IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces

Sponsor

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Abstract: The electrical interfaces among the components comprising the auxiliary power systems and their electrical interface with other train-borne systems are described. As such, this standard treats the auxiliary power system components (e.g., static inverters and converters, low-voltage dc power supplies, back-up battery systems, and battery chargers) as black boxes and addresses only their interface requirements.
Keywords: auxiliary power systems, battery charger, intermediate-voltage power supply, low-voltage power supply batteries, nickel-cadmium batteries, rail-transit vehicles, static inverters and converters

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Introduction

(This introduction is not part of IEEE Std 1476-2000, IEEE Standard for Passenger Train Auxiliary Power Systems Interface.)

Passenger train auxiliary power systems consist of major components or subsystems that may be supplied by different manufacturers/suppliers. These different components/subsystems must be integrated to form the auxiliary power systems that provide ac and dc power to subsystems on the train, which are used for normal and emergency operations. Typically, an auxiliary power system is comprised of

— An auxiliary static inverter to supply the low- and high-power ac loads.

— A low-voltage dc power supply to provide power to the low-voltage dc loads, which may also be used to charge the low voltage dc battery.

— A low-voltage dc battery to drive the emergency/essential loads on the vehicle in case of power failure or component failure.

— A battery charger, in those systems where the low-voltage power supply is not used for charging of the battery.

Nickel-cadmium batteries are specified in 4.5 as the preferred technology for the following reasons:

a) They have a more efficient recharge capability.

b) They have a wider operating temperature range.

c) They deliver more of their stored energy to the loads (lower losses).

d) They result in lower toxic and corrosive fumes.

e) They are lower weight than lead acid batteries for equivalent performance.

Other technologies are allowed under written approval of the authority having jurisdiction to permit their use in special situations.

There are no U.S. standards (including IEEE standards) to define the electrical interface between these components/subsystems, and there are no standards to define the electrical interface between the auxiliary power system and the vehicle subsystems receiving electrical power from it. In the absence of standards, to define these interfaces, important design information is often overlooked resulting in incompatibilities between them.

This standard addresses the electrical interfaces between the components comprising the auxiliary power systems and the electrical interfaces between the auxiliary power system and all of the components devices and subsystems receiving power from the auxiliary power system. It is the intention that through the use of this standard some of the costly design incompatibilities will be precluded.

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IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces

1. Overview

This standard applies to new procurements or major rehabilitation of rail-transit vehicles occurring on or after the publication date of this standard. Existing rail-transit vehicles and those vehicles currently being procured need not comply except when specifically required by the authority having jurisdiction. Where a need exists to maintain compatibility with existing rail-transit vehicles and to the extent defined by the authority having jurisdiction, those portions of this standard in conflict with compatibility requirements need not be applied.

1.1 Scope

This standard prescribes the electrical interfaces among the components comprising the auxiliary power systems and their electrical interface with other train-borne systems. As such, this standard treats the auxiliary power system components (e.g., static inverters and converters, low-voltage dc power supplies, back-up battery systems, and battery chargers) as black boxes and addresses only their interface requirements. It does not provide standards or recommendations for the following:

— Rotating machinery, such as motor alternator sets
— Motive power systems or auxiliary power systems required for locomotives
— Mechanical mounting or vibration isolation of equipment
— Car-body wiring, branch circuits, circuit breakers, protection, and devices to interconnect the auxiliary power components with other car-borne equipment

1.2 Purpose

The purpose of this standard is to standardize the electrical input and output requirements of the auxiliary power system components. This will be conducive to standardized designs rather than custom designs of car-borne equipment utilizing the supply voltages of the auxiliary power systems. It will also aid in more clearly defining the electrical interface requirements between the major component parts that comprise the auxiliary power systems, thus promoting their standardized design. The combined effect should increase the number of potential suppliers and correspondingly result in reduced railcar costs.

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2. References

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ANSI C84.1-1995, Electrical Power Systems and Equipment—Voltage Ratings (60 Hz).[1]

IEC 60571 (1998-02), Electronic equipment used on rail vehicles.[2]

IEC 60850 (1988-03), Supply voltages of traction systems.

IEC 61287-1 (1995-07), Power converters installed on board rolling stock—Part 1: Characteristics and test methods.

IEEE Std 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.[3]

IEEE Std 1473-1999, IEEE Standard for Communications Protocol Aboard Trains.

NEMA MG 1-1998, Motors and Generators.[4]

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. The IEEE Standard Dictionary of Electrical and Electronics Terms [B2][5] should be referenced for terms not defined in this subclause. Webster's New Collegiate Dictionary [B5] shall otherwise apply.

3.1.1 aging factor: A quantitative factor expressing the degradation in the ability of the battery, due to usage, to deliver electrical energy under specified operating conditions such as, but not limited to, operating ambient temperature, cycling, depth of discharge, and maintenance practices.

3.1.2 authority: A geographical or political division created specifically for the purpose of providing transportation service.

3.1.3 authority having jurisdiction: That entity that defines the contractual (including specification) requirements for the procurement.

3.1.4 builder: The entity manufacturing the product.

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[1]This standard is available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

[2]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[4]NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

[5]The numbers in brackets correspond to those of the bibliography in Annex B.

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3.1.5 car: *See:* **vehicle.**

3.1.6 car builder: The entity manufacturing the vehicle.

3.1.7 constant current loads: A load that demands constant current even when the input voltage varies.

NOTE—Typical of such loads is lighting when driven from an inverter ballast configuration.

3.1.8 constant power load: A load that demands constant power from the source even when the voltage value drops such as when switching from the low-voltage power supply to the battery.

NOTE—Typical of such loads are those that have their own built-in regulator such as propulsion control power supplies.

3.1.9 galvanic isolation: A method of electrical isolation where neither the signal nor the common of the output of the isolator is dc coupled to the signal or common of the input of the isolator, except for low-level leakage associated with non-ideal components.

3.1.10 heating ventilation and air conditioning (HVAC) system pull down: The condition wherein the air conditioning system in the car is turned on and is required to cool a car that has been sitting in the heat of the day.

