Electrical Circuits and Equipment for Light Rail Vehicles

Version 1.0
Issued date: 25 May 2017
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Standard governance

Owner: Lead Rolling Stock Engineer, Asset Standards Authority
Authoriser: Chief Engineer, Asset Standards Authority
Approver: Executive Director, Asset Standards Authority on behalf of the ASA Configuration Control Board

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

The ASA has issued this document to state the minimum requirements for the design, manufacture and supply of new and significantly modified light rail passenger vehicles for TfNSW.

This standard has been prepared by the ASA in consultation with other TfNSW agencies and light rail vehicle designers, manufacturers, suppliers and contractors.

This document is a first issue.
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1. Introduction

The performance and safety of electrical systems on Transport for NSW (TfNSW) light rail passenger vehicles is paramount to TfNSW public transport operations. This standard enables TfNSW to ensure the light rail vehicles used in their operations meet the minimum requirements for performance and safety.

1.1. Purpose

This document provides the minimum requirements and recommendations for the electrical circuits and electrical equipment used on TfNSW light rail vehicles. This standard aims to ensure the reliability, availability, maintainability and safety of electrical circuits and equipment in new and refurbished TfNSW light rail vehicles.

1.2. Scope

This standard covers electrical safety requirements, compatibility requirements and minimum design and general requirements for all electrical circuits and electrical equipment in the following light rail rolling stock systems:

- traction systems
- power supply systems
- communications and control systems

1.3. Application

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

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

2. 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 50121-1:2017 Railway Applications - Electromagnetic Compatibility - Part 1: General

EN 50121-3-1 Railway Applications - Electromagnetic Compatibility - Part 3-1: Rolling Stock - Train and Complete Vehicle

EN 50121-3-2 Railway Applications - Electromagnetic Compatibility - Part 3-2: Rolling Stock – Apparatus
EN 50153 Railway Applications – Rolling Stock – Protective Provisions Relating to Electrical Hazards

EN 50155:2007 Railway Applications - Electronic Equipment Used on Rolling Stock

EN 50343 Railway Applications – Rolling Stock – Rules for Installation of Cabling

EN 50526-1 Railway applications - Fixed installations - D.C. surge arresters and voltage limiting devices - Part 1: Surge arresters

IEC 60034-1 Rotating electrical machines – Part 1: Rating and performance

IEC 60051-1 Direct acting indicating analogue electrical measuring instruments and their accessories - Part 1: Definitions and general requirements common to all parts

IEC 60077 (series) Railway Applications – Electric equipment for rolling stock

IEC 60349-1 Electric traction - Rotating electrical machines for rail and road vehicles - Part 1: Machines other than electronic converter-fed alternating current motors

IEC 60349-2 Electric traction - Rotating electrical machines for rail and road vehicles - Part 2: Electronic converter-fed alternating current motors

IEC 60349-4 Electric traction - Rotating electrical machines for rail and road vehicles - Part 4: Permanent magnet synchronous Rotating electrical machines connected to an electronic converter

IEC 60617 (series) Graphical Symbols for Diagrams

IEC 61373 Railway applications - Rolling stock equipment - Shock and vibration tests

**Australian standards**

AS 60038-2012 Standard voltages

AS/NZS 3112 Approval and test specification - Plugs and socket-outlets

**Transport for NSW standards**

T LR EL 00007 ST Traction Power Supply Infrastructure and Light Rail Vehicle Interface

T LR RS 01701 ST Mounting and Installation of Electrical Equipment for Light Rail Vehicles

T LR RS 17010 ST Light Rail Vehicle Fire Safety

T MU AM 01003 ST Development of Technical Maintenance Plans

T MU RS 00164 ST Cables for Passenger Rolling Stock

T MU RS 17001 ST Environmental Conditions for Rolling Stock

T MU RS 17002 ST Prohibited and Restricted Materials
3. **Terms and definitions**

The following terms and definitions apply in this document:

