

IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles

IEEE Vehicular Technology Society

Developed by the
Rail Transportation Standards Committee

IEEE Std 16™-2020
(Revision of IEEE Std 16-2004)



STANDARDS

IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles

Developed by the

Rail Transportation Standards Committee
of the
IEEE Vehicular Technology Society

Approved 30 January 2020

IEEE SA Standards Board

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Abstract: A set of uniform design, application, and test requirements for electrical and electronic control apparatus on rail vehicles is provided in this standard.

Keywords: apparatus, control, design, electrical, electro-hydraulic, electronic, electropneumatic, IEEE 16™, rail, routine test, test, transit, transportation, type test

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Introduction

This introduction is not part of IEEE Std 16-2020, IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles.

This standard is intended to apply to rail vehicles that are electrically powered. These vehicles include locomotives, railway electric multiple unit (EMU) cars, heavy rail vehicles, and light rail vehicles, including units that combine powered and unpowered trucks or axles. Fully-automated, driverless implementations of the above vehicle types are sometimes included in the mode of transit referred to as Automated Guideway Transit, also referred to as Automated People Mover, and, to the extent that the vehicle does not have other unique requirements, this standard can be applied. It is not intended that this standard be universally required for all such systems.

The classes of railway vehicles (such as those termed “Diesel Multiple Unit” [DMU]) that use a non-electric propulsion system have features of the electrical systems used in these vehicles that are similar to those used in “conventional” electrically-powered vehicles. To the extent that these systems are similar to those used in electrically powered vehicles, this standard can be applied.

NOTE—Self-propelled railway vehicles operating on trackage of the general railroad system are subject to regulations issued by governmental bodies (e.g., federal, state, and local bodies). In selected jurisdictions, this is also true for rail transit vehicles. The user of this standard should recognize that such regulations always take precedence over a consensus standard.¹

Certain heavy-duty rubber tired vehicles, notably dual-mode, hybrid, and electric trolley buses and large off-highway haulage trucks, utilize electric propulsion systems. Again, to the extent that these systems are similar to those used in rail vehicles, this standard can be applied.

It should be noted that this standard makes extensive use of the phrase, “as agreed to between the supplier and the authority having jurisdiction”, as well as requiring that the “authority having jurisdiction” provide certain significant parameters and/or make important determinations relevant to a specific project and not necessarily able to be anticipated in advance. [Annex B](#) lists all such citations within the standard and categorizes them as guidance for users of this standard.

¹Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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IEEE Standard for Electrical and Electronic Control

Apparatus on Rail Vehicles

1. Overview

1.1 Scope

This standard prescribes design, application, and test requirements for electrical and electronic control apparatus on rail vehicles.

NOTE—This standard covers neither rotating equipment nor the functional aspects of converters.¹

1.2 Purpose

This standard is intended to provide a set of uniform design, application, and test requirements for electrical and electronic control apparatus on rail vehicles. These requirements are the minimum necessary ~~for to ensure~~ suitability for use in a rail vehicle environment. Use of this standard should lead to enhanced levels of safety and reliability, and lower acquisition and maintenance costs.

1.3 Application

This standard is intended to be applied to the equipment designed for and installed on a rail vehicle. Application of this standard to the completed rail vehicle is beyond the scope and purpose of this standard.

NOTE—The selective application of this standard to the complete rail vehicle, as deemed technically correct and contractually agreed between the authority having jurisdiction and the car supplier, is recognized as appropriate in certain areas and cases.

¹~~Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.~~

1.4 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{2,3}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).

The word *may* is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.~~

²The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

³The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

ANSI C84.1-1995, Electric Power Systems and Equipment—Voltage Ratings (60Hz).⁴²

APTAPR-SS-M-S-011-99, ~~Rev. 2 Standard for~~ Compressed Air Quality for Passenger Locomotive and Car Equipment.⁵

ASTM B172-2001A, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch—Stranded Members, for Electrical Conductors.⁶⁴

ASTM B174-2002, Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors.

EN 50121-3-2: ~~2016 2000~~, Railway Applications—Electromagnetic Compatibility—Part 3-2: Rolling Stock—Apparatus.⁷⁵

Federal Specification W-C-596G-2001, General Specification for Power Electrical Connector (with amendments).⁸⁶

IEC 61287-1: ~~2014 1995~~, Power convertors installed on board rolling stock—Part 1: Characteristics and test methods.⁹

⁴²ANSI publications are available from the ~~Sales Department~~, American National Standards Institute, ~~25 West 43rd Street, 4th Floor, New York, NY 10036, USA~~ (<http://www.ansi.org/>).