NOTE—This condition usually presents the highest/longest sustained power demands on the auxiliary inverter.

3.1.11 heavy rail transit: A mode of rail rapid transit generally characterized by fully grade-separated construction, operation on exclusive rights of way, and station platforms at the floor level of the vehicles.

3.1.12 heavy rail vehicle: A vehicle operating on a heavy rail-transit system. Typically, electrically propelled, bi-directional, capable of operating in multiple unit, and designed for rapid, high-level boarding and discharging of passengers.

3.1.13 interface: The points where two or more physical systems or subsystems meet to transfer energy or information.

3.1.14 intermediate-voltage power supply (IVPS): Power supply that converts the third rail or catenary high-voltage dc or ac into an intermediate-voltage ac or dc to feed other power supplies.

3.1.15 lay-up condition: Idle condition of the equipment and systems between service operations.

3.1.16 light rail transit: A mode of rail transit characterized by its ability to operate on exclusive rights-of-way, street running, center reservation running, and grade crossings, and to board and discharge passengers at track or vehicle floor level.

3.1.17 light rail vehicle: A vehicle operating on a light rail-transit system, capable of boarding and discharging passengers at track or vehicle floor level.

3.1.18 low-voltage power supply (LVPS): A power supply that provides dc power to the low-voltage devices or circuits contained on the vehicle. It can also be configured to charge the vehicle battery.

3.1.19 manufacturer: *See:* **builder.**

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3.1.20 resistive loads: Loads for which the current supplied by the low-voltage power supply/battery varies proportionally with the source voltage.

NOTE—These loads will demand less current when the source voltage is switched from the low-voltage power supply to the battery. Typically, relays fall into this category.

3.1.21 state-of-charge factor: Actual capacity of a battery expressed as a percentage of a fully-charged capacity.

NOTE—This is based on experience, application (cycling/float service), and charging parameters.

3.1.22 supplier: The entity that contractually acts as the source of a product.

NOTE—The supplier may or may not be the actual builder.

3.1.23 vehicle: A land conveyance assembly for carrying or transporting people or objects, capable of traversing a guideway, having structural integrity and general mechanical completeness, but not necessarily designed for independent operation.

3.2 Abbreviations and acronyms

ANSI	American National Standards Institute
BC	battery charger
DOT	United States Department of Transportation
EMI	electromagnetic interference
FRA	Federal Railroad Administration (of the DOT)
FTA	Federal Transit Administration (of the DOT)
IEC	International Electrotechnical Commission
HVAC	heating, ventilation, and air conditioning
IVPS	intermediate-voltage power supply
LVPS	low-voltage power supply
NEC	National Electrical Code® (NFPA 70)
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association

4. Auxiliary power system interface design requirements

The interface design requirements of a vehicle auxiliary power system encompass all of the following subsystems and components as may be present on the car:

a) Auxiliary inverter
b) Intermediate-voltage power supply (IVPS)
c) Low-voltage power supply (LVPS)
d) Battery charger (BC)
e) Battery

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4.1 Functional requirements definition matrix

The vehicle auxiliary power system consists of major components or subsystems, which may be supplied from a number of different suppliers. Successful system performance relies on effective management and control of subsystem specifications and interface definition including the technical detailed requirements. The authority having jurisdiction shall prepare a functional requirements definition matrix (such as that shown in Table 1) that lists the applicable detailed functional requirements and shows the recommended entities for setting the requirement and concurring with the requirement. The matrix prepared by the authority having jurisdiction shall include all of the applicable functional requirements listed in Table 1, along with any additional requirements as determined by the authority having jurisdiction, and shall define who has primary and concurring responsibility for setting the detailed technical requirements. Several entities can have concurring responsibility, but only one shall be designated to have primary responsibility. The responsibility codes (primary and concurring) are not shown filled out in Table 1 as this is the prerogative of the authority having jurisdiction. A sample of the matrix completely filled out is shown in Table A.3.

Table 1— Functional requirements definition matrix

Responsibility function	Authority having jurisdiction (Notes 1&7)	Car builder (Notes 2&7)	Inverter supplier (Notes 3&7)	LVPS/BC supplier (Notes 4&7)	Battery supplier (Notes 5&7)
Identify normal (nonessential) low-voltage loads					
Identify essential loads (lights, radio, PA, doors, etc.)					
Specify emergency duration evacuation					
Car recovery duration					
Specify fleet compatibility (battery trainline voltage)					
Define primary power source (voltage, transients, faults)					
Compile ac and dc loads					
Specify on-board source filter (primary transient snubbing)					
Quantify emergency loads (lights, radio, PA, doors, etc.)					
Define low-voltage value and distribution voltage drops					
Define load current profile in emergency duration					
Specify battery maintenance interval (watering and checks)					
Specify operating temperature range (charging and discharging) (see Note 6)					
Specify battery size and capacity (ampere-hour, cell dimensions)					
Specify battery and cell access provisions for maintenance					
Establish flame smoke and toxicity levels					

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Table 1— Functional requirements definition matrix (continued)

Specify battery charging method					
Specify low-voltage energy source (primary or intermediate)					
Specify LVPS size (rating) for normal and emergency loads					
Specify LVPS electrical current foldback and fault protection					
Define intermediate-voltage nominal value					
Identify intermediate-voltage loads (HVAC, blowers, lights)					
Quantify intermediate-voltage loads and start-up phasing					
Quantify intermediate-voltage short time energy storage need (rail gaps)					
Define intermediate-voltage distribution and protection					
Define the static inverter output isolation					
Specify intermediate-voltage load shed at low primary volts					
Battery aging factor					

NOTES

1—As used herein, the term *authority having jurisdiction,* which was previously defined in 3.1, should be further interpreted to cover the car buyer; the operating agency, if different; any design consultant acting on behalf of these organizations; and any maintenance group not covered by the preceding. In a design-build context the term covers both the intermediate operator and maintainer sub-elements of the consortium as well as the ultimate owner of the vehicle fleet.

