative". A "normative" appendix is an integral part of a Standard and compliance with it is a requirement, whereas an "informative" appendix is only for information and guidance.

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Section 1 Scope and general

1.1 Scope

This Standard is the first part of a three-part series of standards that specifies the requirements for any member or participant of the Australian rail industry that is involved in any phase of the life cycle for 25 kV AC traction systems.

This Standard provides the minimum requirements for the design, construction, testing, commissioning and ongoing asset management of 25 kV traction systems. It does not preclude the application of higher performance standards (e.g., based on local experience and good engineering practice which could be contained in the management of traction systems standards, codes, guidelines and procedures of rail transport operators (RTO).

The traction system is the equipment and systems forming part of the 25 kV power supplies for rolling stock fitted with a pantograph. This Standard provides the overall requirements of the traction system and is supported by Part 2 which specifies the requirements for the overhead contact line and Part 3 for traction system earthing and bonding.

1.2 Normative references

The following documents are referred to in the text in such a way that *some* or all of their content constitutes requirements of this document:

- AS 1768, *Lightning protection*
- AS 2067, *Substations and high voltage installations exceeding 1 kV a.c.*
- AS 60076.1, *Power transformers*
- AS 61439, *LV switchgear and control gear assemblies*
- 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*
- AS 62271.202, *High-voltage switchgear and controlgear, Part 202: High-voltage/low-voltage prefabricated substation*
- AS 7637, *Hydrology and hydraulics*
- AS 7722, *EMC management*
- AS/NZ 1170.2:2021 *Structural design action, Part 2: Wind actions*
- AS/NZS 3000, *Electrical installations (known as the Australian/New Zealand Wiring Rules)*
- IEC 60099, *Surge arresters*
- IEC 60870-5, *Telecontrol equipment and systems - Part 5: Transmission protocols*
- IEC 61508-1, *Functional safety of electrical/electronic/programmable electronic safety-related systems - Part 1: General requirements*
- IEC 61850, *Communication networks and systems for power utility automation*
- IEC 62351, *Power systems management and associated information exchange – Data and communications security*
- IEC 62443, *Network and system security for industrial process measurement and control*
- IEC 62848, *Railway applications - DC surge arresters and voltage limiting devices*
- ISO 11064, *Ergonomic design of control centres*

- ISO 55001, *Management systems - Requirements*
- EN 50119, *Railway applications — Fixed installations — Electric traction overhead contact lines*
- EN 50121-1, *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, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 1: Protective provisions against electric shock*
- EN 50122-3, *Railway applications – Fixed installations – Electrical safety, earthing and the return circuit – Part 3: Mutual interaction of a.c. and d.c. traction systems*
- EN 50124-1, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*
- EN 50152-1, *Railway applications – Fixed installations – Particular requirements for alternating current switchgear – Part 1: Circuit-breakers with nominal voltage above 1 kV*
- EN 50152-2, *Railway applications – Fixed installations – Particular requirements for alternating current switchgear – Part 2: Disconnectors, earthing switches and switches with nominal voltage above 1 kV*
- EN 50163, *Railway applications — Supply voltages of traction systems*
- EN 50317, *Railway applications — Current collection systems — Requirements for and validation of measurements of the dynamic interaction between pantograph and overhead contact line*
- EN 50318, *Railway applications — Current collection systems — Validation of simulation of the dynamic interaction between pantograph and overhead contact line*
- EN 50329, *Railway applications – Fixed installations – Traction transformers*
- EN 50367, *Railway applications — Current collection systems — Technical criteria for the interaction between pantograph and overhead line*
- EN 50388-1, *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*
- EN 50526, *Railway applications - Fixed installation DC surge arresters and voltage limiting devices*
- EN 50633, *Railway applications – Fixed installations – Protection principles for AC and DC electric traction systems*
- EN 50641, *Railway applications – Fixed installations – Requirements for the validation of simulation tools used for the design of electric traction power supply systems*
- EN 60146-1-3, *Semiconductor convertors - General requirements and line commutated convertors - Part 1-3: Transformers and reactors*

- EN 60146-2, *Semiconductor converters - Part 2: Self-commutated semiconductor converters including direct d.c. converters*
- EEMUA 191, *Alarm systems – a guide to design, management and procurement*
- NERC-CIP, *North American Electric Reliability Corporation Critical Infrastructure Protection standards*
- RISSB Guideline, *Reliability, Availability and Maintainability (RAM)*
- National Construction Code 2022
- UIC Leaflet 791-3, *Safety measures to be adopted when working on or nearby overhead contact lines*

NOTE:

Documents for informative purposes are listed in a Bibliography at the back of the Standard.

1.3 Defined terms and abbreviations

For the purposes of this document, the following terms and definitions apply:

1.3.1

AC
alternating current

1.3.2
electrical control operator (ECO)
person responsible for the management of the traction system

1.3.3
EMC
electromagnetic compatibility

1.3.4
gauge
set of rules including a reference contour and its associated calculation rules allowing defining the outer dimensions of the vehicle and the space to be cleared by the infrastructure

Note to entry: According to the calculation method implemented, the gauge can be a static, kinematic or dynamic lateral deviation lateral stagger of contact wire in maximum crosswind.

1.3.5
high voltage (HV)
voltage exceeding 1,000 V

1.3.6
intelligent electronic device
equipment installed with the ability to provide protection and/or control of high-voltage switchgear

1.3.7
line speed
maximum speed measured in kilometres per hour for which a line has been designed

1.3.8
low voltage (LV)
voltage exceeding 50 V AC or 120 V ripple-free DC but not exceeding 1,000 V AC

1.3.9
mean useful voltage

train voltage identifying the dimensioning train and enables the effect on its performance to be quantified

1.3.10
N
system operating condition with normal feeding of the traction power system

1.3.11
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

1.3.12
network service provider (NSP)
entity authorized to provide electricity to the traction system

1.3.13
neutral section
assembly inserted in a continuous run of contact line for isolating two separate sources of power supply and enabling the train to move from one section to an adjacent one without bridging the two power supplies

1.3.14
nominal voltage
voltage by which an installation or part of an installation is designated

1.3.15
normal service
planned timetable service

1.3.16
overhead contact line (OCL)
contact line placed above the upper limit of the vehicle gauge and supplying vehicles with electric energy through roof-mounted current collection equipment

1.3.17
pantograph
equipment fitted to the vehicle and intended to collect current from a contact wire

1.3.18
P-Q diagram
graphical representation used in electrical engineering to illustrate the relationship between active power (P) and reactive power (Q) in a power system. Also, **P-Q curve**

1.3.19
rail infrastructure manager (RIM)
As defined in Rail Safety National Law

1.3.20
rail transport operator (RTO)
As defined in Rail Safety National Law

1.3.21
return circuit
all conductors which form the intended path for the traction return current including other infrastructure subsystems such as track

Note to entry: Refer to AS 7662.3 for more information.