⁵³APTA publications are available from the American Public Transportation Association, (<http://www.apta.com/>).

⁶⁴ASTM publications are available from the American Society for Testing and Materials, ~~100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA~~ (<http://www.astm.org/>).

⁷⁵EN publications are available from the European Committee for Standardization (CEN) (<http://www.cen.eu/>), ~~36, rue de Stassart, B-1050 Brussels, Belgium~~ (<http://www.cenorm.be/>).

⁸⁶Federal specifications are available from the US General Services Administration (<http://www.gsa.gov/>).

⁹⁷IEC publications are available from the ~~Sales Department of the~~ International Electrotechnical Commission, ~~Case Postale 131, 3, rue de Varembe, CH 1211, Genève 20, Switzerland/Suisse~~ (<http://www.iec.ch>) ~~and the IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA~~ (<http://www.ansi.org/>).

[IEC 62236-3-2 Ed2:2008, Railway Applications—Electromagnetic Compatibility—Part 3-2: Rolling Stock—Apparatus.](#)

IEEE Std 11TM-2000, IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles. [10,11](#)

IEEE Std 1476TM-2000, IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces.

IEEE Std 1478TM-[2013](#) ~~2001~~, IEEE Standard for Environmental Conditions for Transit Rail Car Electronic Equipment.

IEEE Std 1482.1TM-[2013](#) ~~1999~~, IEEE Standard for Rail Transit Vehicle Event Recorders.

IPC-2220, Design Standard Series, Printed Boards. [12](#) ~~10~~

IPC-A-610-2001, Acceptability of Electronic Assemblies.

IPC-CC-830B-2002, Qualification and Performance of Electrical Insulating Compound for Printed Wiring Assemblies.

ISO 4406: [2017](#) ~~1999~~, Hydraulic fluid power—Fluids—Method for coding level of contamination by solid particles. [13](#) ~~11~~

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¹² IPC publications are available from IPC (<http://www.ipc.org/>).

¹³ ISO publications are available from the International Organization for Standardization (<http://www.iso.org/>) and the American National Standards Institute (<http://www.ansi.org/>).

~~¹⁰ IPC publications are available from the Institute for Interconnecting and Packaging Electronic Circuits (IPC), 2215 Sanders Road, Northbrook, IL 60062-6135 (<http://www.ipc.org/>).~~

~~¹¹ ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, CH-1211, Genève 20, Switzerland/ Suisse (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).~~

MIL-M-81531, Notice 1, Marking of Electrical Insulating Materials.¹⁴

NEMA LI 1-1998, Industrial Laminated Thermosetting Products. ¹⁵ ~~13~~

NEMA WD 6-~~2016~~ ~~2002~~, Wiring Devices—Dimensional Requirements.

SAE AS4059 APR01, Aerospace Fluid Power—Cleanliness Classification for Hydraulic Fluids. ¹⁶ ~~14~~

UL 498-~~2018~~ ~~2001~~, Standard for Attachment Plugs and Receptacles. ¹⁷ ~~15~~

UL 943-~~2018~~ ~~1993~~, Standard for Ground Fault Circuit Interrupters.

UL 1059-~~2017~~ ~~2001~~, UL Standard for Safety Terminal Blocks.

¹⁴MIL publications are available from the U.S. Department of Defense (<http://quicksearch.dla.mil/>).

¹⁵NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org/>).

¹⁶SAE publications are available from the Society of Automotive Engineers (<http://www.sae.org/>).

¹⁷UL publications are available from Underwriters Laboratories (<http://www.ul.com/>).

~~¹³ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).~~

~~¹⁴ SAE publications are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096, USA (<http://www.sae.org/>).~~

~~¹⁵ UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).~~

3. Definitions, acronyms, and abbreviations~~, and acronyms~~

3.1 Definitions

For the purposes of this document ~~standard~~, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ Dictionary Online ~~Seventh Edition [B8]~~¹⁶ should be consulted ~~referenced~~ for terms not defined in this clause. 18

declared rating: A rating stated by a supplier for a given piece of equipment, representing the characteristics of the equipment as actually manufactured for a particular application.

published rating: A rating publicly stated by a supplier for a commercially available piece of equipment, independent of the use of that equipment in a particular application; typically, a rating embodied in documents prepared for broad distribution through commercial channels.

short-time operating voltage: A supply voltage, other than the continuous operating voltage range, operation at which for a defined period of time is not expected to damage the apparatus.

specified rating: A rating that a given piece of equipment is required to be capable of achieving for use in a particular application; often, in practice, a rating to which a piece of equipment is specially designed or adapted.