2—As used herein, the term *car builder,* which was previously defined in 3.1, should be further interpreted to cover the prime vehicle contractor and any systems integrator specialty support assisting in the car design process. In some recent vehicle procurements, the specifier explicitly mandates the use of a systems integrator by the vehicle prime contractor.

3—As used herein, the term *inverter supplier* should be interpreted to cover the designer and provider of the intermediate-voltage three phase or single phase alternating current converter that produces the intermediate-voltage power for significant (but not emergency critical) car auxiliary loads.

4—As used herein, the term *LVPS supplier*, which was previously defined in 3.1, should be further interpreted to cover the designer and provider of the low-voltage direct current converter that produces the low-voltage for normal loads, for emergency loads under normal operation, and for optional on-line (float) battery charging. The term *LVPS supplier* also covers the supplier of a separate off-line (regulated current) battery charger if that option is selected in the car design process.

5—As used herein, the term *battery supplier* should be interpreted to cover the supplier of the electro-chemical storage battery that supports the car emergency low-voltage loads and may buffer momentary low-voltage loads such as track brakes.

6—For purposes of sizing the batteries, the vehicle operating temperature range is not necessarily the operating range of the batteries. The responsible parties shall consider the environment and temperature of the battery when called upon to perform its backup function. For example, the battery compartment may have heaters to elevate its temperature or be located under the car in a place where it is influenced by or affected by the temperature of surrounding equipment.

7—The codes used within the matrix shall

a) Determine and set the detailed functional requirement.
b) Concur with the detailed functional requirement.

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4.2 Loads analysis

The following subclauses present the requirements for properly sizing the auxiliary power loads. These loads shall be compiled by the car builder and presented to the authority having jurisdiction and the suppliers.

NOTE—The proper determination and sizing of the auxiliary loads is a very important step in the process of specifying auxiliary power supplies. If loads are specified too high by inclusion of conditions that realistically do not occur at the same time, the inverters and power supplies may be sized too large and result in unnecessarily costly or heavy equipment. Conversely, if loads are underestimated or high transient start-up conditions are not accounted for, the auxiliary equipment may be undersized resulting in frequent turn-off, nuisance circuit breaker trips, or low reliability.

4.2.1 Static inverter ac loads

The ac loads shall be compiled to determine the load presented to the static inverter under the following conditions:

a) Quiescent design load during lay-up conditions
b) Full continuous operating load
c) Maximum simultaneous starting load
d) Sustained short-time heavy loads, such as HVAC compressor pull down load

For each of the above conditions, the information compiled for each of the load items addressed shall include the following:

— Nominal voltage, frequency and phases
— Power (kW) for each individual load
— Power factor of each individual load at nominal operating conditions
— Quantity of individual loads, comprising each load item, driven by static inverter
— Total connected power of load item (kW)
— Total kilovolt amperes presented by load item (kVA)
— Inrush current (high starting current) of load item

The compiled loads shall be prepared by the car builder and presented to the authority having jurisdiction and the suppliers. It shall be in the format shown in Table 2 and shall include all applicable loads and an estimate of the size of the loads. An example of a typical summary of ac loads is shown and described in Table A.1.

Table 2—AC loads compilation

Item	Voltage	Load characteristics
List each applicable load and scenario; locked rotor, pull down, etc.	List the nominal voltage and number of phases of each load.	List the load characteristics: —Kilowatts —Power factor —Quantity of loads —Total kW —Total kVA amperes —Other applicable characteristics

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4.2.2 Low-voltage dc loads

To compile and categorize the low-voltage dc loads, the failure management strategies (see NOTE below) shall first be developed, then the low-voltage dc loads categorized accordingly. The sequence of load-shedding shall be developed such that the loads are supported in harmony with the failure management strategies. The low-voltage dc loads shall be compiled to determine the load presented to the LVPS and the back-up battery as follows:

a) Tabulation of constant power loads, such as public address/intercom, radio, propulsion control, etc., that derive their primary power from the LVPS but have their own regulated power supply included within the units. This type of load presents two different current draws. The first current draw is that which occurs while the LVPS is active and the second is an increased current draw when the load is switched to back-up battery wherein the voltage source (now the battery) is approximately 15% lower voltage. This results in a corresponding increased current draw. As the battery voltage continues to drop during discharge, the current draw increases. These are the worst-case loads on the battery.

b) Tabulation of resistive loads, such as incandescent lamps, relay logic, etc., that do not have internal regulated supplies. This type of load also presents two different current draws. The first current draw is that associated with the LVPS providing nominal output voltage, and the second is a reduced current draw when the load is switched to the back-up battery wherein the voltage is approximately 15% lower, thus resulting in a corresponding decreased current draw. As the battery voltage continues to drop during discharge, the current draw correspondingly decreases.

c) Tabulation of momentary/random loads, such as indicator lights, sanding magnet valves, etc., that are applied intermittently. These loads are treated on a duty cycle basis in sizing of the LVPS and the battery. These loads can effect the configuration of the LVPS and back-up battery employed as will be discussed later in 4.4.3.6 and 4.4.10. There are also random loads such as track brakes, side doors, and transient loads resulting from traversing rail gaps that can place significantly high demands for short periods of time on the battery and LVPS. The design of the battery, LVPS, and battery charging system must be coordinated such that these loads can be supplied by the battery without reducing its output voltage below the minimum system operating voltage. Care must also be taken to ensure that the charging system can replenish the battery during the normal operating runs of the vehicle. A peak load on the end of the load profile can significantly increase the battery capacity requirement.

d) Tabulation of constant current loads such as inverter/ballast driven lighting wherein the current draw remains constant, independent of voltage fluctuations of the LVPS/battery voltage.

e) The battery load current draw profile shall be compiled for the condition of a failed LVPS or other emergency conditions wherein the battery must provide power. The profile shall show current demand under various load-shed conditions versus time. This load profile is necessary to facilitate sizing of the battery.

