Onboard Main Power and Auxiliary Power Supply Systems for Light Rail Vehicles

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Standard governance

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Document history

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Preface

The Asset Standards Authority (ASA) is a key strategic branch of Transport for NSW (TfNSW). As the network design and standards authority for NSW Transport Assets, as specified in the ASA Charter, the ASA identifies, selects, develops, publishes, maintains and controls a suite of requirements documents on behalf of TfNSW, the asset owner.

The ASA deploys TfNSW requirements for asset and safety assurance by creating and managing TfNSW's governance models, documents and processes. To achieve this, the ASA focuses on four primary tasks:

- publishing and managing TfNSW's process and requirements documents including TfNSW plans, standards, manuals and guides
- deploying TfNSW's Authorised Engineering Organisation (AEO) framework
- continuously improving TfNSW’s Asset Management Framework
- collaborating with the Transport cluster and industry through open engagement

The AEO framework authorises engineering organisations to supply and provide asset related products and services to TfNSW. It works to assure the safety, quality and fitness for purpose of those products and services over the asset's whole-of-life. AEOs are expected to demonstrate how they have applied the requirements of ASA documents, including TfNSW plans, standards and guides, when delivering assets and related services for TfNSW.

About this document

This standard sets the minimum technical requirements for the main power supply system and auxiliary power supply system onboard new and significantly modified TfNSW light rail vehicles.

The minimum technical requirements in this standard have been developed in consultation with the light rail vehicle industry including operators, manufacturers, and consultants.

This standard is a first issue.
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1. Introduction

The technical performance and safety of light rail vehicles (LRV) is paramount to the public transport operations of TfNSW. This standard enables TfNSW to set out the technical requirements for the onboard main power supply system and auxiliary power supply system to help ensure the performance and safety of new and altered TfNSW LRV assets.

The onboard main power supply system collects power from the overhead contact wire of the infrastructure traction power supply system using pantographs and returns current to the running rails through wheel axle earthing units. The onboard main power supply system supplies power to the traction module and auxiliary systems, and provides over-current and over-voltage protections.

For overhead wire-free operations, the onboard main power supply system may collect power from proprietary ground based third rail power supply systems or contactless (inductive) power supply systems or use power from onboard traction battery systems. The traction batteries can be charged from the overhead wire, when available, or through the proprietary ground based third rail or contactless (inductive) power supply system, or from a combination of the overhead wire and a ground based power supply system.

The auxiliary power supply system is powered from the onboard main power supply and provides power to all LRV auxiliary systems in normal operation and in emergency conditions via the auxiliary battery system.

2. Purpose

This document provides the minimum requirements and recommendations for the main power supply system and the auxiliary power supply system onboard TfNSW LRVs. This standard aims to ensure the reliability, availability, and maintainability of new and refurbished TfNSW LRVs by setting minimum technical requirements and considerations for their design.

2.1. Scope

This standard covers requirements for all electrical circuits and electrical equipment in the following light rail rolling stock systems:

- infrastructure traction power supply interfaces requirements
- main power supply system equipment requirements including pantographs, wheel axle earth units and high-speed circuit breakers (HSCBs)
- over-voltage and over-current protection systems
- auxiliary battery systems and management systems
- traction battery systems and management systems
2.2. **Application**

This standard applies to the procurement of new light rail passenger vehicles for TfNSW.

This standard also applies to existing light rail passenger vehicles that are to undergo substantial modification.

