BS EN 62864-1:2016

BSI Standards Publication

Railway applications — Rolling stock — Power supply with onboard energy storage system

Part 1: Series hybrid system

National foreword

This British Standard is the UK implementation of EN 62864-1:2016. It is identical to IEC 62864-1:2016.

The UK participation in its preparation was entrusted to Technical Committee GEL/9, Railway Electrotechnical Applications.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Railway applications - Rolling stock - Power supply with onboard energy storage system - Part 1: Series hybrid system (IEC 62864-1:2016)

Applications ferroviaires - Matériel roulant - Alimentation équipée d'un système embarqué de stockage de l'énergie - Partie 1: Système hybride série (IEC 62864-1:2016)

Bahnanwendungen - Schienenfahrzeuge - Stromversorgung durch Energiespeichersysteme auf Schienenfahrzeugen - Teil 1: Serienhybridsystem (IEC 62864-1:2016)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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European foreword

The text of document 9/2154/FDIS, future edition 1 of IEC 62864-1, prepared by IEC/TC 9 "Electrical equipment and systems for railways" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62864-1:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-05-04
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-11-04

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IEC 60076-10	NOTE	Harmonized as EN 60076-10.
IEC 60077-1	NOTE	Harmonized as EN 60077-1.
IEC 60216-5	NOTE	Harmonized as EN 60216-5.
IEC 60254-1:2005	NOTE	Harmonized as EN 60254-1:2005 (not modified).
IEC 60254-2:2008	NOTE	Harmonized as EN 60254-2:2008 (not modified).
IEC 60310	NOTE	Harmonized as EN 60310.
IEC 60721-3-5	NOTE	Harmonized as EN 60721-3-5.
IEC 62619	NOTE	Harmonized as EN 62619 [1)].
IEC 62620	NOTE	Harmonized as EN 62620.
IEC 62928	NOTE	Harmonized as EN 62928 [1)].

[1)] At draft stage.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 60050-811	-	International Electrotechnical Vocabulary (IEV) - Chapter 811: Electric traction	-	-
IEC 60349-2	-	Electric traction - Rotating electrical machines for rail and road vehicles - Part 2: Electronic converter-fed alternating current motors	EN 60349-2	-
IEC 60349-4	-	Electric traction - Rotating electrical machines for rail and road vehicles - Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter	EN 60349-4	-
IEC 60529	-	Degrees of protection provided by enclosures (IP Code)	EN 60529	-
IEC 61133	2016	Railway applications - Rolling stock - Testing of rolling stock on completion of construction and before entry into service	-	-
IEC 61287-1	-	Railway applications - Power converters installed on board rolling stock - Part 1: Characteristics and test methods	EN 61287-1	-
IEC 61373	-	Railway applications - Rolling stock equipment - Shock and vibration tests	EN 61373	-
IEC 61377	2016	Railway applications - Rolling stock - Combined test method for traction systems	EN 61377	2016
IEC 61881-3	-	Railway applications - Rolling stock equipment - Capacitors for power electronics - Part 3: Electric double-layer capacitors	EN 61881-3	-
IEC 61991	-	Railway applications - Rolling stock - Protective provisions against electrical hazards	-	-
IEC 62262	-	Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)	EN 62262	-
IEC 62498-1	2010	Railway applications - Environmental conditions for equipment - Part 1: Equipment on board rolling stock	-	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RAILWAY APPLICATIONS – ROLLING STOCK – POWER SUPPLY WITH ONBOARD ENERGY STORAGE SYSTEM –

Part 1: Series hybrid system

FOREWORD

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International Standard IEC 62864-1 has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

The text of this standard is based on the following documents:

FDIS	Report on voting
9/2154/FDIS	9/2176/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62864 series, published under the general title *Railway applications – Rolling stock – Power supply with onboard energy storage system*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

There is an increasing need for efficient use of energy due to the decrease in fossil fuel based energy sources as well as the need to reduce emissions (e.g. CO_2, NO_x, PM, etc.) that contribute to global climate change. The railway system, which is essentially an energy-efficient transportation system, should also meet these requirements. In addition to saving energy, it is necessary to achieve a reduction in peak power, voltage stabilization and the ability to run without collecting power in scenic reserve areas, and the running capability to safely reach the next station in the event of electrical power failure onboard or at power supply system. To address these issues, hybrid systems are appearing in railway vehicles. These hybrid system vehicles are equipped with an energy storage system that allows effective use of regenerative energy. A hybrid system should be required to improve energy efficiency by actively controlling the power flow among the engine or power supply system, auxiliary power supply, traction and braking system, the energy storage system, etc.