NOTE—In accordance with the failure management strategies, the LVPS fall into two general categories, essential loads and nonessential loads. The nonessential loads are shed during periods of emergency (loss of main power or loss of LVPS), while the essential loads remain connected and are thus driven by the battery. The nonessential loads are those loads that are not vital to running the train and can be shed during emergency conditions. Loads, such as lighting (except for emergency lighting) and low-voltage dc associated with heating and air conditioning, fall into this category. Essential loads such as emergency lighting, radio and PA, door control, and any other loads that perform essential functions during periods of loss of the primary power are not shed and are powered from the battery. To prevent spurious or erratic load shedding, it is normal to introduce a time delay before any loads are shed. In this manner, loads such as propulsion and train control circuits are assured of continuous operation during transient LVPS interruptions, for example, during the traversing of rail gaps.

The compilation of loads shall be prepared as shown in the format of Table 3. All of the types of loads shown in Table 3 shall be included. An example showing calculated loads and their compilation into the proper format is shown in Table A.2. The notes associated with Table A.2 offer guidance in determination of load magnitude.

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Table 3—DC loads compilation

Type	Unit	Load characteristics	Total	Battery load discharge profile
Type of load: constant power, constant current, resistive, momentary, etc.	List units: PA, radio, lighting, etc.	List load characteristics: maximum power, average power, stand-by power, quantity of loads, etc.	List total average power and current that shall be delivered by the LVPS at its normal operating voltage.	List currents the battery is expected to deliver during its discharge profile when the LVPS is down (emergency condition). Current listings shall be separated according to the expected load shedding. The listing shall be such that a battery discharge current profile is shown.

4.3 Static inverters

The static inverters provide ac power to run auxiliary equipment on the car. The auxiliary ac loads are divided into two basic categories. They are as follows:

a) *High-power loads*—Air conditioning compressors, air compressors and blowers for traction motors, etc.
b) *Low-power loads*—Housekeeping power to run appliances, such as vacuum cleaners, computers, etc.

Since all of the loads of the static inverter are car-borne, it is essentially a closed system. Therefore, the ultimate requirement of the static inverter is that it shall deliver voltages with tolerances, transient capabilities, and harmonic content suitable to drive the car-borne devices.

If the auxiliary power system configuration is such that the LVPS is fed from the output of the inverter, the inverter shall incorporate a dead battery start capability.

4.3.1 High-power output

4.3.1.1 Voltage output

The nominal system voltages for the high power, three-phase outputs used to drive motors (such as HVAC compressor motors, air compressor motors, and traction blower motors) shall be in accordance with those values specified in the ANSI C84.1-1995 for the low-voltage class category.

The static inverter shall function to provide the specified outputs under conditions of expected variations of both input voltages and output loads. As a minimum, the following parameters shall be specified by the car builder and approved by the authority having jurisdiction:

a) Maximum continuous power output
b) Voltage and tolerances
c) Frequency and tolerances
d) Voltage frequency control (see 4.3.1.2)
e) Total harmonic distortion and/or harmonic voltage factor

NOTE—The voltage factor is used to derate the motor loads to approximate the additional harmonic losses of an asynchronous motor fed by an auxiliary inverter (see 4.3.1.3).

f) Admissible overload
g) Instantaneous peak current

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4.3.1.2 Output voltage frequency

The output voltage frequency of the static inverter can be of two types

a) *Fixed frequency*—In this case, the nominal frequency and tolerance is specified by the car builder and approved by the authority having jurisdiction.

b) *Variable frequency*—In this case, the car builder shall specify if the frequency varies continuously or by steps and shall also define the ratio between voltage and frequency along with the rate of rise of frequency. The results shall be presented to the authority having jurisdiction for approval.

4.3.1.3 Output harmonics

The level of output harmonics shall be determined by analysis of the high-power loads referenced in 4.3.1 as driven by the static inverter. NEMA MG 1-1998 (Subclause IV, Part 30) shall be used for determination of allowable limits of harmonic distortion.

The level of output harmonics generated by the static inverter shall be determined by the criteria set forth in IEEE Std 519-1992.

Together, the car builder and the builder of the static inverter shall determine the static inverter allowable and generated harmonics. The authority having jurisdiction shall have an approval role in the process.

NOTE—Since static inverters by their nature simulate sine-wave output by combinations of step/square waves or pulse width modulation, harmonic distortion is inevitable. Determining the allowable harmonic distortion becomes a trade-off between the cost impact of inverter output filtering, inverter complexity, and reliability/maintainability to minimize harmonics versus the cost and reliability impacts of accommodating harmonics in the loads.

A key aspect of accommodating harmonics in motors is thermal heating. NEMA MG 1-1998 provides guidance. Figure 30-1 of NEMA MG 1-1998 is a derating curve for commercial motors operating at rated frequency with harmonics present in the supply. It depicts the power derating versus a harmonic voltage factor. It excludes the third harmonic and multiples thereof on the presumption that the supply contains delta-connected transformers or similar third harmonic cancellation means. For vehicle applications where the power system is small and transformers are not present, all harmonics actually present should be included in the computation of the harmonic voltage factor. The harmonic voltage factor defined in NEMA MG 1-1998 is not to be confused with the total harmonic distortion as defined in *The IEEE Standard Dictionary of Electrical and Electronics Terms* [B2]. An additional consideration is the potential for audible noise generated by current harmonics in the magnetic structure of transformers and motors.

4.3.1.4 Starting conditions

One or more of the following principal starting conditions shall be defined by the responsible entity identified in Table 1:

a) *Direct starting with input voltage*—The input voltage supplies the energy used to start the static inverter.

b) *Starting by auxiliary battery*—The energy used to start the static inverter is supplied by an auxiliary battery specific to the inverter.

c) *Starting by main vehicle battery*—The main vehicle battery supplies the energy used to start the inverter.

4.3.1.5 Input characteristics

When the static inverter is connected directly to the supply line as is the vehicle propulsion system, IEC 61287-1 (1995-07) shall be used for specification of input requirements.