1.3.22
return circuit
all conductors which form the intended path for the traction return current

1.3.23
remote terminal unit (RTU)
equipment used to control field devices in substations and lineside

1.3.24
supervisory control and data acquisition (SCADA)
system that connects field devices including RTU's together under the control of an authorized electrical control operator

1.3.25
static frequency converter (SFC)
equipment used to convert power supplies provided by network service providers for use in the traction system

1.3.26
substation
place used to house traction system equipment

1.3.27
traction system
equipment and systems forming part of the 25 kV power supplies for rolling stock fitted with a pantograph

General rail industry terms and definitions are maintained in the RISSB Glossary. Refer to: https://www.rissb.com.au/glossary/

Section 2 General

2.1 General requirements for the 25 kV traction system

The 25 kV traction system shall be designed to ensure that traction power is provided safely and reliably under normal and abnormal operating conditions.

The system shall have sufficient capacity to support a normal train service, including planned and unplanned changes to services specified by the RIM.

The system shall be designed to operate within the railway system considering the relevant characteristics of rolling stock and other infrastructure systems.

2.2 Voltage and frequency

The traction system power supply shall be 25 kV at a frequency of 50Hz compliant to EN 50163, Clause 4.

2.3 Parameters relating to traction system performance

The maximum train current shall be defined by the RIM and the mean useful voltage shall comply with the requirements of EN 50388-1 as detailed in Section 3 of this standard.

2.4 Equipment ratings

Equipment ratings shall be based on the appropriate load cycle determined by modelling or engineering decision made by the RIM. The following standards shall be used to determine the equipment ratings

(a) EN 50119, *Railway applications — Fixed installations — Electric traction overhead contact lines*

(b) EN 50152-1, *Railway applications – Fixed installations – Particular requirements for alternating current switchgear – Part 1: Circuit-breakers with nominal voltage above 1 kV*

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

(d) EN 50329, *Railway applications – Fixed installations – Traction Transformers*

(e) AS 61439 (all parts), *LV Switchgear and control gear assemblies*

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

SFCs do not have an overload rating and therefore the approach to equipment rating shall be based on maximum instantaneous loading. The SFC control system approach shall be incorporated when determining the maximum instantaneous load. This may include the following potential mitigations:

(g) Load sharing between feeding circuits to reduce the maximum load.

(h) Meshed feeding across the network to reduce the maximum load.

(i) Load reduction measures instigated by voltage and current control at the SFC.

2.5 Insulation coordination

Insulation coordination shall comply with EN 50124-1.

Lightning and the short-duration power withstand values shall comply with EN 50152 as a Category 4 installation.

2.6 Regenerative braking

The traction system shall be designed to allow the use of regenerative braking to exchange power seamlessly either with other trains or with the NSP where permitted. The control philosophy including P-Q diagram should be provided by the equipment manufacturer to enable the NSP and RIM to achieve an interface agreement.

2.7 Electrical protection arrangements

Electrical protection arrangements shall comply with the requirements of EN 50388-1 and EN 50633.

Autoreclosure shall only be permitted following an assessment by the RIM to determine if the operational and system resilience requirements justify the safety risk associated with autoreclosure. Safety risk controls that may be incorporated are disabling autoreclosure during maintenance and delaying reclosure.

Identical relays shall not be used for primary and secondary protection to prevent common mode failures.

2.8 Maximum fault current and duration

The traction system fault current and duration shall be determined by the equipment ratings and the requirements of EN 50122-1. 25 kV maximum fault levels are typically 12 kA for systems connected at voltages above 275 kV and 6 kA for other circumstances. The maximum fault duration should be less than 200 ms under normal operating conditions. Backup protection shall operate to clear the fault within one (1) second.

2.9 Lightning protection

Lightning protection shall be compliant to AS 1768.

2.10 Harmonic and dynamic effects

To achieve electrical system compatibility, harmonic voltages shall be limited to the values specified in EN 50388-1.

2.11 Overhead contact line geometry

The OCL geometry shall be designed to enable reliable contact between the contact wire and the working lengths of the pantograph. The OCL geometry shall be compatible with the characteristics of the pantograph including the length of the contact strips, head geometry and the provision of insulated or non-insulated horns.

The detailed requirements for the OCL are specified in AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line*.

2.12 Neutral sections

Where power supplies are fed from separate phases, or it is otherwise necessary to separate power sources, neutral sections shall be installed to ensure that train power is zero (0) while travelling from one supply to another.

The overall length of the neutral section is detailed in EN 50367.

2.13 Protective provisions against electric shock

Electrical safety of the traction system shall be achieved by compliance with EN 50122 and where appropriate, Energy Networks Australia Guidelines and Australian Standards. The protective provisions against electric shock are specified in AS 7662.3, *25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding*.

2.14 Design life

The typical design life for 25 kV AC traction system equipment is shown in the subsequent table.

Table 2-1 Typical Design Life for 25 kV AC Traction System Equipment

Equipment	Typical life (years)
Power transformers	40
Static frequency converters and associated equipment	30
Protection and instrumentation transformers and surge arresters, secondary equipment etc.	25
HV switchgear and associated equipment	40
25 kV switchgear and associated equipment	40 or 10,000 cycles
Disconnector switches and earth switches	30 or 2,000 cycles no load; 1,000 cycles load break
Enclosures, insulators and conductors	40
LV switchgear, lighting fixtures and electrical systems	40
Battery chargers	20
Lightning protection and earthing systems	50 (120 inaccessible)
HV Cables	40
Substation building	120 (40 modular)
Foundations.	120
Structural steelwork	100 based on AS/NZS 7000
Main conductors and ancillary conductors.	50
Contact wire	Determined on a project by project basis
Small part steelwork, tubes, fittings and tensioning devices.	50
Insulators	50
In span components, discrete sectioning devices and disconnectors	50

The specified design life for individual components should include the impact of the environmental conditions as detailed in Section 3.3 and the overall design life requirements of the system.

Section 3 25 kV AC traction power system design

3.1 General 25 kV AC traction power system design requirements

The RIM shall determine the functional requirements necessary and specify a reference system where appropriate. If a reference system is specified, it may be possible to adopt the system design characteristics of the reference system without carrying out all the activities detailed in this section. Typical system designs are provided in Appendix A and the system selection is determined by the outputs of the system modelling, availability of supply points from NSPs and the choice of system immunisation at source.

3.2 Traction system modelling

Traction power system modelling shall be carried out using simulation tools that comply with EN 50641. The modelling shall be carried out to meet the following requirements and the RIM shall determine what the relevant functional requirements are.