The purpose of introducing hybrid systems includes:

- reducing energy consumption;
- improving vehicle performance;
- providing the ability to run with energy stored onboard; and
- improving environmental characteristics.

The aim of this standard is to establish the basic system configuration for series hybrid systems (electrically connected) and the tests to verify effective use of energy, as well as to provide railway operators and manufacturers with guidelines for manufacturing and evaluating hybrid systems.

The hierarchy of relevant standards related to hybrid systems are summarized in Figure 1. The standards listed in Figure 1 are not exhaustive.

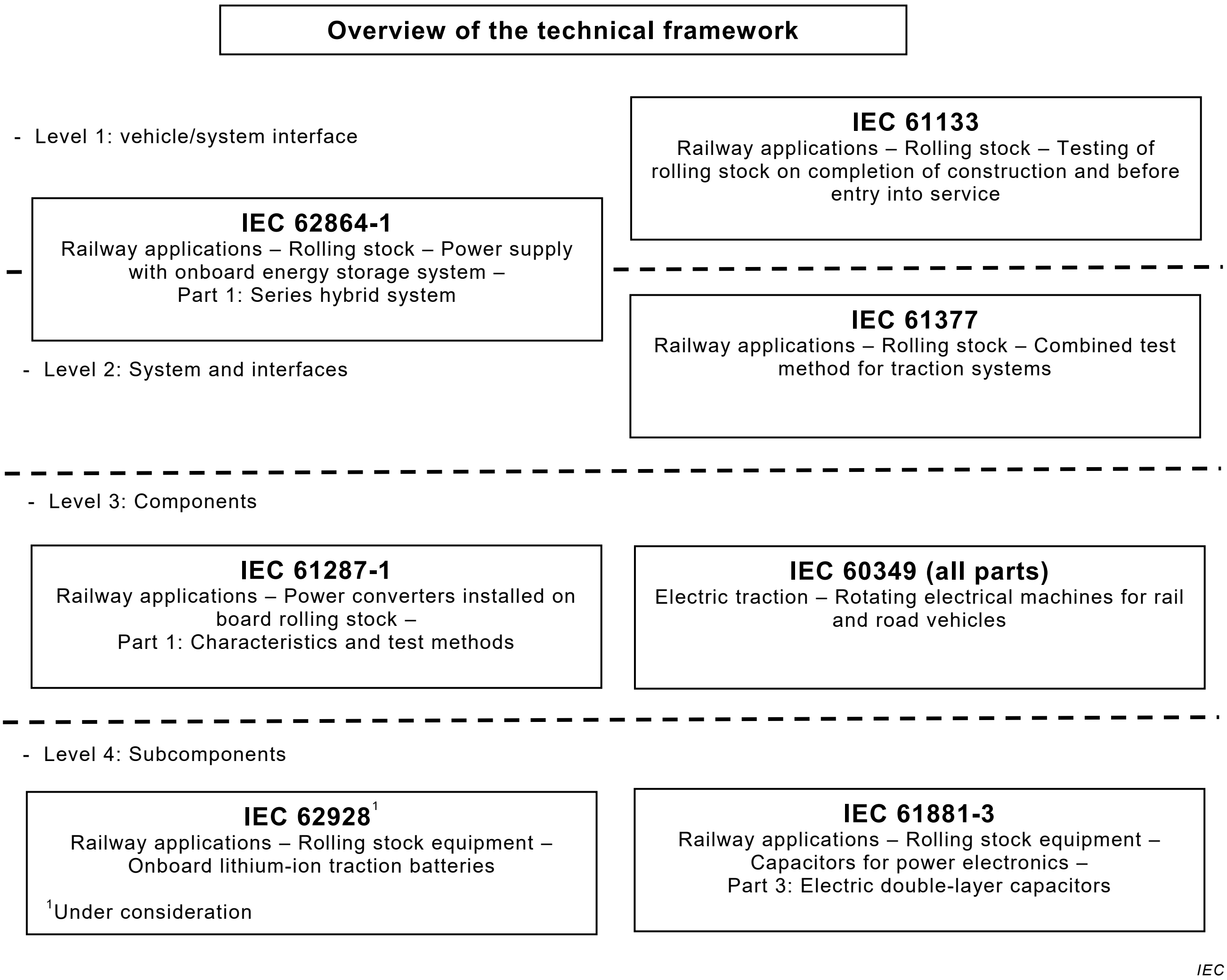


Figure 1 – Hierarchy of standards related to IEC 62864-1

In this standard, the hybrid system has the following four levels of hierarchy:

a) vehicle/system interface (level 1);
b) systems and interfaces (level 2);
c) components (level 3); and
d) subcomponents (level 4).