There shall be galvanic isolation between the high-input dc supply voltage and the ac output of the static inverter. If the static inverter is connected directly to the supply line, the galvanic isolation shall be in the

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static inverter. If an IVPS is used, either it or the static inverter may have the galvanic isolation. Alternately a fast-acting electronic device may be employed to reduce the output voltage or trip appropriate circuit protection, if such a scheme is allowed by the authority having jurisdiction. However, if such a scheme is employed, it shall include reliable quick acting protection. The device shall be tested with simulated input failures to assure that adequate protection is provided. The loads connected to non-isolated inverter outputs shall be capable of withstanding the maximum voltage (including transients) that may be impressed upon the output phases with respect to ground.

NOTE—From the standpoint of protection to equipment and safety, it is recommended to have galvanic isolation (a transformer between the high-input dc voltage and ac output) such that if an input power device shorts, the output voltage automatically reduces to zero and equipment protection is assured.

4.3.2 Low-power output

ANSI C84.1-1995 shall be used for specifying power and voltage ratings for lower power output equipment. Galvanic isolation shall be provided in these devices.

NOTE—The lower power outputs are usually used for housekeeping to run vacuum cleaners, computers, and other such commercial products. Since the loads do not have a high power demand, it may be cost effective to provide a single phase ac output, which has the additional filtering required to achieve the low-voltage distortion levels. Alternatively, additional filtering could be provided outside the inverter, close to the convenience outlets in the car. In accordance with the recommendations of IEEE Std 519-1992, those systems employing computers generally require a voltage source with less than 5% harmonic voltage distortion factor with the largest single harmonic content no more than 3% of the fundamental voltage value.

4.3.3 Distributed inverters

In some cases it is the preference of the authority having jurisdiction and/or the car builder to have a system of distributed inverters wherein the incoming high-voltage dc is converted to a regulated IVPS. This regulated IVPS output in turn feeds a bus line. The individual load devices (such as air conditioners, air compressors, etc.) receive the regulated dc and convert it via its own internal inverter to the proper three-phase ac to drive the device. In this case, the individual inverter outputs are tailored to the load device and usually include variable voltage and variable frequency outputs such that it can accommodate a wide range of load variations and start-up and shut-down conditions in a more efficient manner.

In such cases, the car builder shall define the loads as seen by the IVPS. Since the inverters are tailored to each specific load device, it becomes the responsibility of the car builder and the manufacturer of the load device to set the interface requirements for the distributed inverters.

If the device manufacturer supplies its own distributed inverter, the inverter interface requirements should be provided to the car builder and the authority having jurisdiction for approval. If the inverter and motor are received from different suppliers, the car builder shall set the interface requirements and the authority having jurisdiction shall approve them. NEMA MG 1-1998 provides application guidance.

For distributed inverters supplied directly from the line supply (without IVPS), input shall comply with 4.3.1.5.

The IVPS builder shall define the output characteristics of the inverter such as voltage range, output power, start-up sequence under initial start up and after traversing third rail and catenary gaps, and shut-down sequence in third rail and catenary gaps. Any-time delay required until the output voltage returns to within its operating range shall be stated.

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4.4 Low-voltage power supplies

4.4.1 LVPS configuration

The car builder shall set the requirements for the LVPS configuration and define its interface with other low-voltage systems such as the battery and battery charger. The car builder shall also assure that the LVPS configuration is in accordance with the failure management strategies and load shedding schemes specified or required by the authority having jurisdiction.

NOTE—There are several configurations for the LVPS depending on its application. Some of these are as follows:

— LVPS driving nonessential low-voltage loads not backed-up by the battery.
— LVPS driving the low-voltage loads in the car and recharging the battery in the car.
— LVPS driving the low-voltage loads and charging the battery in the car and in case of failure of the LVPS in the coupled car(s), sharing the loads of the coupled car(s) after load shed of nonessential loads in the coupled car(s).

In each of these cases performance demands placed upon the LVPS will be different.

4.4.2 Input voltages

The LVPS can be fed from an ac source such as the output of the static inverter, directly from the high-voltage dc line input, or from an IVPS. The voltage values and ranges shall be as specified herein for the static inverter output subclause 4.3.1.1 or the static inverter line voltage input as specified in 4.3.1.5.

4.4.3 Output voltages

The low-voltage system outputs shall be as shown in Table 4.

Table 4—Low-voltage outputs

Nominal voltage	Nominal LVPS output voltage at 25 °C	Minimum voltage at load	Maximum voltage at load
24	28.5	17.0	34.0
32	37.5	23.0	42.5
48	57.0	34.0	68.0
64	74.0	46.0	85.0

NOTE—The values shown in Table 4 are based on discharging to 1.0–1.1V per cell measured at the battery terminals.

The car builder, LVPS builder, and battery builder shall select the charging voltage, number of cells, and wire size to assure that the minimum voltage at the loads is maintained. If long train lines are encountered the voltage drops along the line may result in voltages below the minimum values shown. In such cases the car builder shall assure that the driven equipment will operate as required by specification over the output voltage range. The deviations shall be presented to the authority having jurisdiction for approval and concurrence.

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4.4.3.1 Nominal voltage values

The nominal voltage values shall be taken from the preferred battery values of 24 V, 32 V, 48 V, or 64 V as shown in Table 4. Also shown in Table 4 is the LVPS output voltage at 25 °C. The LVPS output voltage range shall be sufficient to provide the proper charging voltage, at the battery, as required by the battery supplier.

NOTE—Nominal voltage values are those commonly referred to in the industry to identify or classify power supplies. These nominal voltage values are given only as standardizing value for the design of the equipment. They should not be considered as equipment operating voltages.

4.4.3.2 Operating voltages of the equipment, backed by the battery

Equipment backed by the battery shall be designed for normal operation over the voltage range as shown in the last two columns of Table 4.

4.4.3.3 Operating voltages of the equipment, not backed by the battery

Equipment not backed by the battery and which are load shed immediately when LVPS shuts down shall be designed for normal operation within the voltage range between –10% of nominal voltage to the maximum voltage at the load shown in Table 4.

4.4.3.4 Voltage fluctuations

Voltage fluctuations of the low-voltage dc power output, such as may occur during start-up of the auxiliary power supply apparatus, shall be limited to the range of –40% and +40% of the LVPS output voltage found in Table 4. These fluctuations shall not exceed 0.1 second in duration. The equipment supplied from the low-voltage dc power output shall be designed for normal operation under these voltage fluctuation conditions.