3. **Reference documents**

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

**International standards**

- EN 45545-2 Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behavior of materials and components
- EN 50123-1 Railway applications - Fixed installations - D.C. switchgear – General
- EN 50128 Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems
- EN 50153 Railway applications – Rolling stock – Protective provisions relating to electrical hazards
- EN 50155 Railway applications - Electronic equipment used on rolling stock
- EN 50163 Railway applications - Supply voltages of traction systems
- EN 50343 Railway applications – Rolling stock – Rules for installation of cabling
- EN 50388 Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability
- EN 50526-1 Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 1: Surge arresters
- IEC 60077 (series) Railway applications – Electric equipment for rolling stock
- IEC 60494-2 Railway applications - Rolling stock - Pantographs - Characteristics and tests - Part 2: Pantographs for metros and light rail vehicles
- IEC 61373 Railway applications - Rolling stock equipment - Shock and vibration tests
- IEC 61881-3 Railway applications - Rolling stock equipment - Capacitors for power electronics - Part 3: Electric double-layer capacitors
- IEC 62497-1 Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment
- IEC 62497-2 Railway applications - Insulation coordination - Part 2: Overvoltages and related protection
IEC 62864-1 Railway applications – Rolling stock – Power supply with onboard energy storage system – Part 1: Series hybrid system

IEC 62928 Railway applications — Rolling stock equipment — Onboard lithium-ion traction batteries

I.S. EN 50463-2 Railway applications - Energy measurement on board trains - Part 2: Energy measuring

Transport for NSW standards

T LR EL 00001 ST Traction Power System Requirements
T LR EL 00007 ST Traction Power Supply Infrastructure and Light Rail Vehicle Interface
T LR RS 00117 ST Electrical Circuits and Equipment for Light Rail Vehicles
T LR RS 01701 ST Mounting and Installation of Electrical Equipment for Light Rail Vehicles
T LR RS 12001 ST Interior and Exterior Lighting for Light Rail Vehicles
T MU RS 17001 ST Environmental Conditions for Rolling Stock

4. Terms and definitions

The following terms and definitions apply in this document:

ADD automatic dropping device

ASA Asset Standards Authority

EAPS electric auxiliary power supply

HSCB high-speed circuit breaker

LRV light rail vehicle

TfNSW Transport for NSW

vehicle body (in the context of this document) refers to the body of individual LRV vehicle modules
5. General requirements

The onboard main power and auxiliary power supply systems shall comply with the applicable sections of the following international standards:

- EN 50153 *Railway applications – Rolling stock – Protective provisions relating to electrical hazards*
- EN 50155 *Railway applications - Electronic equipment used on rolling stock*
- EN 50163 *Railway applications - Supply voltages of traction systems*
- EN 50526-1 *Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 1: Surge arresters*
- EN 50343 *Railway applications – Rolling stock – Rules for installation of cabling*
- EN 50388 *Railway applications - Power supply and rolling stock - Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability*
- IEC 60077 (series) *Railway applications – Electric equipment for rolling stock*
- IEC 60494-2 *Railway applications - Rolling stock - Pantographs - Characteristics and tests - Part 2: Pantographs for metros and light rail vehicles*
- IEC 62497-1 *Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment*
- IEC 62497-2 *Railway applications - Insulation coordination - Part 2: Overvoltages and related protection*

The onboard main power and auxiliary power supply systems shall comply with the applicable sections of the following TfNSW standards:

- T LR EL 00007 ST *Traction Power Supply Infrastructure and Light Rail Vehicle Interface*
- T LR RS 00117 ST *Electrical Circuits and Equipment for Light Rail Vehicles*
- T LR RS 01701 ST *Mounting and Installation of Electrical Equipment for Light Rail Vehicles*

T LR RS 00117 ST and T LR RS 01701 ST detail the following requirements for the onboard main power and auxiliary power supply systems:

- operating environment
- electromagnetic compatibility
- prohibited materials
- fire performance
- circuit drawing diagrams
• technical manuals and maintenance plans
• general circuit voltages
• mounting and installation of electrical equipment

6. Onboard main power supply system

The onboard main power supply system requirements includes requirements for the infrastructure traction power supply interface, overcurrent protection, current return system, pantographs, safety earthing switch and onboard energy measurement.