- **ac** alternating current
- **ASA** Asset Standards Authority
- **dc** direct current
- **earthing** (in the context of this document) refers to protective earthing and rolling stock functional earthing. Protective earthing within the vehicles includes equipotential bonding of exposed conductive parts to prevent electric shocks and to enable the operation of overcurrent protection devices. Functional earthing prevents the flow of current through the vehicle body and structures in normal operation. The rolling stock earth connects to the running rails via the axle-earthing units.
- **extra low voltage** a voltage not exceeding 50 V ac or 120 V ripple-free dc (EN 50153)
- **HSCB** high-speed circuit breaker; (in the context of this document) is a mechanical switching device used to detect, interrupt, and limit prospective fault currents to prevent damage and isolate the current collection device from the rolling stock main power supply circuits
- **line-switch** a mechanical switching device used to isolate the traction system including interrupting its normal operating current
- **LOTO** lockout-tagout; safety procedure 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
- **low voltage** a voltage exceeding 50 V ac or 120 V ripple-free dc but not exceeding 1000 V ac or 1500 V dc (EN 50153)
- **LRV** light rail vehicle
- **prospective fault current** a current that would flow in the circuit if the circuit breaker were replaced by a conductor of negligible impedance
- **surge arrester** device designed to protect the electrical apparatus from high transient overvoltages and to limit the duration and frequently the amplitude of the follow-on current (IEV 811-31-09)
- **terminal** is a fixed point to which an electrical cable can be attached
- **TfNSW** Transport for NSW
- **vehicle** (in the context of this document) refers to individual light rail passenger vehicle modules
4. General requirements

All passenger rolling stock electrical circuits and equipment shall comply with the relevant sections of the following standards:

- EN 50121-1:2017 Railway Applications - Electromagnetic Compatibility - Part 1: General
- EN 50121-3-1 Railway Applications - Electromagnetic Compatibility - Part 3-1: Rolling Stock - Train and Complete Vehicle
- EN 50121-3-2 Railway Applications - Electromagnetic Compatibility - Part 3-2: Rolling Stock - Apparatus
- EN 50153 Railway Applications – Rolling Stock – Protective Provisions Relating to Electrical Hazards
- EN 50155:2007 Railway Applications - Electronic Equipment Used on Rolling Stock
- EN 50343 Railway Applications – Rolling Stock – Rules for Installation of Cabling
- IEC 60077 Railway Applications – Electric equipment for rolling stock
- IEC 60034-1 Rotating electrical machines – Part 1: Rating and performance

Mounting and installation of electrical cable and equipment shall comply with T LR RS 01701 ST Mounting and Installation of Electrical Equipment for Light Rail Vehicles.

4.1. Electromagnetic compatibility

Light rail vehicle (LRV) electrical circuits and equipment shall not have an impact on the operation of other on-board electrical systems.

LRV electrical circuits and equipment shall not have an impact on the operation of light rail and road electrical infrastructures such as signalling systems. The LRV shall comply with and be tested for electromagnetic compatibility in accordance with the following standards:

- EN 50121-1:2017 Railway Applications - Electromagnetic Compatibility - Part 1: General
- EN 50121-3-1 Railway Applications - Electromagnetic Compatibility - Part 3-1: Rolling Stock - Train and Complete Vehicle
- EN 50121-3-2 Railway Applications - Electromagnetic Compatibility - Part 3-2: Rolling Stock - Apparatus

4.2. Prohibited materials requirements

Materials used in rolling stock electrical circuitry and electrical equipment shall comply with the requirements of T MU RS 17002 ST Prohibited and Restricted Materials.
4.3. Fire performance requirements

Materials used in light rail vehicle electrical circuitry and electrical equipment shall comply at minimum with the fire performance requirements of T LR RS 17010 ST Light Rail Vehicle Fire Safety.

Electrical cable fire performance requirements shall at minimum comply with T MU RS 00164 ST Cables for Passenger Rolling Stock.

4.4. Operating environment

The maximum and minimum ambient operating temperature ranges, humidity levels, precipitation levels and other environmental operating conditions in NSW shall be considered in the selection and design of vehicle electrical systems and equipment to ensure the specified reliability and life span.

For the purpose of design calculations and applying referenced standards, the operating temperatures and environmental conditions shall be derived using the environmental conditions as defined in T MU RS 17001 ST Environmental Conditions for Rolling Stock.