Detailed descriptions of the levels are described in 7.1.

E.g. subcomponent (level 4) is a cell, module etc. (for a battery, a subcomponent is defined in IEC 62620).

RAILWAY APPLICATIONS – ROLLING STOCK – POWER SUPPLY WITH ONBOARD ENERGY STORAGE SYSTEM –

Part 1: Series hybrid system

1 Scope

This part of IEC 62864 applies to series hybrid systems (electrically connected) with onboard energy storage (hereinafter referred as hybrid system).

A hybrid system has two (or more) power sources including energy storage system (ESS) on board to achieve the following features by combining converter and motors and performing energy management control:

- improving energy and fuel efficiency, improving acceleration characteristics, increasing running distance and uninterrupted running in the event of the loss of the primary power source (PPS), by using an ESS in addition to the primary power source under conditions where the power and capacity of the power source including regenerative power are limited, thus alleviating those limitations;
- reducing fuel consumption, reducing emissions (e.g. CO_2, NO_x, PM, etc.);
- reducing environmental impact (e.g. visible obstruction, noise, etc.).

By extension, systems that have only onboard ESS, without other PPSs, is also considered in this standard.

This standard intends to specify the following basic requirements, characteristics, functions and test methods for hybrid systems:

- energy management to control the power flow among primary power source, energy storage system and power converters;
- energy consumption, energy efficiency and regenerated energy;
- vehicle characteristics achieved by energy storage system;
- test methods of combined test; and
- test methods of completed vehicles based on factory (stationary) and field (running) tests.

NOTE Converter in this standard means combined equipment consisting of one or more converters (e.g. rectifier, inverter, chopper, etc.).

The interfaces between the following power sources are covered:

- external electric power supply system;
- onboard ESSs (including pure onboard energy storage);
- fuel cell, diesel electric generator; and
- other power sources.

As for the combination of inverters and motors, this standard applies to asynchronous motors or synchronous motors that are powered via voltage-source inverters.

Power source systems and combination of inverters and motors are not limited to the listed above, but this standard can also be applied to future systems.

This part of IEC 62864 covers electrically connected systems (series hybrid), and not systems that mechanically transmit the driving force (parallel hybrid).

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-811, *International Electrotechnical Vocabulary (IEV) – Chapter 811: Electric traction*

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 electrical machines connected to an electronic converter*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61133:2016, *Railway applications – Rolling stock – Testing of rolling stock on completion of construction and before entry into* service

IEC 61287-1, *Railway applications – Power converters installed on board rolling stock – Part 1: Characteristics and test methods*

IEC 61373, *Railway applications – Rolling stock equipment – Shock and vibration tests*

IEC 61377:2016, *Railway applications – Rolling stock – Combined test method for traction systems*

IEC 61881-3, *Railway applications – Rolling stock equipment – Capacitors for power electronics – Part 3: Electric double-layer capacitors*

IEC 61991, *Railway applications – Rolling stock – Protective provisions against electrical hazards*

IEC 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

IEC 62498-1:2010, *Railway applications – Environmental conditions for equipment – Part 1: Equipment on board rolling stock*

3 Terms, definitions and abbreviations

For the purposes of this document, the terms and definitions given in IEC 60050-811, as well as the following, apply.

3.1 Terms and definitions

3.1.1
hybrid
system that combines two (or more) different types of components for a specific purpose

Note 1 to entry: An approach for using multiple motive power sources and one for using multiple electric power sources exist for rolling stock applications.

3.1.2
parallel hybrid
system for transmitting power from multiple motive power sources to the wheels

Note 1 to entry: The driving force from the engine and that from the motor are transferred to the wheels via the transmission system.

3.1.3
hybrid
series hybrid
system which drives a motor supplied via the power converter for combined operation of electric power from multiple power sources

Note 1 to entry: The wheels are driven by the driving force from the motor only.