6.1. Infrastructure traction power supply interface

The onboard main power supply directly interfaces with the TfNSW light rail infrastructure traction power supply systems. Unless otherwise specified in this standard, the specific interface requirements are detailed in T LR EL 00007 ST Traction Power Supply Infrastructure and Light Rail Vehicle Interface. T LR EL 00007 ST includes specific requirements for the following:

• pantographs
• overhead wire-free operations
• ground and overhead contact charging of traction batteries
• traction return
• electrical protection equipment
• power generation requirements
• information to be provided to TfNSW
• in-rush current limiting

6.2. In-rush current limiting

The onboard main power supply and auxiliary systems shall be designed to limit the in-rush input current from the infrastructure overhead power supply after either the re-closing of the onboard HSCBs or substation HSCBs. The total in-rush current magnitude limit is specified in T LR EL 00007 ST.
6.3. **High-speed circuit breaker overcurrent protection**

Overcurrent from short circuits and failures in the traction and auxiliary circuits shall immediately trip an onboard HSCB to limit the fault currents and clear the fault.

Where applicable, continuous monitoring using sensor systems, protection relays or equivalent systems shall be used to detect fault conditions and instantaneously trip the HSCB to prevent fault currents from developing.

6.3.1. **Coordination of short circuit protection between the onboard and substation HSCBs**

The onboard HSCB shall be configured to enable co-ordination with the traction power supply substation HSCBs for onboard short circuit protection.

The coordination of the onboard short circuit protection between the onboard and the substation HSCB shall comply with EN 50388 and it shall nominally result in the onboard HSCB tripping, limiting and clearing the prospective fault current before it is seen by the substation HSCB. The prospective fault current is the current that would flow in the circuit if the circuit breaker were replaced by a conductor of negligible impedance.

TfNSW acknowledges that coordination may not be possible at all times. For example onboard fault currents with very steep rate of rise and occurring at short overhead wire distance to the substation would likely be detected simultaneously by both the onboard HSCB and substation HSCB.

6.3.2. **HSCB excessive resets protection**

Protection shall be provided against excessive consecutive automatic or manual (by the driver) resets of the onboard HSCB after consecutive tripping due to short circuits.

Where applicable, fault finding techniques or systems shall be provided to aid the driver in identifying the cause of HSCB trips.

The remote monitoring of the operational status of the HSCBs shall be available through the light rail vehicle (LRV) operating system screen or equivalent driver interface.

6.3.3. **HSCB equipment requirements**

The HSCB shall comply with the requirements of T LR EL 00007 ST and EN 50388.

HSCBs and line-switches type testing shall be in accordance with IEC 60077-3 and IEC 61373 *Railway applications - Rolling stock equipment - Shock and vibration tests*.

HSCBs and line-switches operational frequency rating shall be 'C3' as defined in IEC 60077-3.

HSCBs and line-switches shall primarily use passive cooling; any other type of cooling shall be supplemental only.
The electrical cable routing between the HSCB and the current collecting device shall be as short and as direct as possible to reduce resistance and the length of unprotected cabling.

Parallel connection with HSCBs and line-switches shall be limited to detection, measurement and control equipment.

The HSCB selection shall consider the capacitance that exists in the input filters of traction systems and in the filters in substations which can influence the switch-off time. Longer switch-off time can impact the HSCB’s ability to limit the prospective current and can reduce the HSCB contact tips' lifespan.

Where applicable, the speed of the selected HSCB operation type, as defined in EN 50123-1 Railway applications - Fixed installations - D.C. switchgear - General, either high speed ‘type H’, very high speed ‘type V’ or semi-high speed ‘type S’, shall be indicated to the purchaser.

### 6.4. Over and undervoltage protection

#### 6.4.1. Transient overvoltage protection

Transient overvoltage due to onboard and infrastructure switching operations and lightning (environmental electrical discharge) shall be suppressed by onboard surge arrester(s) to protect onboard systems.

The surge arrester shall provide protection to onboard equipment from arcing voltages of the onboard and substation HSCBs during electrical fault clearing.