4.5. Circuit diagram drawings

Circuit diagram drawings shall be provided for all vehicle electrical circuits to enable maintenance and future alterations.

Drawings shall be provided for the following:

- legends of all component symbols
- abbreviation tables
- zone index of numbered circuit links, wires and circuit components

Circuit diagrams shall use graphical symbols defined in IEC 60617 or equivalent national standards.

4.6. Technical manuals

All vehicle electrical circuits and electrical equipment shall be provided along with a detailed technical manual.

The technical manuals shall include relevant safety warnings against risks and hazards while operating or maintaining all electrical circuits and equipment.

The technical manuals shall use, where applicable, functional systems diagrams, sequence charts and other diagrams necessary to explain the operation of circuits and electrical equipment to electrical technicians and engineers to enable detailed assessment, maintenance, fault-finding and future modification and upgrades to the rolling stock electrical system.
Technical manuals shall be included for plug-in type modules including plug-in circuit board cards, contained within larger equipment modules which may not be readily accessible.

Explanation of relevant circuit theory may also be included to completely describe the operation of electrical circuits.

The technical manuals shall include detailed installation and overhaul instructions, for all electrical equipment, including the tools and equipment required to efficiently complete the task.

The technical manuals shall include a comprehensive diagnostics and fault-finding procedure including test sequence and expected measurable values such as voltage, resistance and current readings.

Technical manuals shall also be included for bespoke test equipment used to test electrical equipment.

4.7. **Technical maintenance plans**

The technical maintenance plan shall detail all the maintenance requirements to enable the electrical circuits and equipment to operate as specified and to prevent in-service failures.

The technical maintenance plan shall detail all the maintenance requirements to ensure the specified life of the electrical circuits and equipment.

Technical maintenance plans shall be provided for all light rail vehicle electrical circuits and equipment. The technical maintenance plan shall comply with T MU AM 01003 ST *Development of Technical Maintenance Plans*.

4.8. **General circuit voltages**

Vehicle control and lighting circuits shall not exceed extra low voltage.

Vehicle single-phase ac circuit voltages and frequency shall be nominal 230 V ac, 50 Hz for auxiliary systems and general power outlets, as per AS 60038-2012 *Standard voltages*.

Maintenance accessible general power outlets shall comply with AS/NZS 3112.

Vehicle three phase ac circuit voltages and frequency shall be nominal 400 V ac, 50 Hz as per AS 60038-2012 *Standard voltages*.

The traction power supply infrastructure voltage for the TfNSW light rail networks is nominal 750 V dc as per T LR EL 00007 ST *Traction Power Supply Infrastructure and Light Rail Vehicle Interface*.

The minimum electrical creepage distance between energised parts and any part of the vehicle body shall be determined in accordance with EN 60077-1 *Railway Applications – Electric Equipment for Rolling Stock – Part 1: General service conditions and general rules*. 
Where applicable, for voltages over 1000 V in the traction circuits, creepage distance shall not be less than 45 mm/kV.

5. **Electrical protection and safety**

LRV electrical safety provisions shall comply with EN 50153 *Railway applications - Rolling stock - Protective provisions relating to electrical hazards.*

LRV’s shall be provided with the following electrical protection and safety systems:

- safety earthing switch or equivalent system
- on-board power source protection
- protection and isolation of individual circuit functions

5.1. **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.

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

- open the high-speed circuit breaker (HSCB) to disconnect the main power supply circuit from the pantograph and prevent the HSCB from being closed
- lower the pantograph
- earth the main power supply circuit to the traction current return circuit 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

The earthing contactors of the safety earth switch shall withstand the prospective fault current of the traction power supply infrastructure substation circuit breakers.

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.

5.2. **On-board power source protection**

All on-board power sources including auxiliary inverters, auxiliary batteries and on-board traction power storage systems shall be protected by magnetic circuit breakers.
The performance and reaction time of individual magnetic circuit breaker circuits shall be verified by simulation or testing.

Auxiliary battery banks shall be protected by high rupture current (HRC) fuses on both the positive and negative terminals.

All on-board power sources including auxiliary inverters, auxiliary batteries and on-board traction power storage systems shall be provided with a method of isolation that can be protected using a LOTO procedure.