The traction power system model shall have the following inputs as a minimum:

(a) Operational – The normal operating timetable shall be provided detailing the train configuration, stopping patterns, point to point times and any operating conditions that could apply.

(b) Electrical infrastructure –The electrical characteristics of the system including conductor configuration, cable/conductor sizes/types, return circuit details, the interface between the NSP and the railway and the details of the transformers, SFC and other equipment. The use of simplified circuits for SFC's and other equipment is acceptable but shall be described in the modelling report.

(c) Track infrastructure – The track layout including line speeds on open route and across junctions, gradients, curve radius, cant and features such as stations, tunnels are all necessary to enable an infrastructure model to be created that accurately reflects the railway infrastructure.

NOTE:
In regard to item (a), altered operating parameters should be described where they could impact the system design e.g., special events, typical service disruptions.

The traction power system model should also include the following input:

(d) Signals infrastructure – The signalling system should be overlayed to enable speed restrictions and operating characteristics to be predicted under normal single train operation as well as part of a timetable

(e) Rolling stock – The rolling stock characteristics such as weight, traction and braking systems are necessary to enable the performance of the train to be calculated. Any auxiliary loads should be provided including the associated operating parameters, e.g., air conditioning loads at normal and extreme temperatures.

The performance of the rolling stock at different line voltages should be described to ensure that there is automatic power regulation including reference to compliance with the characteristics for power regulation in EN 50388-1 and behaviour under different voltage conditions in EN 50163.

Typical input curves are as follows:

(i) Resistance to forward motion against speed.

(ii) Maximum traction force against speed.

(iii) Maximum current against traction system line voltage.

(iv) Maximum braking motor force against speed.

(v) Service deceleration.

(vi) Tractive effort against motor current.

The modelling should incorporate other input data where it is likely to impact the system design this could include an estimate of any depot and non-rolling stock loads and the potential for battery charging.

The traction power system model shall have the following outputs as a minimum:

(f) Minimum voltage at the pantograph for each train and each location highlighting any that are below 19.5 kV

(g) Mean useful voltage for each train highlighting any sections that are less than 22 kV

(h) Instantaneous and overall total system power consumptions including details of any system losses

(i) Any journey time impacts due to the electrical infrastructure

(j) The impact of any train interactions that could impact performance

(k) Energy regeneration using the braking system

(l) Traction substation locations and feeder current values

(m) Instantaneous and average power demand for major equipment including traction transformers, autotransformers, SFC's, switchgear, cables and the OCL in normal operation and with equipment outages. The average power durations used for the analysis shall be based on the methodology adopted to determine equipment rating

The results of the modelling shall be included in a report detailing the inputs, assumptions and providing an analysis of the results for normal and outage conditions.

Additionally, the traction power system model may be used to determine the approach for immunisation and earthing and bonding.

The RIM should determine the level of resilience required based on the operating requirements, the risks associated with a loss of power and other business design specifications. Typically, a full service is expected to operate with any one piece of equipment (N-1) out of service and a reduced service with more than one piece of equipment (N-2+) out of service.

3.3 Environmental

The traction power system design should accommodate the environmental aspects of the design throughout the asset life. The RIM shall specify the environmental conditions that the system is expected to operate without restrictions and provide details of any acceptable levels of reduced performance including the limiting environmental condition. The minimum environmental conditions to be specified are detailed in Table 3-1.

Table 3-1 Minimum Environmental Conditions

Environmental Parameter	Measure
Altitude	Metres above sea level
Flood risk	Flooding expressed as a likelihood in years
Ambient air temperature	Min and maximum daily temperatures
Maximum wind speed	As detailed in AS/NZS 1170.2
Maximum solar radiation	Watts per metre squared
Air Conditions	Levels of salinity, dust and other contaminants

The environmental conditions specified should also include the impact of climate change.

The RIM may also consider the whole life environmental impact of the traction power supply system and carry out an environmental impact assessment including the following:

(a) Energy consumption during construction and throughout the asset life.

(b) Energy recovery through regenerative braking or energy storage.

(c) Carbon content during construction and throughout the asset life.

(d) The use of any 'green house' gases such as Sulphur Hexafluoride (SF6).

3.4 Operational

The traction power system design shall support the concept of operation for the railway. If there is no documented concept of operation the following operating characteristics should be considered as part of the design review.

(a) Normal train services.

(b) Special event timetables.

(c) Minimum operating headways.

(d) Regulating rules for operating the railway under disruptions including infrastructure outages, rolling stock issues and other incidents impacting services.

(e) Maintenance and other planned changes to services.

3.5 Earthing and bonding

The earthing and bonding design shall be integrated into the system design. This design shall incorporate the maximum load and fault currents when determining the cable ratings. Traction power supply modelling may be used to demonstrate that the system is compliant with the requirements detailed in Section 2 under normal and N-1 conditions. Further details of the earthing and bonding requirements are provided in AS 7662.3, 25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding.

3.6 Electrical system compatibility

The traction power system design shall comply with AS 7722.

A compatibility plan should be developed to demonstrate how the project is to meet its obligations in respect of ESC. The approach should be based on the following three controls.

(a) Compliance with standards.

(b) Comparison with existing system.

(c) Technical, risk-based assessment.

The RIM may determine that a reference system can be used as a comparison, and it is therefore not necessary to have a compatibility plan demonstrating how the electrical system compatibility is managed.

If a full compatibility study is considered necessary, the requirements of EN 50388 may be followed.

3.7 Reliability, maintainability and maintenance

Reliability, maintainability and maintenance (RAM) requirements shall be considered during the traction power system design. The selection of standard architecture and equipment with demonstrated levels of performance should avoid the need for a detailed RAM analysis. An assessment that considers the site-specific circumstances should be considered to determine if the historic performance evidence can be relied upon for the current system design.

Where it is necessary to carry out a full RAM study, the approach detailed in EN 50126 should be adopted using actual performance data where possible and designers' failure modes effects and criticality analysis (FMECA) methodology.

The *RISSB Reliability, Availability and Maintainability Guideline* also provides further guidance on the approach and techniques to use.

3.8 Safety

Safety is an essential requirement for the traction system design and the solution shall meet all the necessary requirements to demonstrate that the system risk is reduced so far as is reasonably practical (SFAIRP).

A designer's safety risk assessment shall be carried out and consider incorporating the whole rail system, including the risk of:

(a) impact of the safety impact of total and partial power loss;

(b) electric shock;

(c) circulating currents;

(d) earthing and bonding failure;

(e) traction equipment failure;

(f) unbalanced electrical loading;

(g) operation and maintenance activities in proximity to live traction equipment; and

(h) all weather/environmental risks.