The overvoltage protection shall be tested in accordance with IEC 62497-2 Railway applications - Insulation coordination - Part 2: Overvoltages and related protection.

#### 6.4.2. Surge arrester requirements

The surge arrester rating and lifespan selection shall be compatible with the intensities and frequency of strikes expected in NSW as detailed in T MU RS 17001 ST Environmental Conditions for Rolling Stock. Refer to T LR EL 00007 ST for specific surge arrester lightning impulse withstand requirements.

The surge arrester shall not degrade due to the highest non-permanent voltage of the infrastructure traction power supply as detailed in T LR EL 00001 ST Traction Power System Requirements.
The surge arresters shall be functionally type tested in accordance with EN 50526-1 *Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 1: Surge arresters* or equivalent internationally recognised standard for non-linear, metal-oxide surge arresters with no spark gaps that covers the following tests:

- operating duty
- accelerated ageing
- weather ageing
- operation in high humidity
- resistance to UV degradation
- resistance to degradation from exposure to pantograph sparking
- overload test

The surge arrester shall be immune to shocks and vibration for body mounted equipment in accordance with IEC 61373.

The cable connection between the pantograph and surge arrester shall be as short and as straight as possible.

The surge arrester design shall not have the potential to shatter or it shall be enclosed to prevent the forceful release of porcelain shards and other material from the vehicle where it may cause a safety risk.

### 6.4.3. Undervoltage protection

The onboard HSCB shall open automatically if the line voltage falls below 400 V for more than 2 seconds in accordance with the requirements of the infrastructure traction power supply system detailed in T LR EL 00007 ST.

The onboard HSCB shall close automatically after the line voltage has restabilised. The voltage at which the HSCB re-closes shall be coordinated with the requirements of the infrastructure power supply system and shall comply with EN 50163.

### 6.5. Current return arrangement

The running rails forms the infrastructure negative return rail as described in T LR EL 00001 ST *Traction Power System Requirements*.

The main power supply current return circuit shall maintain a robust electrical connection to the running rails under all operating speeds and foreseeable operating conditions affecting the wheel rail interface.
To protect against single point failures and single point loss of electrical contact with the running rails, the main power supply current return circuit shall use multiple wheels fitted with wheel axle earth units.

To protect against the loss of electrical contact with the running rails after a bogie derailment, the current return path to the running rails shall be distributed over multiple wheels on multiple bogies.

Connections to the wheel axle earthing units shall be direct with no intermediate electrical connections to the bogie frame.

6.6. **Pantograph**

The following overhead wire traction supply interface requirements shall be in accordance with T LR EL 00007 ST:

- pantograph dimensional characteristics
- pantograph height range
- pantograph dynamic performance
- pantograph raising and lowering
- pantograph upwards thrust
- pantograph static current draw
- contact strip material
- pantograph operations in overhead wire-free sections

6.6.1. **Pantograph dielectric test**

Pantograph dielectric testing, performed on the pantograph and related equipment installed on the vehicle, shall be in accordance with IEC 62497-1 Ed. 1.1 (Bilingual 2013) *Railway applications - Insulation coordination - Part 1: Basic requirements - Clearances and creepage distances for all electrical and electronic equipment*.

Pantograph frame insulators shall have a minimum dielectric strength of 40 kV dry.

6.6.2. **Pantograph mechanical requirements**

Pantographs shall use single-piece carbon contact strips integrated to the pantograph head.

The pantograph head and carbon strips shall be fastened using an anti-loosening system to positively prevent failure of the fastening system.

The mechanical design of the pantograph shall be inherently fail-safe such that any failure will not cause the pantograph to overextend or collapse outwards outside the vehicle’s static gauge.
Failure of vulnerable components, such as chains and linkages, shall not cause catastrophic damage to the vehicle and infrastructure.