Three-phase ac power load shall be balanced to ensure that load at each phase remain within +/-5% of each other under normal operating conditions.

### 5.3. Protection and isolation of individual circuit functions

Individual circuit functions and equipment shall be protected using overcurrent magnetic circuit breakers that can be used to isolate the individual circuit functions.

The selection of circuit breaker shall take into account circuit characteristics, including the effects of long cable runs, to ensure the desired reaction time of the circuit breaker.

The performance of individual circuit breaker circuit shall be verified by simulation or testing.

Three-phase ac power sources and circuits shall be protected by a ganged three phase magnetic circuit breaker.

Circuit breakers shall not be used in lieu of dedicated switches or switch controlled contactors where regular manual hand switching is required for an electrical circuit or equipment.

### 6. Traction supply current return system

The LRV traction supply current return system shall effectively conduct the traction return current to the running rails, infrastructure traction supply current return system, at all operating speeds and conditions up to the maximum test speed.

The configuration of the LRV traction supply current return system shall ensure an electrical path to the running rails when up to one bogie derails from the rail.

#### 6.1. Traction current return circuit

The traction supply current return circuit shall use a minimum of two separate redundant paths to the running rails using a minimum of two separate wheel axle current return units on separate bogies.

The two separate traction current return paths shall go directly to the wheel axle current return units with no intermediate electrical connections on the bogies.
The traction supply current return circuit shall be isolated from the vehicle body earthing circuit up to the wheel axle current return units.

Failure of the wheel axle current return units shall not allow traction supply current return currents to flow to the vehicle body earthing circuit.

6.2. **Wheel axle current return units**

The wheel axle current return units shall be immune to shocks and vibrations as per IEC 61373 for axle mounted equipment.

Access to the electrical connection points of the wheel axle current return units shall allow for periodical electrical resistance testing between the connection points and the wheels.

7. **Earthing system**

The earthing arrangements shall provide robust protective and functional earthing to protect passengers and staff and to prevent the flow of electrical current through vehicle bodies, bogie frames and uninsulated bearings.

The earthing system shall prevent dangerous voltages from developing between the rails and the vehicle body.

All vehicle electrical circuits shall comply with the protective earthing requirements in EN 50153.

7.1. **Vehicle body earthing system**

The vehicle body earthing circuit shall use a minimum of two separate redundant paths to the running rails using a minimum of two separate wheel axle current return units on separate bogies.

The two separate vehicle body earthing circuit paths shall go directly to the wheel axle current return units with no intermediate electrical connections to the bogies.

The vehicle body, including structural and conductive body panels, shall be connected to the vehicle body earthing system.

The vehicle body earthing system shall cause immediate tripping of the infrastructure overhead traction power supply circuit breakers in the event of overhead power supply cables and equipment making contact with the vehicle body.

The vehicle body earthing circuit shall be isolated from the traction supply current return circuit up to the wheel axle current return units.

The vehicle body earthing system shall ensure no electrical currents flow through any non-insulated bearings including the wheel bearings.
7.2. Earthing bars

Separate insulated earthing bars shall be provided for extra low voltage circuits and low voltage circuits on each vehicle.

The extra low voltage and low voltage earthing bars shall be directly connected to the vehicle body earthing system.

Each electrical circuit or equipment shall have a separate negative or neutral cable connected directly to its earthing bar.

Low voltage power sources shall have the neutral and negative lines connected to the vehicle body earthing system.

7.3. Earth bar terminal connections

All earthing bar terminal connections shall be of a bolted connection designed to withstand unscrewing forces when subjected to shock and vibration conditions in compliance with IEC 61373 Railway applications - Rolling stock equipment - Shock and vibration tests.

Similar circuits, such as circuits of the same voltages, shall be grouped together on earth bar terminals.

Ac and dc circuits and circuits with different voltages shall not be connected to the same earth bar terminal bolted connection.

The vehicle body earthing terminals shall use a permanent screw stud design fixed to the vehicle body’s structural member. All internal and external conductive body panels shall be connected electrically to the vehicle body earthing circuit through direct contact or a wired connection.

8. Electrical equipment requirements

This section details requirements and recommendations for specific electrical equipment.