The risk should be eliminated or controlled using the following approaches:

(i) Residual electrical hazards shall be eliminated to avoid the risk of hazards within the limits of permits to work.

(j) Motorise disconnectors and remote earthing devices to accelerate the creation of a safe system of work for isolations. This enables faster restoration of power for trains stranded without power.

(k) Locate equipment used to manually isolate and earth the OCL close to access points where practical.

(l) Design electrical sectioning to minimize loss of power to services whilst isolating any faulty equipment and providing safety for operators, the public or others.

(m) Working with adjacent live lines should be minimized.

(n) Isolation limits should l be at the same location for each track.

(o) Earth attachment points should be provided to avoid the use of long earths.

(p) An earth wire should normally be installed to reduce the requirement for track bonding.

(q) Access to energized electrified areas shall be restricted using physical barriers and clearances as detailed in EN 50122.

These measures are not exhaustive and each RIM shall document the controls that are appropriate to manage risks to meet the legislative and regulatory requirements.

3.9 Integrated review

The RIM should carry out an integrated review of the traction power system design to ensure that the design meets the requirements of other engineering disciplines, railway operations, other stakeholders and is fully integrated.

The review should follow a recognized process for progressive integrated design assurance throughout the project life cycle. This should include confirming that the topics described in this section and the interfaces in Section 6 are resolved without introducing unacceptable risks. Some examples of review topics for the integrated design review may include:

(a) alignment with current and future projects that have the potential to impact the infrastructure (e.g., future timetable changes or new rolling stock, new track layouts, signalling alterations/upgrades, NSP changes etc.);

(b) physical clashes between proposed new or amended equipment and existing equipment (e.g., impact on access/egress for vehicles, plant and people, impact on signal and signage visibility, physical and electrical clearances between equipment);

(c) physical and electrical clearances between infrastructure and rolling stock;

(d) operational impacts for normal and disrupted services including outages for maintenance and construction; and

(e) electrical system compatibility across all internal and external systems that may be impacted by the traction power system.

Section 4 Electrical protection

4.1 Description of a protection system

The traction system design shall include a protection system that consists of devices and equipment that each fulfil a required protection function. The protection system shall include:

(a) intelligent electronic devices (IEDs);

(b) dedicated communication for protection;

(c) auxiliary supplies including battery chargers; and

(d) measuring/sensing devices (e.g., current/voltage transformers, temperature sensors).

The protection system shall preserve the safety and integrity of the system by disconnecting faulty equipment, maintaining supplies to non-faulted equipment and comply with EN 50633.

4.2 Protection system reports

Unless a protection reference design is specified by the RIM, the following reports are required.

The protection scheme philosophy and design report shall demonstrate compliance with EN 50633, arc flash requirements and the proposed protection approach, including:

(a) main protection;

(b) backup protection;

(c) busbar protection;

(d) incoming feeder protection;

(e) SFC protection;

(f) transformer protection;

(g) outgoing feeder protection;

(h) protection device failure;

(i) protection lockout functions;

(j) interlocking;

(k) voltage synchronisation check;

(l) prevention of earthing onto a live circuit;

(m) bulk supply point protection interfaces;

(n) inter-tripping;

(o) fault clearance times;

(p) depot circuit protection;

(q) siding or stub end protection;

(r) system behaviour under failure modes;

(s) inrush mitigation;

(t) distance to fault detection;

(u) scheme logic diagrams;

(v) control block diagrams;

(w) communications failures;

(x) protection scheme architecture and functional description;

(y) control room and operator interaction;

(z) system restoration and automation;

(aa) mapped reliability assessment as detailed in EN 50633;

(bb) current transformer and voltage transformer sizing calculations;

(cc) inter-substation IEC61850 communications and functionality; and

(dd) specification of telecommunications requirements to support protection scheme functionality.

The protection scheme shall accommodate several feeding configurations including:

(ee) normal feeding arrangements;

(ff) alterative feeding arrangements;

(gg) scenarios involving disconnection of subsections of the OCS; and

(hh) degraded feeding arrangements including but not limited to half and full busbar outages, substation bypass scenarios.

The protection coordination report shall include the following:

(ii) Detection of abnormal operating situations to prevent injury to personnel, to minimize equipment damage and to limit loss of supply to consumers.

(jj) Initiation of fault clearance.

(kk) Discrimination between all protection devices from the point of power utilisation towards the source of power (as far as practical).

(ll) Determination of auto-reclose facilities.

(mm) Discrimination between traction loads and faults.

(nn) Discrimination between on-train faults and the traction power supply system.

The settings report shall include the following;

(oo) Settings and configuration for each relay, circuit breaker, current transformer and voltage transformer.

(pp) The approach to implementing the different setting groups.

(qq) Any degraded system conditions which will require ECO intervention.

4.3 Protection system requirements

The 25 kV rail system fault clearance times shall achieve compliance with the requirements of EN 50388-1 and EN 50122.

Relays shall have an assigned SIL 1 in accordance with IEC 61508-1 or the manufacturer shall be able to demonstrate that equivalent processes are in place to verify their integrity.

Relays shall incorporate self-monitoring facilities to monitor internal software and hardware operations. The monitoring function shall discriminate between critical and non-critical failures and shall generate an independent alarm output for each.

No single failure of any part of the protection system shall allow a fault to remain in the primary system.

Identical relays shall not be used for primary and backup protection schemes to avoid common mode failure events.

4.4 Protection Interfaces

The interface between the electric traction system, the transmission and distribution systems is generally the bulk supply point feeder (the HV feeder originating from the NSP) circuit breaker at the traction power supply feeder substation. The upstream installation that covers the upstream bulk supply point should be agreed between the RIM and the NSP. The HV connection agreement with the NSP typically covers the following areas:

(a) protection settings

(b) communication

(c) automatic reclosure

(d) direction of power flow (consumption and regeneration)

(e) power quality

(f) operations and maintenance

The requirements in EN 50633 and EN 50388-1 shall apply for the interface 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. Faults on the train roof shall normally be cleared by the traction power system track feeder circuit breaker.

When internal faults occur downstream of the interface, they shall be cleared by the protection on the rolling stock without impact on 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.

The SFC protection and control design shall be integrated into the overall traction power protection design.

4.5 Lightning protection

The assessment and management of risk due to lightning shall be in accordance with AS 1768. To protect the system against over voltages which are above the insulation level, protective devices such as surge arresters shall be used. Surge arresters and voltage limiting devices shall comply with the requirements of IEC 62848 series, EN 50526 series and IEC 60099 series documents.

Section 5 SCADA and telecoms

5.1 SCADA

The traction power SCADA system shall include the control and monitoring of relevant traction power equipment.