Pantograph mounting insulators shall be impact resistant and shall not fail in the event of the pantograph overextending and impacting overhead infrastructure. A minimum compressive strength of 180 kN, and a minimum cantilever strength of 565 Nm is recommended.

Pantograph pneumatic hoses shall maintain physical integrity and low electrical conductive properties after long-term exposure to ultraviolet (UV) radiation and other external environmental conditions.

Pantograph bearings shall be maintenance free between overhaul periods.

### 6.6.3. Pantograph lowering and raising requirements

Pantographs shall have a fail-safe automatic dropping device (ADD) to lower the pantograph to prevent over reach and subsequent collision with overhead power and road infrastructure in the event of failed overhead contact wiring.

For operation in overhead wire-free areas, the pantograph shall automatically be lowered prior to the LRV entering the wire-free sections without the need to trigger the ADD.

The pantograph shall lower below the static rolling stock outline of the LRV within three seconds of activating the “pantograph lower button” or activation of the ADD.

A manual system shall be provided to enable emergency lowering and raising. The pantograph shall enable manual raising within three minutes.

### 6.7. Safety earthing switch (disconnect and earth)

A safety earthing switch, or equivalent system, shall be provided to enable maintenance personnel to positively disconnect and earth the LRV’s main power supply circuit and secure it to provide protection from inadvertent application of power from any source.

Due to the safety critical nature of the safety earthing switch, it shall be designed with an applicable Safety Integrity Level (SIL) in accordance with EN 50128 *Railway applications - Communication, signalling and processing systems - Software for railway control and protection systems*.

The safety earthing switch, or equivalent system, when placed in the ‘disconnect and earth’ position shall do the following:

- open the HSCB to disconnect the main power supply circuit from the pantograph and prevent the HSCB from being closed
- open the onboard energy storage system circuit to disconnect the main power supply circuit from the onboard energy storage system, and prevent the onboard energy storage system from supplying the main power supply circuit
- lower the pantograph
- earth the main power supply circuit using an earthing contactor(s) to remove residual charge, from capacitive elements, and to protect against inadvertent application of power
- allow a lockout-tagout (LOTO) device to be used to secure the ‘disconnect and earth’ state of the safety earth switch while maintenance work is undertaken
- allow a lockout-tagout (LOTO) device to be used to secure the ‘isolated’ state of the onboard energy storage system while maintenance work is undertaken

*Note: The LOTO safety procedure is used in industry to ensure that dangerous machines are properly shut off and not started up again prior to the completion of maintenance or servicing work.*

The earthing contactors shall withstand the maximum possible onboard prospective short circuit current.

The safety earthing switch shall be protected from unauthorised operation.

Where applicable, the safety earthing switch contactors shall be protected against welded contacts and any consequential mal-operation.

### 6.8. Wheel axle earthing units

Wheel axle earthing units use carbon brush contacts to pass current to the wheel axles either radially or axially to provide a stable electrical connection to the wheels for the main power current return and for equipotential earthing to the running rails.

The wheel axle earthing units, including their electrical connectors, carbon brushes and spring systems shall be compatible with the shocks and vibrations for axle mounted equipment given in IEC 61373.

To enable periodical testing of the condition of wheel axle earthing units, a procedure shall be provided to enable electrical resistance testing between the electrical terminals and the wheels.

### 6.9. Onboard energy metering

An onboard energy meter shall be provided to measure the current and voltage at the pantograph or other current collecting devices, to accurately determine the energy consumed or returned to the infrastructure power supply system by the LRV.

Onboard energy metering systems shall comply with the accuracy requirements in I.S. EN 50463-2 *Railway applications - Energy measurement on board trains - Part 2: Energy measuring.*
7. **Electric auxiliary power supply system**

The electric auxiliary power supply (EAPS) system converts the infrastructure power supply line voltage to provide power to onboard auxiliary systems, for example, the climate control systems, lighting systems and control circuits.