All electrical equipment shall comply with the relevant requirements of the following standards:

- IEC 61373 Railway applications - Rolling stock equipment - Shock and vibration tests
- EN 50155:2007 Railway Applications - Electronic Equipment Used on Rolling Stock

8.1. Electric traction motors

Electric traction motors for light rail vehicles shall comply with the following applicable standards:

- IEC 60349-1 Electric traction - Rotating electrical machines for rail and road vehicles - Part 1: Machines other than electronic converter-fed alternating current motors
8.2. Electrical cables
All electrical cables shall be in accordance with T MU RS 00164 ST Cables for Passenger Rolling Stock.
The colour coding and marking of cables shall be in accordance with T MU RS 00164 ST.

8.3. Extra low voltage contactors and switches
Electrical contacts in switches, relays and contactors in control and power circuit are subject to potential burning and electrical corrosion when breaking dc current that may lead to immediate failure or intermittent failures in service. When selecting switches and contactors the magnitude and inductive time constants of the current it needs to break shall be considered to determine the rated life expectancy of the contacts.

Switches and contactors with voltage ratings of ‘extra low voltage’ and below shall be selected to provide an operating life equal to the specified life of the vehicle.

The auxiliary contacts of contactors and relays, which are used for lower current control circuits, shall not be used in lieu of the main power contacts unless equally rated as the main power contacts.

8.4. Power contactors
Power contactors with voltage ratings of ‘low voltage’ and above shall be provided with a maintenance plan to prevent in-service failures due to eventual degradation of the contacts.

The electrical contact tips used to make and break current on high current devices, where applicable, shall be replaceable.

Power contactors with replaceable contact tips shall be provided with the necessary tools and instructions to ensure proper tightening and alignment of the contact tips.

All arc chute components shall have adequate resistance to erosion and burning from the arcs to which they might be subjected.

8.5. High-speed circuit breakers and line-switches
HSCBs and line-switches type testing shall be in accordance with IEC 60077-3 and IEC 61373.
HSCBs and line-switches operational frequency rating shall be 'C3' as defined in IEC 60077-3.

HSCBs shall primarily use passive cooling; any other type of cooling shall be supplemental only.

The cable connection between HSCBs and the electrical supply shall be as short and as direct as possible.

HSCBs shall use direct over-current instantaneous release.

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

HSCBs and line-switches shall have the provision to be monitored remotely by the driver through the LRV operating system or equivalent driver interface.

The vehicle’s main power supply HSCB’s performance characteristic and configuration shall ensure discrimination with respect to the infrastructure traction power supply substation dc circuit breakers (DCCBs) so that it can quickly detect, break and limit on-board electrical fault currents before the fault can trip the overhead power supply DCCBs.

The main power supply HSCB system shall provide protection against excessive automatic and manual HSCB reset.

### 8.6. Surge arrester

The surge arrester rating shall be suited to provide protection against the atmospheric voltage discharge intensities and frequency of strikes expected in NSW as detailed in T MU RS 17001 ST *Environmental Conditions for Rolling Stock*, ‘Lightning’ section.

The surge arrester shall provide protection to on-board equipment from arching voltages of HSCBs and overhead power supply system substation DCCB during electrical fault clearing.

The surge arrester shall not degrade due to the highest non-permanent voltage of the overhead power supply.

The surge arrester shall be located in close proximity to the pantograph with the high-tension connections as short and as straight as possible.

The surge arresters shall not have the potential for uncontained shattering which can result in the ejection of porcelain shards and other material from the vehicle.

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 that test the following:

- operating duty
- accelerated ageing
• weather ageing
• operation in high humidity
• resistance to UV degradation
• resistance to degradation from exposure to pantograph sparking
• overload test
• vibration and shock testing in accordance with IEC 61373

8.7. **Coil windings**

The coil windings of inductors and transformers shall be continuously rated and physically designed for suitability in the railway environment.

Insulated coils shall be fully impregnated to prevent the ingress of fluids and moisture.

The coil conductor and its insulation system shall have mechanical protection to prevent any chafing or movement damage caused by normal installation, removal or storage conditions.