The system shall comply with the cyber security standards for control of real time systems as specified in relevant critical infrastructure specification, IEC 62351, NERC-CIP and IEC 62443 series. The NSP and railway SCADA systems shall be coordinated such that all interfacing equipment can be jointly monitored and/or controlled as required in accordance with the NSP interface agreement.

Alarm systems shall be designed in accordance with EEMUA 191. Where shared indication and control is required, auxiliary contacts from the equipment shall be connected to a marshalling cabinet from where the signals can be presented to the SCADA system providing secondary control and monitoring.

SCADA workstations shall be designed in accordance with ISO 11064. Secure distributed network protocol or an IEC protocol (e.g., IEC 61850 series or IEC 60870-5) shall be used.

5.2 Telecommunications

The system shall apply standard communications via high speed-WAN/LAN connections in redundant configuration using international standard protocols such as IEC 60870-5, IEC 61850, etc.

Section 6 Interfaces

6.1 Network service provider

The design interface with the NSP shall be agreed and include the following topics:

(a) insulation coordination

(b) power factor

(c) load

(d) supply diversity

(e) negative phase sequence levels

(f) load balancing

(g) voltage levels

(h) harmonics and power quality

(i) regeneration

An interface agreement shall be developed to confirm the responsibilities between the NSP and RIM including the following.

(j) asset ownership

(k) maintenance and renewal responsibilities

(l) reciprocal support during testing and inspection

(m) approach for issuing and receiving safety documentation

(n) procedures for carrying out switching operations

(o) joint control of circuit breakers, visibility of status and sharing information

(p) responsibilities for coordinating and cooperating during incidents and emergencies

(q) technical conditions applicable under normal and outage conditions

6.2 Rolling stock

The design interface with the rolling stock shall be agreed and include the topics described in the subsequent table.

Interface Parameter	Typical Approach
Insulation coordination	EN 50124-1
Power Factor	Determined by the system design
Maximum Current (>0.5 m/s)	Determined by the system design
Maximum Current (static <0.5 m/s)	Determined by the OCL design and pantograph interface
Voltage and frequency	EN 50163
Regenerative braking	Not permitted when system voltage is greater than 27.5 kV
Electrical protection	Coordination design as per EN 50388

Interface Parameter	Typical Approach
Harmonics	Subject to study as per EN 50388 and EN 50121 series requirements
Maximum speed	Modelled in accordance with EN 50318 and tested to EN 50317 to achieve the line speed at the specified current collection quality (refer to AS 7662.2, *25 kV AC Rail Traction Systems - Part 2: Overhead Contact Line*)
Pantograph number and configuration	Modelled in accordance with EN 50318 and tested to EN 50317 to achieve the line speed at the specified current collection quality (refer to AS 7662.2, *25 kV AC Rail Traction Systems - Part 2: Overhead Contact Line*)
Gauge	Refer to AS 7662.2, *25 kV AC Rail Traction Systems - Part 2: Overhead Contact Line.*
Power control	The method of interrupting power to travel through neutral sections (including other discontinuities) and any requirements for lowering and raising pantographs shall be agreed during the design stage

6.3 Track and civil infrastructure

The management of the OCL mechanical interface with track and civil is described in AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line*.

The rail shall form part of the traction return circuit and there shall be provisions within the track asset management system to ensure that the integrity of the rail return circuit is maintained.

6.4 Signalling

The traction power SCADA system should be designed to enable operators to prohibit electric trains to operate in deenergized sections and to manage the use of bimode rolling stock.

The location of neutral sections shall be agreed with the signal engineer during the system design.

Signal and signage sighting shall be carried out incorporating the location of the OCL as detailed in AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line*.

6.5 Earthing and bonding

AS 7662.3, *25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding* provides details of the earthing and bonding requirements associated with the traction power supply system. These requirements impact all the interfaces described in this section and other lineside infrastructure that might need to be bonded or separated from the traction power system to maintain safety and asset integrity.

6.6 Stations and depots

The management of the OCL interface with stations and depots is described in AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line*.

6.7 Third parties

Third parties, such as water, telecoms, gas and other services, are often in the rail corridor and the impact on existing services shall be assessed when introducing new or amending existing traction power supply systems. Excavations for construction, repairs and maintenance activities are examples of the physical risks that shall be assessed as including during normal and fault conditions. Electrical and mechanical clearances shall comply with AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line* and earthing and bonding shall meet the requirements of AS 7662.3, *25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding*.

6.8 Operations

Rail operations shall be incorporated into the design to ensure that there are adequate controls for the management of train services and people during normal, disrupted and fault scenarios. These different scenarios should be planned, tested and regularly reviewed.

6.9 Other railways

The interface with other railways shall be incorporated into the system design to ensure that the traction power system does not have any adverse effects including introducing hazardous voltages, impacting existing infrastructure or altering the operational requirements. Interfaces with DC electrified railways require compliance with EN 50122-3.

Section 7 Equipment

7.1 Switchgear

All HV switchgear and control gear shall be in accordance with AS 62271 (series) and EN 50152-1.

7.2 Traction power transformers including autotransformers

All traction power transformers shall be compliant with EN 50329 and the load cycle chosen should be based on the traction power system design under normal and outage conditions.

7.3 Static frequency converter

The static frequency converter (SFC) shall maintain a voltage output as close to 27.5 kV as practical whilst maintaining compliance with EN 50163.

The SFC shall comply with EN 60146-1-1, EN 60146-1-3 and EN 60146-2.

The SFC shall be rated for peak traction load taking incorporating the SFC control system measures for load sharing.

If required by the RIM and agreed with the NSP the SFC shall provide bi-directional real and reactive power flow.

The designer and equipment manufacturer shall state any potential forward compatibility issues highlighting any aspects of the design or equipment that could prohibit other manufacturers equipment being used in future.

The SFC protection and control design shall be integrated into the overall traction power system design to comply with EN 50388 and the requirements of the Network Service Provider.

The SFC shall comply with EN 50121 to avoid interference with other railway and non-railway assets.

The method of SFC synchronization shall be specified and the SFC shall be capable of operating as an island feeding a traction area from a black start.

The configuration options available from the SFC shall be agreed with the RIM and may include the ability to mesh with adjacent SFCs, load share, alter reactive power and operate under various outage and fault conditions.

7.4 Disconnectors, earthing switches and switches

Disconnectors, earthing switches and switches shall be designed and manufactured in accordance with IEC 62271 Part 102 and Part 103, and EN 50152 Part 2.

Disconnectors and earthing switches shall either form an integral part of 25 kV AC switchgear or shall be suitable for installation on structures adjacent to the track. Switches shall be suitable for installation on structures adjacent to the track.

Disconnectors and switches shall have a rated impulse voltage of 220 kV and a short-duration power frequency withstand voltage of 110 kV across the isolating distance.