7.1. **Electrical protection**

The EAPS system electrical protection requirements shall be in accordance with T LR RS 00117 ST *Electrical Circuits and Equipment for Light Rail Vehicles*.

The EAPS system electrical outputs shall be galvanically isolated from the infrastructure power supply input.

The equipment shall provide protection to cover a full range of credible failures and abnormal conditions and shall have not the capacity to affect LRV and road infrastructure including power supply and signalling systems.

Interruptions to the EAPS power output shall be indicated to the driver. Where applicable the cause of the output interruption, such as system faults or automatic cut-off due to substation traction supply undervoltage or overvoltage conditions, shall be recorded for fault finding purposes.

The EAPS system shall be protected from the effects of induction motor failures in auxiliary equipment.

All operational EAPS modules shall automatically reset upon restoration of interrupted input power after automatic shutdown due to over and undervoltages.

7.2. **EAPS system voltages**

The EAPS system voltage shall comply with the general voltages specified in T LR RS 00117 ST *Electrical Circuits and Equipment for Light Rail Vehicles*.

7.3. **EAPS system redundancy**

The EAPS system shall continue to operate normally through momentary interruptions of infrastructure power supply input power due to pantograph bounce.

The EAPS system shall provide a level of redundancy to enable the continuation of a passenger service after a single point failure or the failure of one EAPS module. For example, power to the following systems shall be maintained to enable continuation of operation:

- ventilation and climate control systems
- lighting circuits
• traction and vehicle control circuits and equipment
• communication, control and signalling systems
• battery chargers
• other safety and operation critical systems and equipment

7.4. Auxiliary battery system

The auxiliary emergency battery system shall provide emergency backup power to safety critical onboard electrical systems during interruptions to the EAPS system including substation input power interruptions and tripping of the onboard main power supply HSCB.

The auxiliary battery system at minimum shall provide emergency power to enable the following:

• minimum ventilation requirements in crew and passenger areas under crush load conditions
• minimum lighting requirements in crew and passenger areas
• operation of the emergency exit lights, step lights, hazard lights, direction indicator lights, and stop lights
• operation of the onboard communication systems including the public address and radio communication systems
• operation of all passenger doors for emergency egress
• operation of the driver’s display unit and control interfaces to maintain control of critical systems and enable fault-finding activities
• operation of event recorders, video surveillance and fire detection systems
• orderly shutdown of processor driven systems to prevent inadvertent effects due to sudden loss of power
• re-start of the LRV traction and auxiliary power supply systems after the input power has been restored

7.4.1. Battery capacity and emergency load duration

In the absence of specified minimum emergency battery system load duration requirements in the contractual specification, the emergency loads duration shall be as listed in Table 1 and Table 2. The contractual specification is the scope and performance requirements of the contract between the rolling stock purchaser (for example, TfNSW) and supplier.

The battery system at 80% state of charge shall have sufficient charge capacity to power the emergency loads specified in Table 1 and Table 2. This capacity shall be available over the full operating life cycle of the battery storage system.
The battery system shall have excess capacity to start the LRV, with the pantographs in the lowered position, after providing emergency power for the durations specified in Table 1 and Table 2.

### Table 1 - Control circuit minimum emergency load duration

<table>
<thead>
<tr>
<th>System to be maintained</th>
<th>Minimum operation duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video surveillance systems</td>
<td>4 hours</td>
</tr>
<tr>
<td>Door open and close controls and actuators</td>
<td>20 open and close cycles over 4 hours</td>
</tr>
<tr>
<td>Train radio equipment, public address and intercom systems</td>
<td>4 hours</td>
</tr>
<tr>
<td>Driver’s display unit and control interface</td>
<td>4 hours</td>
</tr>
<tr>
<td>Fire detection system</td>
<td>4 hours</td>
</tr>
<tr>
<td>Event recorders</td>
<td>4 hours</td>
</tr>
</tbody>
</table>