8.8. **Cable connectors and plug-in components**

All cable connectors and plug-in components including relays, printed circuit boards, electronic cards and electrical modules shall comply with the following:

• cable connectors and plug-in components shall use a mechanical restraining system to prevent dislodgement under railway shock and vibration conditions defined in IEC 61373
• electrical contacts of cable connectors and plug-in components shall be adequately safeguarded to protect from damage during transportation and handling
• incorrect insertion of a plug or plug-in component shall be prevented by the use of a guide, shield or otherwise
• where non-interchangeable plug-in devices have similar plug-in components they shall be provided with a means to prevent them being inserted in the wrong position or equipment

Circular cable connectors, upon connection, shall produce an audible or otherwise mechanical feedback, able to be sensed by the technician to indicate that the connector has been fully engaged and is locked into position.

8.9. **Calibrated devices**

Electrical equipment requiring calibration or adjustments shall be provided with an adjusting mechanism and method to protect against shock and vibration as defined in IEC 61373 and accidental re-adjustment.
Electrical equipment requiring calibration or adjustments shall be provided with a technical manual and any special equipment required for calibration.

8.10. **Low and extra low voltage switches, push buttons and indicators**

Push buttons and indicators shall use a design that prevents tampering and un-authorised removal.

All visual indicating lights shall be LED-based and shall be compatible with the power supply voltage spikes and over-voltage characteristics.

Low voltage switches selection shall take into consideration the effects of breaking dc currents and inductive loads in light rail operating conditions.

All low and extra low voltage switches, push buttons and indicators shall be selected to provide an operating life equal to the specified life of the vehicle.

8.11. **Circuit breakers**

All circuit breakers shall be the direct acting overcurrent magnetic type.

Circuit breakers shall be installed such that the operating lever shall be down in the 'off' or 'triped' position. The 'off' position shall be clearly marked.

Each circuit breaker shall be labelled with the circuit it protects.

Circuit breakers shall comply with the following standards:

- IEC 60077-3 *Railway applications - Electric equipment for rolling stock - Part 3: Electrotechnical components - Rules for DC circuit-breakers*
- IEC 60077-4 *Railway applications – Electric equipment for rolling stock - Part 4: Electrotechnical components – Rules for AC circuit-breakers*

8.12. **Fuses**

Traction circuit voltage fuses shall comply with IEC 60077-5 *Railway applications – Electric equipment for rolling stock - Part 5: Electrotechnical components - Rules for HV fuses.*

A fuse tester using extra low voltage test voltage shall be provided in the same enclosure as the battery fuses.

Spare fuses of each type shall be mounted in unconnected fuse holders adjacent to each fuse panel or group of panels in one location.

When determining the number of spare fuse supplied for each type of fuse, consideration shall be taken of the probability of multiple fuse failures of the same type in the same or related circuit, to ensure the availability of same fuse type.
8.13. **Resistors**

Traction circuit voltage resistors or resistors that carry greater than 30 A shall be prevented from shorting out in fault or overload conditions.

Resistors greater than 5 W rating shall be of the wire or strip wound type that is encapsulated to provide mechanical protection and protection from contaminants.

The adjustable mechanism of adjustable resistors shall be secured and protected against vibration in the light rail operating environment.

Fixed resistors of standard resistance values shall be used with the value, power rating and tolerance clearly marked.

8.14. **Capacitors**

Electrolytic capacitors shall not be used as single-phase capacitor starter motors.

Where capacitors are used as part of a surge suppression circuit, the required capacity shall be available at the surge frequency.

Discharge resistors shall not be integrated with suppression capacitors.

Capacitors in power supplies shall be over rated where applicable or selected to ensure the specified operating life span.

8.15. **Electrical measuring instruments**

All analogue electrical measuring instruments and their accessories shall comply with IEC 60051-1 *Direct acting indicating analogue electrical measuring instruments and their accessories - Part 1: Definitions and general requirements common to all parts*.

All analogue electrical measuring instruments shall have a true zero and the movement needle be suitably damped to prevent vibrations in all direction in light rail vehicle operating conditions.

All instruments and their parts shall be protected from tampering.

All instruments shall have an accuracy greater than ± 0.75% of the measuring range of the instrument.