The equipment shall have a short-time nominal withstand current rating compatible with the maximum peak load current and the maximum fault current.

The equipment shall be designed to be padlocked in the open, closed or earth positions as applicable. The equipment local/remote control selector switch shall be designed to be padlocked in both positions.

The equipment shall be designed such that the loss of control or the low voltage power supply does not result in a change of state of equipment position.

The equipment shall be provided with reliable and robust position status indication which shall meet the requirements of EN 62271-102.

The mechanical endurance requirements of EN 62271-102 shall accommodate any support structure deflection and mechanical drive chain misalignment where required.

Disconnectors and switches that are electrically operated shall be fitted with a Disconnector Lockout Relay (DLR). The DLR shall interface with the SCADA system and when operated, shall prevent all remote and local electrical and mechanical means of operation of the disconnector or switch without interfering with the alarms and indications provided by the device

7.5 Cable management

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 RIM shall be consulted to ensure that the following requirements are accommodated as part of the system design:

(a) access and egress measures

(b) provision for EMC management

(c) risk of cable theft and inclusion of deterrence techniques

Access for outside buildings and cable containment shall be reviewed at the design stage. This shall involve assessment of the location and access covers of the containment, so that the maintainer has sufficient access and egress for general maintenance and responding to failures and faults.

External cable pits shall be designed and constructed to minimize the build-up of water within the pits causing damage to cables or hindering maintenance access. This may be achieved through graded floors, drainage, and sump pumps.

Cable locations should be recorded in the asset management system (geographic information system) and Before You Dig Australia as applicable.

7.6 Low voltage supplies

Auxiliary low voltage supply shall be provided for HV substations such that failure of LV equipment does 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.

The substation 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.

7.7 Fire protection

Fire safety systems within a traction substation shall be designed and installed in accordance with the requirements of AS 2067.

7.8 Overhead Contact Line

AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line* shall describe the requirements for OCL equipment based on EN 50119.

7.9 Short circuit test device

Short circuit test devices shall be designed to work safely at full fault current for the fault current predicted under N-1 protection operation. The device should be operated from a position of safety greater than the normal minimum approach distance. The device should be installed to apply a short circuit to live equipment and return the fault current to the rail at the point of the short circuit.

The short circuit device mechanism should be designed to avoid bouncing contacts and should be tested mechanically prior to energisation.

7.10 Building

The substation building shall comply with the National Construction Code.

Section 8 Entry into service

8.1 Assurance requirement

A progressive assurance approach should be adopted that demonstrates how at each stage of the project life cycle the equipment and systems comply with the requirements.

8.2 Equipment testing requirements

Individual equipment shall complete the testing required by the relevant product standards including type testing where applicable.

8.3 System testing requirements

The traction system shall be tested at equipment level, sub system level and progressively at a whole system level. A testing and commissioning strategy and plan shall be produced including the following information:

(a) staging details

(b) sub system tests

(c) roles and responsibilities

(d) contingencies

(e) pass/fail criteria

(f) high level testing methodology

(g) emergency arrangements

(h) communications

(i) interface management

For system testing requirements associated with OCLs and earthing and bonding, refer to AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line* and AS 7662.3, *25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding*.

Section 9 Sustainability and environment

9.1 Energy efficiency

During system design (as detailed in Section 3) the whole life energy efficiency should be reviewed focusing on energy usage during construction and throughout the asset life. Electrical loses should be calculated based on the current timetabled services and any future proposed services that the traction power system is designed to accommodate

9.2 Environmental impact

The use of SF_6 and other gases that are damaging to the environment should be limited based on the requirements of the RIM.

9.3 Resilience to climate change

The traction power system design shall accommodate for the impact of climate change:

(a) when determining flood risk of the location of the substation and other critical traction equipment infrastructure; and

(b) the environmental parameters selected in Section 3.3.

The design of the traction power system shall comply with the requirements of AS 7637 in relation to climate change.

Section 10 Maintenance and operation

10.1 Electrical clearances

The traction power system design shall include electrical clearances that are achieved through physical barriers and separation by distance in non-public and publicly accessible areas. The electrical clearances shall meet the RIM requirements and comply with EN 50122 as a minimum. The normal minimum approach distance for workers, plant, tools and equipment should be maintained at three (3) metres and activities that have the potential to come within three (3) metres of live equipment should be carried out under a permit to work that includes disconnecting the power unless alternative control measures are adopted.

Alternative control measures can include enhanced competencies, mechanical and electrical controls on plant and equipment and physical demarcation reminders. Further guidance on safety measures is provided in EN 50488.

10.2 Isolation and earthing

The traction power supply system shall have the following provisions for isolation and earthing.

(a) Isolation – A secure means of disconnecting the power supply. This may include remote securing of devices where a physical separation is achieved, and the status of the disconnection can be confirmed.

(b) Proving Dead – A method of testing that confirms that the power has been disconnected for the separate sectioned part of the system.

(c) Earthing – A method of earthing to reduce the risk if there is the possibility of inadvertent reenergisation and to protect from other energy sources. The earthing arrangements shall be sufficient to comply with EN 50122 under N-1 conditions. Earth attachment points or equivalent shall be installed to avoid the use of long earths wherever practical.

(d) Safety Documentation – A method of issuing safety documentation to competent people shall be developed to ensure that the safety of workers and the public who are at risk of or plan to come within the minimum approach distance.

10.3 Asset management

The asset management of traction power supply assets should comply with the requirements of ISO 55001 and the RIMs safety management system. The maintenance of OCL is described in AS 7662.2, *25 kV AC Rail Traction Systems – Part 2: Overhead Contact Line* and the maintenance of earthing and bonding is described in AS 7662.3, *25 kV AC Rail Traction Systems – Part 3: Earthing and Bonding*

10.4 Operation

The assets shall be operated within their design parameters and only trained people are permitted to operate traction power supply assets. The functional capabilities of the traction power supply system under outage and fault conditions shall be published and communicated to the operators and other relevant stakeholders.

Appendix A Example Traction Power System Designs (Informative)

A.1 Overview

This appendix describes the typical 25 kV AC electrification system designs that are used internationally highlighting the following:

(a) Main conductor configuration including return circuit.