The LVPS shall survive transients generated by other equipment according to requirements specified in IEC 60571 (1998-02).

4.4.3.5 Power supply over-voltage

Low-voltage dc power supply output over-voltages, such as may occur in case failure of the low-voltage power supply control systems, shall be limited to 40% above the nominal LVPS output voltage specified in Table 4, and shall not exceed one second in duration. The equipment supplied from the low-voltage dc power supply shall be designed to withstand this over-voltage without damage.

4.4.3.6 Battery charging voltage

The battery charging voltage is determined by taking into account the type of battery, number of cells and the operating conditions.

Conditions such as temperature compensation requirements, allowable battery charger ripple (voltage and current), and the capacity of the battery charger to replenish the battery during a normal train run load profile (while accounting for all loads including expected rail gaps and any other momentary or random loads) shall be resolved and specified by the car builder.

NOTE—This may require an iterative process wherein the car builder receives feedback from the LVPS, battery charger, and battery suppliers to resolve the optimum specification requirements.

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4.4.4 Over-voltage protection

Protection shall be provided such that if the voltage output goes above the limits specified, the LVPS will shut off. During shut-off or start-up, the voltage transients shall remain within the specified limits.

4.4.5 LVPS current limit

The LVPS shall employ current limit protection such that when a load exceeding the maximum allowable output current is present, the output voltage will drop to limit the LVPS power dissipated.

4.4.6 Dead battery start

The LVPS shall employ a dead battery start capability. If the LVPS is line fed it may derive start-up power from the line. If it is fed from the inverter, then the inverter shall start first.

4.4.7 Load-shedding control

The LVPS or low-voltage distribution system shall include a load-shedding device that will remove the non-essential loads from the LVPS bus, thus allowing the essential loads to operate from the battery as described in 4.2.2. If the train employs a computer controlled train management system, then it may be utilized to control the load shedding.

4.4.8 Automatic LVPS start-up during lay-up condition

If the LVPS output is being used to charge the battery and there are long overnight conditions wherein the battery may be depleted, automatic start-up of the LVPS to charge the battery may be employed. If such is the case, the operating entity and/or the car builder shall clearly define the conditions and requirements for automatic start-up.

4.4.9 Galvanic isolation

The LVPS output shall be galvanically isolated from its input supply line voltage.

4.4.10 LVPS battery charge capacity

The capacity of the LVPS shall be such that it will drive all the required loads and recharge the battery. This shall be based on a normal train run load profile for all expected loading including depletion resulting from rail gaps or track brake applications and any other momentary high-current loads. If a dedicated battery charger is used to charge the battery, as will be subsequently presented in 4.6, the requirements for the LVPS charging the battery do not apply.

4.5 Battery

Nickel-cadmium batteries shall be used unless otherwise approved by the authority having jurisdiction.

NOTE—All parameters given in 4.5 are based on nickel-cadmium batteries.

4.5.1 Battery parameters

When defining the battery requirements, the following parameters about the dc system shall be obtained from the authority having jurisdiction or the car builder as described in Table 1.

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a) Minimum voltage that is measured at battery terminals while taking into account the expected voltage drop on the line between the battery and the load. Minimum load voltages are presented in Table 4.

b) Maximum voltage that is measured at the battery terminals. Since maximum battery voltage can occur coincident with minimum battery load current, the voltage drop on the line will be minimal; therefore the maximum voltage at the battery terminals is the same as the maximum voltage at the load as presented in Table 4.

c) Load type—resistive, constant current, and constant power. (For battery loads relays that are considered as resistive loads, see Clause 3.)

d) Battery duty cycle (load profile). Amperes required for a period of time; this includes momentary loads (periodic and random).

e) Battery ambient operating temperature range.

f) Temperature compensation inclusion. This may be required when operating over a wide range of temperatures to improve the battery performance and reduce the water consumption.

g) The type of charging system employed—single-, dual-, or multiple-rate charging.

h) Discharge cycles include the numbers of discharges (per day, month, or year) and depth of discharge.

i) Design margin. The amount of excess capacity to meet the user's margin of safety and/or allowance for additional future loads.

Based on the information outlined in the previous list, the battery supplier shall establish the following design parameters:

— The state-of-charge factor.

— The battery aging factor to take into account the required lifetime in years, the normal operating temperature, and the cycling, including numbers of discharges (per day, month, or year), the depth of discharge, and the recommended maintenance required.

— The temperature derating factor, which is based on operating temperature specified, the rate of discharge, and/or discharge time and/or minimum operating voltage.

— Temperature compensation parameters.

4.5.2 Battery selection/sizing

Battery sizing shall be accomplished in accordance with the battery builder's recommended method. The battery builder shall provide written rationale/method along with applicable curves and supporting data to the car builder. The car builder and the authority having jurisdiction shall have the right of approval of the battery selection. The battery builder may refer to IEC 60623 (1990-03) [B1] and IEEE Std 1115-1992 [B3] for guidance in determination of the battery size.

4.6 Battery chargers

A dedicated battery charger shall be used only to recharge the vehicle battery. It shall not be used to supply voltage to equipment loads.

NOTE—Usually the LVPS output is utilized to charge the batteries as previously described in 4.4.3.6. However, there are conditions under which the authority having jurisdiction or car builder may require a separate dedicated battery charger. Such a system provides the advantage of producing a rate of charge tailored to the existing charge state of the battery; thus it can be designed to produce a faster charging rate and can be tailored to the environmental conditions (hot summer/cold winter). This clause of the standard addresses the requirements for a dedicated battery charger.

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4.6.1 Battery charger output voltage

The battery charger shall provide output voltages in accordance with the requirements stated in 4.4.3.6.

4.6.2 Battery charger capacity

The charger shall have the capability to completely recharge a depleted vehicle battery within the period of time specified by the authority having jurisdiction. The charger shall be configured such that it will not discharge the battery when input power to the charger is interrupted, a fault occurs within the charger, or for any other reason.