### Table 2 - Lighting and ventilation minimum emergency load duration

<table>
<thead>
<tr>
<th>System to be maintained</th>
<th>Minimum duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency ventilation</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>Emergency internal lights, exit lights and step lights</td>
<td>4 hours</td>
</tr>
<tr>
<td>External lights including rear position lights, visibility lights, direction indicators or hazard lights and stop lights. Head lights excluded. Refer to T LR RS 12001 ST Interior and Exterior Lighting for Light Rail Vehicles.</td>
<td>4 hours</td>
</tr>
</tbody>
</table>

#### 7.4.2. Auxiliary battery system mechanical requirements

The auxiliary battery system’s mounting shall be designed to minimise the safety risks during collisions with other LRVs or other road vehicles.

The battery system's batteries shall be safely accessible for replacement or maintenance by maintenance personnel.

If the batteries are accessed from within the vehicle, for example if located under the seats, the battery compartment shall be sealed and vented to the outside of the vehicle to prevent any battery vapours or smoke entering the vehicle. The battery compartment and its sealing system shall withstand any fire intensity and duration expected from the battery type used.

For roof mounted batteries, the battery storage system type shall be compatible with the increased ambient temperatures to be expected inside compartments exposed and prone to
solar radiation and heat gain. Refer to T MU RS 17001 ST *Environmental Conditions for Rolling Stock* for typical operating environmental conditions.

### 7.4.3. Auxiliary battery management system

The auxiliary battery system shall be equipped with the necessary battery management system to manage the monitoring, charging and protection of the battery storage system to ensure the specified minimum operating life.

The battery management system, where applicable shall protect the battery energy storage system from the following:

- overcurrent during charging and discharging
- overvoltage during charging
- over discharge (undervoltage)
- effects of generated and ambient temperatures during charging and discharging

The battery charging system shall charge the batteries from an initial 20% state of charge to 80% state of charge within three hours under normal EAPS operation.

Where applicable, automatic removal or reduction of charging current shall be used to protect the batteries.

Optimised charging cycles shall be used to ensure energy efficiency and minimum impact to battery energy storage system life.

Passive charging systems that permanently connect the battery banks to the EAPS direct current supply shall not be used. These charging systems provide no active overcharge protection nor provide optimised charging.

For battery banks with series-connected batteries, where applicable, the charging system shall prevent the batteries from localised undercharging or overcharging.

The battery condition monitoring system should monitor and provide the following information where applicable:

- voltage: total battery bank voltage, voltage of individual battery package in the battery bank
- battery current during charging and discharging
- temperature: average temperature of the battery bank, or temperatures of individual battery packages
- state of charge or depth of discharge that indicates the charge level of the battery
- state of health: a measurement of the overall condition of the battery
7.5. **Fixed shore power supply**

Where applicable, LRVs shall be provided with fixed shore power supply connection capability to provide power to the auxiliary systems and battery charging systems from an external source (maintenance centre infrastructure) during extended stabled maintenance where auxiliary power is required, to ensure the auxiliary batteries are not depleted.

Where applicable, cabled fixed shore power supply connections shall use an interlocking system to prevent the LRV from moving while the fixed shore power supply system is connected to the vehicle.

Onboard shore supply sockets shall not be energised prior to the connection of the shore supply cable.

The shore supply cable shall be protected with a residual current device (RCD).

8. **Onboard energy storage system**

The onboard energy storage system is primarily used to provide power to the onboard main power supply system to provide power to the traction and auxiliary systems in 'wire-free' systems where applicable.

LRVs fitted with an onboard energy storage system shall comply with IEC 62864-1: *Railway applications – Rolling stock – Power supply with onboard energy storage system – Part 1: Series hybrid system.*

8.1. **Electrical protection**

The onboard energy storage system battery banks shall be protected by high rupture capacity (HRC) fuses or equivalent fuses on both the positive and negative terminals.