3.1.4
hybrid vehicle
vehicle that can store energy in an onboard ESS and is driven by using the stored energy as well as electric power from a generator or overhead lines

3.1.5
subsystem <**of a series hybrid system**>
constituent of a series hybrid system

EXAMPLE Primary power source, energy storage system, traction equipment.

3.1.6
component <**of a series hybrid system**>
constituent of a subsystem in a series hybrid system

EXAMPLE Converter, motor, diesel electric generator, ESU.

3.1.7
subcomponent <**of a series hybrid system**>
constituent of a component in a series hybrid system

EXAMPLE Lithium ion battery, electric double-layer capacitor.

3.1.8
energy consumption
total energy consumption of the entire vehicle for a specified operation (duration, distance, speed, etc.)

3.1.9
specific energy consumption
energy consumption for a specific distance and weight

Note 1 to entry: The value is obtained by dividing the energy consumption by the distance and the vehicle weight or number of vehicles. This value can be expressed, e.g. in kWh/(t·km), kWh/(car·km), kWh/(person·km) or kWh/(seat·km), etc.

Note 2 to entry: If an onboard power source, e.g. diesel generator set or fuel cell, is used, the unit may be l/(t·km), l/(car·km), l/(person·km) or l/(seat·km), etc. depending on the type of fuel.

3.1.10
power source
equipment that supplies power to a traction unit and/or APS and/or ESSs via a converter

Note 1 to entry: Converters (such as chopper for fuel cell (FC.CH)) for power generation and converters (such as ESS chopper (ESS.CH)) for energy storage units/systems are considered as power sources, but traction converters and converters for APS are not considered as power sources.

3.1.11
primary power source
PPS
subsystem in a series hybrid system the primary purpose of which is to supply electric energy to other subsystems in the series hybrid system by either consuming the fuel stored onboard or taking in energy from external sources

3.1.12
traction equipment
subsystem in a series hybrid system the primary purpose of which is to consume electrical energy and to output tractive effort so that the railway vehicle is propelled

3.1.13
state of charge
SOC
remaining capacity to be discharged, normally expressed as a percentage of full capacity as expressed in relevant standards

Note 1 to entry: Practical definitions of SOC are dependent upon chosen technologies. SOC is applicable to batteries. See Annex A.

3.1.14
state of energy
SOE
remaining energy to be discharged, normally expressed as a percentage of full energy as expressed in relevant standards

Note 1 to entry: Practical definitions of SOE are dependent upon chosen technologies. SOE is applicable to both batteries and capacitors. See Annex A.

3.1.15
end of life
EOL
point at which the ESU cannot fulfil the required functionality or operational pattern as initially agreed among the user and the manufacturers

3.1.16
beginning of life
BOL
point at which the ESU has the rated capacity or energy fully available as minimum performance at manufacturer's delivery

3.1.17 Definition of capacity

3.1.17.1
capacity
electrical charge that can be delivered from ESU

Note 1 to entry: In case of the battery the electrical charge is often expressed in ampere-hours (A·h).

Note 2 to entry: In case of the capacitor the electrical charge is often expressed in coulombs (C).

Note 3 to entry: Capacitance is measured in farads (F),which is charge (C) divided by voltage (U), and is different from capacity.

3.1.17.2
theoretical capacity
maximum capacity available without loss

3.1.17.3
rated capacity
available capacity measured according to certain “rating” condition as expressed in relevant standard

Note 1 to entry: Refer to IEC 62928.

3.1.17.4
usable capacity
capacity available to be discharged depending upon applications

3.1.18 Definition of energy

3.1.18.1
theoretical energy
maximum energy available without loss stored in the ESU

3.1.18.2
rated energy
energy available measured according to certain “rating” condition as expressed in the relevant standard

Note 1 to entry: Practical definitions of rated energy storage capacity are dependent upon chosen technologies.

3.1.18.3
usable energy
energy available to be discharged depending upon applications

3.1.19
operational pattern
definition by the user and/or the manufacturers in order to fulfil the needs of operations including auxiliaries, e.g. duty cycle, auxiliary loads, safety margin of energy content, degraded mode, etc.

3.1.20
energy storage unit
ESU
physical equipment which is comprised of energy storage technologies such as batteries, EDLC, flywheel, etc.

Note 1 to entry: Refer to the relevant standards for components.