4.6.3 Charging level

The charging system shall be capable of automatically selecting the full voltage float (temperature compensated if required), trickle, completely off, or equalizing battery charging mode (including one or more constant/variable voltage/current charging schemes) as applicable for the charge state of the battery.

4.6.4 Fault protection

Input, output, and over-temperature fault protection shall be provided.

4.7 Control via vehicle communications bus

If the power converters are intended to be networked via the vehicle communications bus, it shall interface with the communications hardware through channel connections and communication protocol as defined in IEEE Std 1473-1999.

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Annex A

(informative)

Functional requirements and loads analysis guidelines

Table A.1—AC loads compilation, example

Number	Item	Voltage	KW/motor	Power factor	Qty. Total	kW Total	kVA
1	HVAC compressor motor (locked rotor load)	230 3∅	40.0	0.6	2	80.0	133.3
2	HVAC compressor motor (design load)	230 3∅	13.1	0.8	2	26.2	32.8
3	HVAC compressor motor (pull down load)	230 3∅	15.0	0.8	2	30.0	37.5
4	Condenser blower motor	230 3∅	2.6	0.8	2	5.2	6.5
5	Evaporator blower motor	230 3∅	1.3	0.8	2	2.6	3.3
6	Windshield heater	120 1∅	1.0	1.0	2	2.0	2.0
7	Convenience outlets	120 1∅	2.4	0.8	1	2.4	3.0
8	Design load nominal					38.4	47.1
9	Pull down load total (20 min)					39.8	48.9
10	Design load total including 15% margin					44.2	54.9

In Table A.1, the maximum inrush current would be used by the designer of the static inverter to size the inverter for transient start conditions. The importance of the peak transient load condition must not be underestimated. Most auxiliary inverters have a peak output current limitation (determined by the output power), which is determined by the current rating of the semiconductor devices and the magnetic components used in the construction of the inverter. To avoid costly over-sizing of the inverter, the loads must be sequenced such that starting currents do not occur simultaneously on two units. This can be accomplished via the car communications or monitoring system, if available, or by separate sequencing control added to the car. Control of load switching becomes more important when the loads that the inverter supplies are *high-efficiency* machines. A characteristic of this type of machine is the high inrush drawn by the motor during starting. Note that the total design load and pull-down load do not include the locked rotor load. In this manner, the static inverter is sized to start the heaviest load while all of the rest of the loads are running at their nominal condition. The pull down load in the example lasts 20 minutes, which is a long enough duration to stabilize to a higher thermal level; thus assuring that the static inverter with its design margin is able to produce the pull down load current. A minimum safety design margin of 15% is added to the power rating of the inverter to allow for additional unaccounted-for loads. This is a sufficient margin if care is taken in tabulating loads such that all known loads and conditions are considered. As refinements are made to loads analysis, the design margin may be reduced. It must also be recognized that the minimum load on the static inverter can be zero for an indefinite period of time.

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Table A.2—DC loads compilation, example

Type	Unit	LVPS load (Watts) @ 37.5 Vdc (Vps)				Total		Battery load (Amps) @ 25.0 Vdc (Vbb) or 27.5 Vdc (Vba)				
		Max.	Avg.	Std.-By	Qty.	Wt_o	It_o	It_1	It_2	It_3	It_4	Remarks
Constant power	PA/Intercom	50	6	3	1	6	0.16	0.24	0.24	0.24	0.24	See Notes 1, 2, & 11
	Radio	18	10	8	1	10	0.26	0.4	0.4	0.4	0.4	See Notes 1, 2, & 11
	Frk.Brk.Cont.(CPL)	100	—	—	3	300	8	12.0	12.0	12.0	12.0	See Notes 1, 2, & 11
	HVAC Cont.	100	—	—	2	200	5.3	8.0	—	—	—	See Note 8
	•											
	•											
	•											
	Subtotal					516	13.72	20.64	12.64	12.64	12.64	
Constant current loads	Lighting	36	—	—	40	356	9.5	9.5	—	—	—	See Notes 1 , 8, & 14
	Subtotal					356	9.5	9.5				
Resistive loads	Tail lights	5	—	—	2	10	0.267	0.196	0.196	0.196	0.196	See Note 3 & 12
	Frk.Brk.Cont.(CRL)	50	—	—	3	150	4	2.93	2.93	2.93	2.93	See Note 3 & 12
	•											
	•											
	•											
	Subtotal					160	4.267	3.126	3.126	3.126	3.126	
Momentary loads 10% Duty cycle	Sanding valves	10	0	0	4	4	0.11	—	—	—	—	See Notes 4 & 8
	Mag. Trk. Brks.	600	11	—	6	66	1.76	0.77	0.77	0.77	0.77	See Notes 4 & 9
	door operators	244	—	—	4	975	26	—	—	—	39	See Note 5
	•											
	•											
	•											
	Subtotal					1045	2.13	0.77	0.77	0.77	39.77	
	Totals					WT	IT	I1	I2	I3	I4	See Notes 6 & 7

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NOTES:

1—The current (It_o) is the steady state current when the LVPS is operating. It is equal to the watts (Wt_o) divided by the LVPS voltage (V_{ps}) (37.5 V). The currents It_1 though It_4 are the battery discharge currents which comprise the load profile that must be provided by the battery during the emergency back-up period.

2—Constant power loads: the load currents for time periods t_1 through t_4 are determined by

$$I(t_1 - t_4) = \frac{Wt_o}{V_{bb}} = \frac{Wt_o}{25\text{vdc}}$$

3—Resistive loads; the load currents for time periods t_1 through t_4 are determined by

$$I(t_1 - t_4) = \frac{V_{ba}}{(V_{ps})^2} \times Wt_o = 27.5 \times \frac{Wt_o}{25\ \text{vdc}}$$

4—The sanding valves and magnetic track brakes are treated as resistive loads.

5—The door operators are shown as constant power loads applied only during the end of the emergency operation cycle (t_4). This load is often critical in the design of the battery in that the battery must support this load when it is at its end of discharge cycle and its terminal voltage is at its lowest value.