The onboard energy storage system shall be provided with a management system or equivalent to ensure the operational safety of the onboard energy storage system. For example, the management system might include automatic shutdown if unsafe conditions or failure modes are detected.

The output cabling of the onboard energy storage system shall be protected by an insulation monitoring device (IMD) or equivalent to protect against ground faults due to insulation breakdown or failure.
8.2. **Energy storage medium safety**

The energy storage medium holds the electrical charge or energy and can pose risks if a large amount of energy is quickly released. Safety shall be ensured during the operation and maintenance of the LRV and the energy storage medium.

All safety aspects of the operation and maintenance of the LRV fitted with an energy storage system shall be addressed, including risks during operation and maintenance (for example, the risks of operation in enclosed areas such as tunnels and maintenance facilities).

The energy storage medium shall comply with the following standards where applicable:

- EN 45545-2 *Railway applications - Fire protection on railway vehicles - Part 2: Requirements for fire behavior of materials and components*
- IEC 62864-1 *Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system*
- IEC 61881-3 *Railway applications - Rolling stock equipment - Capacitors for power electronics - Part 3: Electric double-layer capacitors*
- IEC 62928 *Railway applications — Rolling stock equipment — Onboard lithium-ion traction batteries*

The selected energy storage medium shall be inherently safe against the following:

- combustion due to any internal failure modes
- combustion due to being punctured by a sharp metal object resulting in the shorting of internal conductive elements
- combustion or crushing after a derailment or completely by a sharp metal object
- combustion due to being crushed while on the vehicle or while being handled during transportation
- the release of toxic smoke during failure modes and damage

The energy storage system type shall not release fluids and gases in any orientation.

8.3. **Onboard energy storage management system**

The onboard energy storage system is key to the operation, active monitoring and safety of the onboard energy storage system.

Due to the potential risks involved with high capacity electrical energy storage systems, the onboard energy storage system and its management system shall be designed with an applicable safety integrity level (SIL) in accordance with EN 50128.
The onboard energy storage system management system shall do the following:

- control the charging and discharging process to ensure efficiency, safety and operating life
- control the secondary cooling systems where applicable

The onboard energy storage system shall monitor and provide the following information:

- voltage – total energy storage bank voltage, voltage of individual storage units, for example each individual battery or cell
- charging and discharging current
- temperature – average temperature of the energy storage bank or temperatures of individual energy storage units
- state of charge or depth of discharge that indicates the charge level of the energy storage system
- state of health – a measurement of the overall condition of the energy storage system

8.4. Cooling systems

The primary cooling system shall preferably be passive in nature with the use of forced ventilation or pumped fluid cooling systems to be secondary for the purpose of extending the energy storage system’s life span and to extract the maximum power output from the energy storage system in high temperature conditions. A failure of the secondary cooling system shall enable the energy storage system to maintain traction power to enable the LRV to clear un-electrified sections and return to the maintenance facility for repair.

8.5. Onboard energy storage system redundancy

Onboard energy storage system redundancy shall be provided where an onboard energy storage system is used to provide the only source of power for the traction system during wire-free operation.

The onboard energy storage system and traction system shall be configured to enable the LRV to clear wire-free sections and return to the maintenance facility for repair after failure of onboard energy storage system modules. For example, the use of two onboard energy storage system modules can each provide power to separate traction modules.
8.6. Mechanical requirements

The onboard energy storage system should be located on the roof area of the LRV for the following reasons:

- protect against collision damage from other LRV or road vehicles
- enable safe venting of smoke and fumes away from pedestrians and other road users during failure modes
- minimise potential onboard energy storage module fires away from passengers and road users
- aid maintenance activities

The crash worthiness and mounting performance of the onboard energy storage system modules shall be designed to minimise safety risks during and after a collision with other LRVs or other road vehicles.

The onboard energy storage modules shall be bonded to the LRV vehicle body earthing system using multiple earthing wires that can readily be inspected.