3.2 Acronyms and abbreviations

~~AGT — Automated Guideway Transit~~

~~ANSI — American National Standards Institute~~

APTA American Public Transportation Association

AREMA American Railway Engineering and Maintenance of Way Association

¹⁸IEEE Standards Dictionary Online is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

~~ASTM American Society for Testing and Materials~~

DMU diesel multiple unit

EMC electromagnetic compatibility

EMI electromagnetic interference

EMU electric multiple unit

~~EN European Norm~~

ESD electrostatic discharge

GFCI ground fault circuit interrupter

LVPS low voltage power supply

MU multiple unit

~~ICEA Insulated Cable Engineers Association~~

~~IEC International Electrotechnical Commission~~

~~IEEE Institute of Electrical and Electronics Engineers~~

~~IPC Association Connecting Electronics Industries (previously Institute of Interconnecting and Packaging Electronic Circuits)~~

~~ISO International Organization for Standardization~~

~~LVPS low voltage power supply~~

~~MIL military (related to U.S. Department of Defense standards and other documents)~~

~~MU multiple unit~~

~~NEMA National Electrical Manufacturers Association~~

~~NFPA National Fire Protection Association~~

~~NRTL nationally recognized testing laboratory~~

~~SAE Society of Automotive Engineers~~

~~UL Underwriters' Laboratories, Inc.~~

~~UNS Unified Numbering System (for metals and alloys)~~¹⁷

4. Design requirements

4.1 Service conditions

All apparatus, including, but not limited to, electronic apparatus, shall be designed for the standard environmental conditions given in IEEE Std 1478^{TM-2013-2001,}¹⁸ unless otherwise agreed between the supplier and the authority having jurisdiction.¹⁹

¹⁷~~This system is managed jointly by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE).~~

¹⁹¹⁸Information on references can be found in Clause 2.

4.2 Supply voltages

4.2.1 General

Equipment shall operate normally or without damage when exposed, for the duration listed in this standard, to any voltage from zero to the maximum value listed in this standard. If necessary, appropriate protection from damage may be provided by other elements of the system in which the equipment is configured (e.g., undervoltage cutout devices). The authority having jurisdiction shall specify the performance expected of the equipment at nominal voltage conditions. At voltages other than nominal, performance shall be as described in this standard unless otherwise agreed to between the supplier and the authority having jurisdiction.

In the absence of a specification or agreement to the contrary, the minimum time duration to be considered for “short time” operation shall be taken as 1.0 ~~s second~~ for undervoltage operation and 0.2 ~~s second~~ for overvoltage operation. Conditions existing for shorter times shall be considered transient conditions governed by 4.3.1.

4.2.2 DC-powered low-voltage control equipment

Nominal supply voltages for low-voltage control equipment shall be chosen from the preferred values given in 4.4.3 of IEEE Std 1476TM-2000. The nominal, minimum operating, and maximum continuous values and the required operating characteristics of the equipment within and outside of these voltage ranges shall be as given in 4.4.3 of IEEE Std 1476-2000. Equipment shall not be damaged by continuous application of voltage between zero and minimum operating.

NOTE—These nominal supply voltages correspond to nominal battery voltages of 24 ~~V~~, 32 ~~V~~, 48 ~~V~~, and 64 ~~V volts~~. Refer to IEEE Std 1476-2000 for details.

4.2.3 AC auxiliary apparatus

Nominal supply voltages and required continuous and short-time operating voltage ranges for ac auxiliary apparatus shall be chosen from the preferred values given in ANSI C84.1–1995, Table 1, Low Voltage Class. Unless otherwise agreed between the supplier and the authority having jurisdiction, rated performance shall be obtained at the nominal frequency and within the Utilization Voltage limits of Voltage Range A of ANSI C84.1–1995, Table 1. Operation at other frequencies shall be as specified in NEMAMG 1-2003, section 12.45. Operation outside of Voltage Range A but within the Utilization Voltage limits of Voltage Range B of ANSI C84.1–1995, Table 1, shall be as specified by the authority having jurisdiction.

4.2.4 High-voltage dc-powered traction and auxiliary apparatus

Supply voltages for high-voltage dc-powered traction and auxiliary apparatus powered from a dc source (e.g., overhead contact system or third rail) shall be as shown in Table 1. Unless otherwise agreed between the supplier and the authority having jurisdiction, rated performance shall be obtained at the nominal voltage and above, up to the maximum voltage listed in Table 1 for that nominal voltage case. At other voltages, performance shall be in accordance with the design or inherent characteristics of the apparatus.