6—WT is the summation of Wt_o and is the power rating required for the LVPS to support nominal loads with the exception of the track brakes for which the load is supported in part by the battery.

7—I1, I2, I3, and I4 is the summation of currents during the periods t_1 through t_4 and are the current ratings for the battery load profile. They must be supported by the battery during emergency.

8—These loads are shed on loss of LVPS power, but must be supported by the battery during the period t_1 which occurs prior to load shedding.

9—In this example the track brakes are applied randomly and the battery must be designed to help support the application of track brakes. However; the LVPS must be designed to replenish the charge lost from the battery during a normal train run.

10—The load I1 which occurs during the initial period of battery discharge prior to the time the nonessential loads are shed. This load can be quite high and lasts for a duration of approximately 30 seconds. The battery must be designed to support these loads during the traversing of rail gaps.

11— V_{bb} is the minimum end voltage at the battery terminals (25 V or 1.0 V per cell based on a 25 cell battery). This provides a conservative method of converting watts to amperes assumes a constant current for the entire load duration which is equal to the current being supplied by the battery at the end of the discharge period (minimum volts, maximum amperes).

12— V_{ba} is the average discharge voltage of the battery (27.5 V or 1.1 V per cell) based on a 25 cell battery.

13—The loads shown in the table are typical, but not all inclusive, of types of loads encountered on a transit car.

14—The constant current loads It_1 though It_4 are equal to the steady state current It_0.

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Table A.3—Functional requirements definition matrix, example

Responsibility function	Authority having jurisdiction (Notes 1 & 7)	Car builder (Notes 2 & 7)	Inverter supplier (Notes 3 & 7)	LVPS/BC supplier (Notes 4 & 7)	Battery supplier (Notes 5 & 7)
Identify normal (nonessential) low-voltage loads	1	2			
Identify essential loads (lights, radio, PA, doors, etc.)	1	2			
Specify emergency duration evacuation	1	2			
Car recovery duration	1	2			
Specify fleet compatibility (battery trainline voltage)	1	2			
Define primary power source (voltage, transients, faults)	1	2			
Compile ac and dc loads	2	1			
Specify on-board source filter (primary transient snubbing)	2	1			
Quantify emergency loads (lights, radio, PA, doors, etc.)	2	1			
Define low-voltage value and distribution voltage drops	2	1			
Define load current profile in emergency duration	2	1			
Specify battery maintenance interval (watering and checks)	1	2		2	2
Specify operating temperature range (charging and discharging) (see Note 6)	1	2		2	2
Specify battery size and capacity (Ampere-Hr., cell dimensions)	2	2			1
Specify battery and cell access provisions for maintenance	1	2			2
Establish flame smoke and toxicity levels	1	2			2
Specify battery charging method	1	2		2	2
Specify low-voltage energy source (primary or intermediate)	1	2		2	
Specify LVPS size (rating) for normal and emergency loads	2	1		2	
Specify LVPS electrical current foldback and fault protection	2	1		2	2
Define intermediate-voltage nominal value	1	2	2		

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Table A.3—Functional requirements definition matrix, example (continued)

Responsibility function	Authority having jurisdiction (Notes 1 & 7)	Car builder (Notes 2 & 7)	Inverter supplier (Notes 3 & 7)	LVPS/BC supplier (Notes 4 & 7)	Battery supplier (Notes 5 & 7)
Identify intermediate-voltage loads (HVAC, blowers, lights)	1	2			
Quantify intermediate-voltage loads and start-up phasing	2	1	2		
Quantify intermediate-voltage short time energy storage need (rail gaps)	1	2	2		
Define intermediate-voltage distribution and protection	2	1	2		
Define the static inverter output isolation	1	2			
Specify intermediate-voltage load shed at low primary volts	1	2	2		
Battery aging factor	2	2			1

NOTES:

1—As used herein, the term *authority having jurisdiction,* which was previously defined in 3.1, should be further interpreted to cover the car buyer; the operating agency, if different; any design consultant acting on behalf of these organizations; and any maintenance group not covered by the preceding. In a design-build context the term covers both the intermediate operator and maintainer sub-elements of the consortium as well as the ultimate owner of the vehicle fleet.

2—As used herein, the term *car builder,* which was previously defined in 3.1, should be further interpreted to cover the prime vehicle contractor and any systems integrator specialty support assisting in the car design process. In some recent vehicle procurements, the specifier explicitly mandates the use of a systems integrator by the vehicle prime contractor.

3—As used herein, the term *inverter supplier* should be interpreted to cover the designer and provider of the intermediate-voltage three phase or single phase alternating current converter that produces the intermediate-voltage power for significant (but not emergency critical) car auxiliary loads.

4—As used herein, the term *LVPS supplier,* which was previously defined in 3.1, should be further interpreted to cover the designer and provider of the low-voltage direct current converter that produces the low-voltage for normal loads, for emergency loads under normal operation, and for optional on-line (float) battery charging. The term *LVPS Supplier* also covers the supplier of a separate off-line (regulated current) battery charger if that option is selected in the car design process.

5—As used herein, the term *battery supplier* should be interpreted to cover the supplier of the electro-chemical storage battery that supports the car emergency low-voltage loads and may buffer momentary low-voltage loads such as track brakes.

6—For purposes of sizing the batteries the vehicle operating temperature range is not necessarily the operating range of the batteries. The responsible parties shall consider the environment and temperature of the battery when called upon to perform its backup function. For example the battery compartment may have heaters to elevate its temperature or be located under the car in a place where it is influenced by or affected by the temperature of surrounding equipment.

7—The codes used within the matrix shall

a) Determine and set the detailed functional requirement.
b) Concur with detailed functional requirement.

Annex B

(informative)

Bibliography

[B1] IEC 60623 (1990-03), Vented nickel-cadmium prismatic rechargeable single cells [including IEC 60623-am1 (1992-04) and IEC 60623-am2 (1992-07)].

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[B4] *Urban Public Transportation Glossary,* Transportation Research Board, Washington, DC, 1989.

[B5] *Webster's New Collegiate Dictionary,* Springfield, MA: Merriam-Webster, Inc.

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