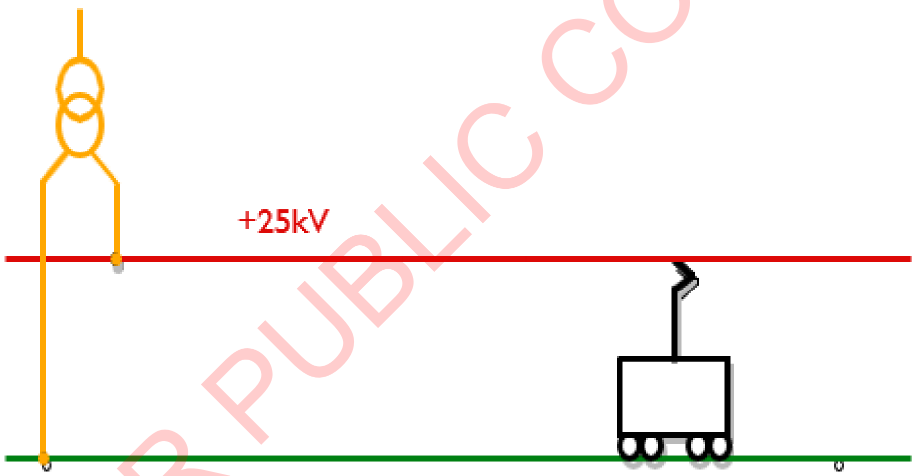
(b) Electrical system compatibility approach.

(c) Impact from an NSP perspective.

(d) Other characteristics that encourage or discourage the selection of the traction power system.

The traction power systems described in this appendix are only examples of the approaches that could be adopted. Designers should work with stakeholders to determine the most appropriate system selection and include the features necessary to meet the project requirements. The advantage of using an existing known reference system is that some features are well understood, and the assurance arrangements can be based on a process of cross acceptance.

A.2 Rail return



Appendix Figure A-1 Rail return electrical layout

(a) The simplest conductor configuration with only contact wire and catenary this system design relies entirely on the rails for the return circuit. Each structure is bonded to rail.

(b) The approach to electrical system compatibility is to have no built-in immunisation. The rail earth voltages are high due to maximum current returning through the rail. Induction into adjacent conductors is significant because there are minimal immunisation effects at source. This reduces the length of parallel cables that are permitted and increases the risks of electrical system compatibility issues with internal and external systems

(c) The section impedances are typically high unless large conductors are used, and this requires more frequent connections to incoming supply points provided by the local Network Service Providers

(d) This system is typically used in sidings, infrequently used sections of track and areas that don't require any built-in immunisation

A.3 Return earth wire

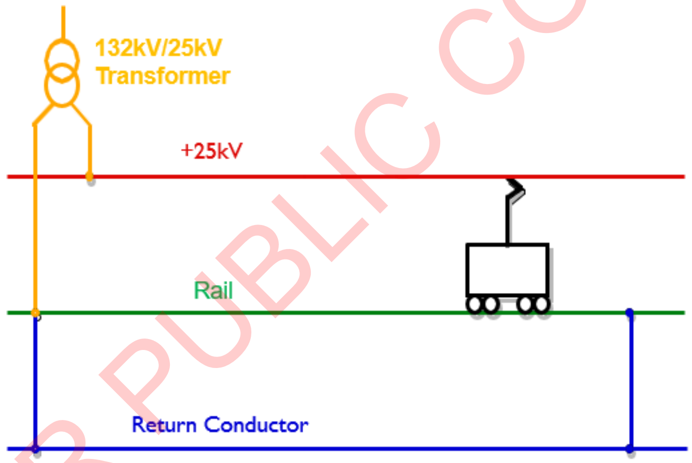
(a) This system has main contact and catenary but an additional aerial conductor that is designed to act as an earth wire and also provide an effective return circuit. Not every structure is bonded directly to the rail because of its connection to the earth wire. Connections are required at typically 400m intervals

(b) The return earth wire provides some immunisation at source with a proportion of the return current flowing through the return earth wire this cancels out some of the electromagnetic effects from the main OCL conductors. A reduction in the current flowing in the rail reduces rail earth voltages and the system can be configured to have different conductor locations and sizes to improve the immunisation effects.

(c) The system impedance is typically less than the rail return system but is obviously dependent upon the conductor sizes. Feeder stations are required relatively frequently depending upon load and other characteristics.

(d) This system design is a good choice for metro systems without large distances between feeder stations and modern lineside infrastructure that does not require high levels of immunisation at source.

A.4 Boosterless return conductor



Appendix Figure A-2 Boosterless return conductor electrical layout

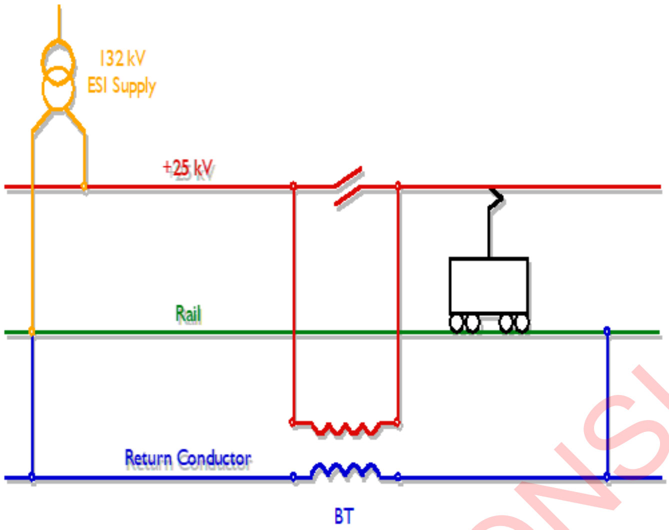
(a) This system has main contact and catenary but an additional return conductor that is installed on insulators and connected to the rail at regular intervals (typically 3.2km). This arrangement can also include a separate earth wire which improves system impedance and removes the need for each structure to be connected to rail.

(b) The return conductor provides good immunisation at source with a proportion of the return current flowing through the return conductor cancelling out the electromagnetic effects from the main OCL conductors. A significant reduction in the current flowing in the rail reduces rail earth voltages and the system can be configured to have different conductor locations and sizes to improve the immunisation effects.

(c) The system impedance is typically less than the rail return system and with an additional earth wire this is a low impedance system design but is obviously dependent upon the conductor sizes.

(d) This system design is a good choice for metro systems without large distances between feeder stations and where improved immunisation is required.