NOTE—By agreement between the supplier and the authority having jurisdiction, the minimum performance (e.g., rating) voltage may be taken at a value lower than the nominal system voltage; ~~and~~ the voltage at which the equipment ceases operation may be taken as a value lower than the minimum continuous voltage. This is commonly done for auxiliary apparatus but may also be done for propulsion equipment where circumstances dictate, such as a chronically “soft” power supply.

Table 1—Standard voltages for high-voltage dc-powered traction and auxiliary apparatus powered from a dc source

Nominal system voltage (V)	Operating voltage range (V)		
	Minimum continuous	Maximum continuous	Maximum short-time
600	400	720	800
750	500	900	1000
1500	1000	1800	1950
3000	2000	3600	3900
NOTE—Nominal voltages of 600 Vdc and 3000 Vdc, while widely used, are not recommended for new applications.			

~~NOTE—Nominal voltages of 600 Vdc and 3000 Vdc, while widely used, are not recommended for new applications.~~

For nominal system voltages other than those shown in Table 1, the minimum continuous operating voltage shall be taken as ~~minus~~ 30% ~~percent~~ relative to the nominal system voltage, and the maximum continuous operating voltage shall be taken as $\pm$ ~~plus~~ 20% ~~percent~~ relative to the nominal system voltage. For any nominal voltage, voltages outside the limits given in Table 1 or the percentages given above shall be considered surges or sags, and performance under those conditions shall be governed by 4.3.1.

4.2.5 High-voltage single-phase ac systems

Supply voltages for high-voltage single-phase ac systems shall be as shown in Table 2:

Table 2—Standard voltages for high-voltage single-phase ac systems

Nominal system voltage (V)	Nominal frequency (Hz)	Operating voltage range (V)			
		Minimum short-time	Minimum continuous	Maximum continuous	Maximum short-time
12 000	25	8 400	9 600	13 200	14 400
12 500	60	8 750	10 000	13 750	15 000
25 000	60	17 500	20 000	27 500	30 000

~~NOTE—Systems operated at 25 Hz, while widely used, are not recommended for new applications.~~

Table 2—Standard voltages for high-voltage single-phase ac systems

(continued)

Nominal system voltage (V)	Nominal frequency (Hz)	Operating voltage range (V)			
		Minimum short-time	Minimum continuous	Maximum continuous	Maximum short-time
50 000	60	35 000	40 000	55 000	60 000
15 000	50	11 000	12 000	17 250	18 000
25 000	50	17 500	19 000	27 500	29 000
NOTE—Systems operated at 25 Hz, while widely used, are not recommended for new applications.					

(New)

The authority having jurisdiction shall specify the time duration of short-time operation and the expected performance under those conditions. Voltages outside these limits shall be considered surges, and performance under those conditions shall be governed by 4.3.1.

4.3 Electrical transient withstand capability

4.3.1 Spikes and surges

The equipment shall operate normally and shall not be damaged when subjected to input voltage variations as defined in the remainder of this subclause.

4.3.1.1 Supply system

Unless otherwise agreed between the supplier and the authority having jurisdiction, input overvoltage and time duration limits shall be assumed to be in accordance with the following:
~~followings sections of IEC 61287-1:1995.~~

For maximum voltages with duration of 20 ms or more, assume no less than EN 50124-2, Annex A.
For nominal voltages other than those of Annex A, use proportioning and/or extrapolation based on similar nominal voltages.

For maximum voltages with duration of less than 20 ms it is recommended to assume no less than IEC 61287-1:2014, as follows:

- AC system, normal operation: Curve 1 of Figure 3—AC supply system overvoltage levels

- AC system, no damage: Curve 2 of Figure 3 for guidance
- DC system, normal operation: Curve 1 of Figure 4—DC supply system overvoltage levels
- DC system, no damage: Curve 2 of Figure 4 for guidance

4.3.1.2 Auxiliary ac systems

Unless otherwise agreed between the supplier and the authority having jurisdiction, equipment connected to the auxiliary ac system shall operate normally when subjected to voltage fluctuations defined in 4.3.1 of IEEE Std 1476-2000.

4.3.1.3 Low voltage system

Equipment connected to the low voltage dc system shall operate normally when subjected to voltage fluctuations defined in 4.4.3.4 of IEEE Std 1476-2000.

The equipment shall not be damaged when subjected to overvoltages as defined in 4.4.3.5 of IEEE Std 1476-2000.

The equipment shall not be damaged when subjected either to a voltage from zero to the minimum operating voltage or to positive or negative voltage steps between minimum and maximum operating voltages.

NOTE ~~NOTES~~ 1—It is recommended that equipment be designed not to be damaged when continuously subjected to nominal low voltage power supply (LVPS) output voltage at reverse polarity, combined with voltage fluctuations and transients as defined in this standard.