A.5 Boostered return conductor



Appendix Figure A-3 Boostered return conductor electrical layout

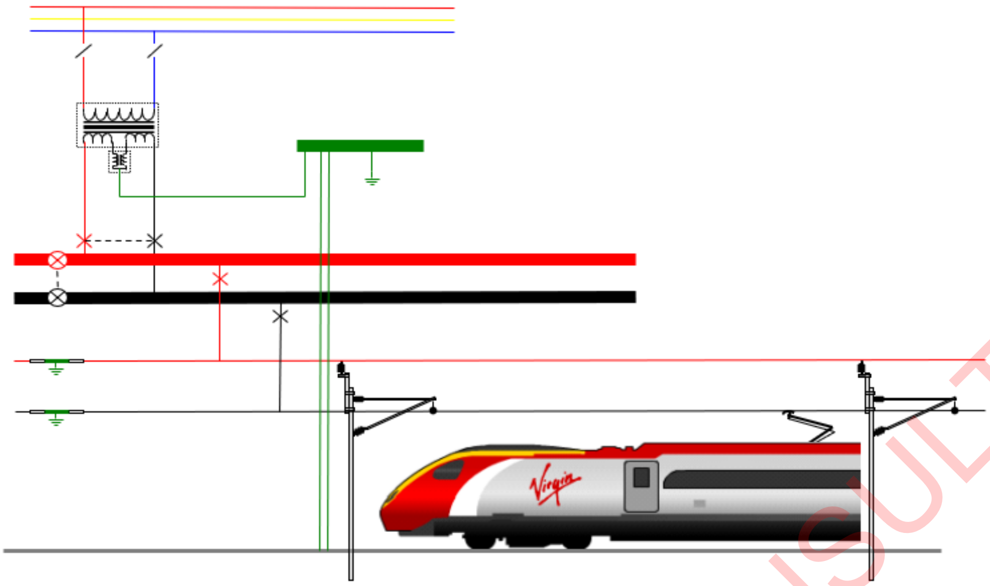
(a) This system has the same conductors as the return conductor system but with the addition of a booster transfer (BT).

(b) This system design has very good immunisation at source with the booster conductor designed to create an equal current in the return conductor compared to the main contact and catenary. This system design reduces the rail currents except in the section that the train is directly positioned in and minimizes rail earth voltages and the induction effects on adjacent lineside conductors.

(c) The system impedance is significantly higher than a return conductor only or return earth wire system due to the inclusion of the booster transformer which is a lumped impedance in the system. This reduces the maximum distance between feeder stations obviously dependent upon the conductor sizes and other characteristics.

(d) This system design used to be a popular choice due to good immunisation properties but is no longer popular due to disadvantages of booster transformers and the better performing alternatives and modern lineside infrastructure.

A.6 Autotransformer fed



Appendix Figure A-4 Autotransformer fed layout

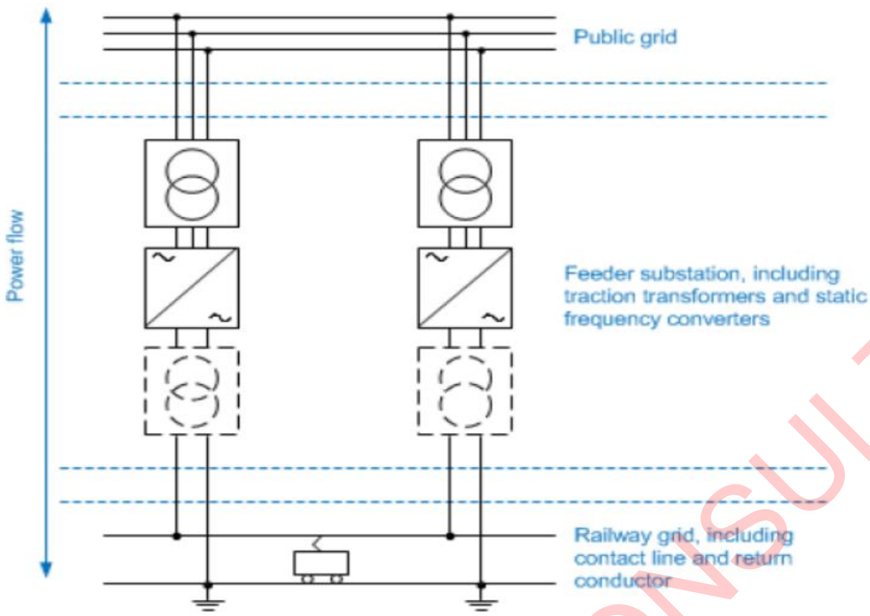
(a) This system has main contact and catenary and auto transformer feeders installed on 25 kV insulators. The system acts as a 50 kV distribution system with the current returning through the autotransformer feeder. An aerial earth conductor is typical used and not every structure is bonded directly to the rail because of its connection to the earth wire. The centre tap of the autotransformer is connected to rail enabling the operation of the autotransformer system

(b) The system is designed to equalize currents between the main OCL conductors and the autotransformer feeder conductors. This provides an effective immunisation at source. Similar to the boostered and boosterless systems there is an in section effect where the current in rail remain high when a train is operating in the section away from the rail connections. This effect is higher in an Autotransformer system due to larger distances between the transformers (typically 10km).

(c) The system impedance is typically low and due to the distribution of power at effectively 50 kV it is possible to have higher power loads and feeder stations further apart.

(d) This system design is commonly chosen for long distances and situations that have high power loads and require good immunisation.

A.7 Static frequency converter fed solutions



Appendix Figure A-5 Substation electrical layout

Static frequency converters can be used in all of the previously described traction power system designs. They replace conventional transformers which are used to convert the supply voltage provided by the NSP into a single phase 25 kV supply. They use power electronics to convert the supply voltage which can be relatively weak compared with conventional supplies into a stable 25 kV supply that does not vary at source. This approach is beneficial for NSPs because it represents at balanced 3phase load and reactive power can be controlled reliability. A fully meshed static frequency converter fed system allows neutral section to be removed and the system can control the share of load between the different supply points.

The use of static frequency converters is increasing as technology improves although they are more expensive that conventional transformers, they offer the benefits previously described.

Appendix B Bibliography (Informative)

The following referenced documents are used by this Standard for information only:

- 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 4100, *Steel structures*
- AS 5577, *Electricity network safety management systems*
- AS 60529, *Degrees of protection provided by enclosures (IP Code)*
- AS 61000.3.6, *Electromagnetic compatibility (EMC)*
- AS 62271.1, *High-voltage switchgear and controlgear, Part 1: Common specifications for alternating current switchgear and controlgear*
- AS/NZS 7000, *Overhead line design*
- IEC 60071-1, *Insulation co-ordination − Part 1: Definitions, principles and rules*
- IEC 61580, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements*
- IEC 62497-1, *Railway applications – Insulation coordination – Part 1 – Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*
- ISO 31000, *Risk management – Principles and guidelines*
- EN 15663, *Railway applications − Vehicle reference masses*\
- EN 50126-1, *Railway applications - The specification and demonstration of reliability, availability, maintainability and safety (RAMS) – Part 1: Generic RAMS process*
- EN 50149, *Railway applications — Fixed installations — Electric traction — Copper and copper alloy grooved contact wires*
- EN 60146-1-1, *Semiconductor converters - General requirements and line commutated converters - Part 1-1: Specification of basic requirements*
- PAS 2080, *Carbon management in buildings and infrastructure*