NOTE 2—Power supplies within equipment connected to the LVPS are not specifically addressed, but the supply voltage quality and the loads should ~~must~~ be coordinated for proper functionality in order to meet the overall requirements of this standard.

NOTE 3—In some cases, LVPS voltage may rise gradually as a result of float battery charging. This standard requires functionality within certain voltage ranges. Therefore, equipment that requires a fast rate of rise of supply voltage may not ultimately meet the system requirements.

4.3.1.4 Electrostatic discharge

Protection shall be provided against electrostatic discharges (ESDs) in compliance with EN 50121-3-2: [2016](#) ~~2000~~, Table 9. The discharge is to be delivered to the enclosure in which the equipment is housed (if an enclosure exists), to the enclosure of each line-replaceable unit, and to all surfaces and controls that are accessible to operating staff and passengers (e.g., knobs, switches, fasteners, printed circuit board faceplates, handles). The equipment shall function properly after such testing.

NOTE—This requirement is not intended to apply to the contacts of electrical connectors that are exposed in the course of removing, replacing, and/or handling a line-replaceable unit.

ESD-sensitive equipment shall be labeled. The label shall be affixed in a location that clearly indicates the ESD concern to maintenance personnel.

4.3.1.5 Transients

With respect to immunity to fast transient bursts and immunity to surges, the equipment shall be designed in accordance with the requirements of ~~Tables 7 and 8 of~~ EN 50121-3-2: [2016 or IEC 62236-3-2 Ed2 \(2008\)](#) ~~2000~~. Power supply inputs sourced from the low voltage system shall also withstand transients, [with a 2-Ω source impedance based on EN 50121-3-2:2016 or IEC 62236-3-2 Ed2 \(2008\)](#), ~~of at least 20 joules~~ without damage or misoperation.

4.3.2 Interruptions

Equipment shall not be damaged when exposed to random interruptions in the power supply. The authority having jurisdiction shall specify the nature of the performance to be obtained under such conditions. In the absence of information from the authority having jurisdiction, the supplier shall identify the interruption criteria assumed for the design and resulting system response. High-voltage interruptions that occur frequently shall not require a deliberate fault reset action as a prerequisite for resumption of normal operation.

NOTE—Examples of high-voltage interruptions include, but are not limited to, bouncing of the power collector device (e.g., third rail shoe or pantograph), gaps in the third rail, phase/frequency breaks or supply transition zones in an overhead supply wire, and ice or snow buildup on the third rail or overhead supply wire. Examples of low voltage or auxiliary voltage interruptions include, but are not limited to, temporary shutdown of the on-board power supply resulting from interruptions in the high voltage supply, short-term overloads of the low voltage or auxiliary power supply, and undercharged batteries.

4.4 Electromagnetic compatibility

Electromagnetic compatibility shall be verified ~~ensured~~ by an Electromagnetic Compatibility (EMC) plan. Unless otherwise agreed between the supplier and the authority having jurisdiction, the plan shall be created in accordance with the requirements of APTA SS-E-010–98.

NOTE—Ordinarily, the EMC plan is required of the vehicle supplier and contains requirements for the individual suppliers.

4.4.1 Train-wayside system compatibility

The authority having jurisdiction shall define the communication system and the wayside signal system operating frequency bands, coupling modes, and permissible vehicle or train emissions corresponding to those frequencies and coupling modes. Emissions limits shall be defined as a function of time duration if appropriate for a particular wayside system implementation.

The vehicle supplier and/or systems suppliers shall calculate vehicle and train emissions considering normal operation, infrequent operating modes, transient operation modes, environmental conditions, and failure modes, including but not limited to, the following:

- Variations in power feed and power return impedances
- Power feeds configuration including third rail and catenary gaps
- Ice and rust accumulation on the power collector and return surfaces
- Degraded wayside power supply capability
- Variations in supply voltage
- Substation phase imbalance limits
- Variations in regenerative current receptivity
- Variations in train consist configuration
- Other vehicles of the same or different type operating in the same area
- Towing and other non-typical and emergency vehicle operating modes
- Reduced rail adhesion conditions with corresponding equipment responses
- Intermittent and variable auxiliary power demand conditions

Based on total vehicle emissions limits, the vehicle supplier shall allocate emissions limits for individual systems. The vehicle and/or systems with credible failure modes—as determined by a Failure Modes and Effects Criticality Analysis performed under the EMC Plan of 4.4—that create emissions exceeding the limits shall react automatically in a manner to reduce the emissions below the allocated limits within a time period that is expected to avoid ~~will prevent~~ adverse effects on system operation.