3.1.21
battery
ESU which is used primarily for traction purpose in this standard

Note 1 to entry: This document does not cover auxiliary batteries. Refer to IEC 62973.

3.1.22
energy storage system
ESS
physical system which consists of one or more ESUs and the other equipment required to connect to the DC link such as converters, control and monitoring systems, inductors, protection devices, cooling systems, etc.

3.2 Abbreviations

APS Auxiliary power supply

AUX Auxiliaries

BOL Beginning of life

EDLC Electric double-layer capacitor

EOL End of life

ESU Energy storage unit

ESS Energy storage system

PPS Primary power source

SOC State of charge

SOE State of energy

4 Power source configuration of hybrid systems

4.1 General

4.1.1 Overview

There can be a variety of system configurations for the series hybrid systems to which this part of IEC 62864 is applicable. In Clause 4, it is intended to give an overview of the possible configurations by presenting a number of examples. These examples, however, are not meant to impose constraints on the final system architecture.

4.1.2 System configuration requirements

As described in Clause 1, a series hybrid system shall have two or more power sources, including one ESS, and the traction equipment which serves as the primary power sink. The system may have a secondary power sink, such as a brake resistor, in case the power sources are either entirely or partly unreceptive of the power regenerated by the traction equipment during regenerative braking. These subsystems shall be connected electrically to enable exchange of power among them. In addition to these main circuit subsystems, the series hybrid system may have one or more auxiliary power supplies (APS). However, the connection between the APS and other subsystems in the series hybrid system may be either electrical, non-electrical or even non-existent, i.e. the APS is independent of the main circuit subsystems. If connected, the auxiliary loads shall be considered because of their significant impact on the energy consumption.

Figure 2 shows an example block diagram of a series hybrid system with five main subsystems, i.e. one primary power source (PPS), one ESS, one traction equipment, one APS and its loads, and one brake resistor as a secondary power sink. In Figure 2, the block Link transfers power among these main subsystems through itself.

As shown in Figure 2, the possible PPS configurations include, but are not limited to:

- the combination of a diesel engine with a generator and an electric power converter;
- fuel cells and an electric power converter;
- DC contact lines; or
- the AC contact lines and an electric power converter.

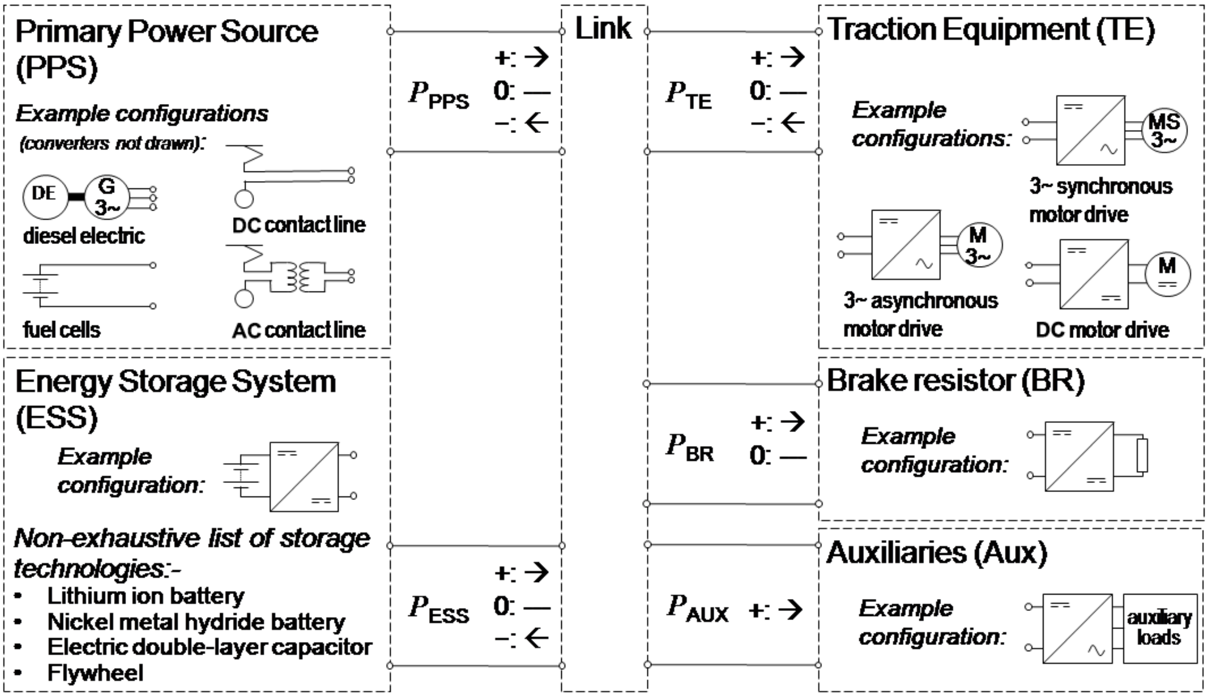
As shown in Figure 2, the storage technologies usable in the ESS include, but are not limited to:

- Lithium ion batteries;
- Nickel metal hydride batteries;
- Electric double-layer capacitor (EDLC); or
- flywheels.

As shown in Figure 2, the possible traction equipment configurations include, but are not limited to:

- four quadrant choppers and DC traction motors;
- voltage source inverters and AC asynchronous traction motors; or
- voltage source inverters and AC permanent magnet synchronous traction motors.

NOTE The word "power sink" in Clause 4 is used to denote subsystems in Figure 2 that receive power from the Link block. These subsystems are not always regarded as power sinks in more general terms; for example, the traction equipment generates tractive effort that physically accelerates the rail vehicle, and therefore it is sometimes regarded as the power source of that vehicle.



Key

DE	Diesel engine
P_{PPS}	Power of primary power source (PPS)
P_{TE}	Power of traction equipment (TE)
P_{ESS}	Power of energy storage system (ESS)
P_{BR}	Power of brake resistor (BR)
P_{AUX}	Power of auxiliaries (AUX)

Figure 2 – Block diagram of a series hybrid system

4.1.3 Major operating modes of the series hybrid system

In Figure 2, there can be power flows between the Link block and the five main subsystems, namely:

a) the PPS and the link block, denoted in Figure 2 as P_{PPS};
b) the ESS and the link block, denoted in Figure 2 as P_{ESS};
c) the link block and the traction equipment, denoted in Figure 2 as P_{TE};
d) the link block and the brake resistor, denoted in Figure 2 as P_{BR}; and
e) the link block and the APS (auxiliaries), denoted in Figure 2 as P_{AUX}.

Among these,

- a), b) and c) are bidirectional, and their values P_{PPS}, P_{ESS} and P_{TE} can be both positive and negative;
- d) is unidirectional, and its value P_{BR} cannot be negative, i.e. zero power is allowed;
- e) is also unidirectional, but unlike d), its value P_{AUX} is always positive and non-zero when the system is in operation.

In Figure 2, the possible signs (+, 0 and −) of these variables and the corresponding directions of the power flows are also shown. Note that the directions are defined so that the power flow from the power source subsystem to the link block and the power flow from the link block to the power sink subsystem become positive, e.g. when the hybrid vehicle is accelerating with power from PPS or ESS.

Using these notations, the major operating modes of the system can be classified by the signs of these variables as in Table 1.

Among the modes shown in Table 1, Mode II (pure power source mode) is the mode in which the PPS supplies all the power required by the traction equipment and can be used in all of the example system configurations shown in this clause. Similarly, Mode XIII (idling mode) is the mode in which the PPS supplies all the power required by the auxiliaries when the power required by the traction equipment is zero and can be used in all of the example system configurations shown in this clause. Also, Mode XIV (zero emission coasting mode) is the mode in which the ESS supplies all the power required by the auxiliaries when the power supplied by the PPS and the power required by the traction equipment are both zero; there may be a series hybrid system with the energy management strategy which uses only Modes X (regenerative braking to ESS and power source mode), XI (regenerative braking to ESS only mode) and XII (supplementary charging during braking mode) to charge the ESS and only Mode XIV (zero emission coasting mode) to discharge it.

Table 1 – Major operating modes of the series hybrid system

Mode	P_{PPS}	P_{ESS}	P_{TE}	P_{AUX}	P_{BR}	*Description*	Figure 4	Figure 5	Figure 6	Figure 7
I	+	–	+	+	0	Supplementary charging during motoring	Y	Y	Y	N
II	+	0	+	+	0	Pure power source	Y	Y	Y	Y
III	+	+	+	+	0	Boosting	Y	Y	Y	Y
IV	0	+	+	+	0	Zero emission/contact line free	Y	Y	Y	N
V	–	+	+	+	0	ESS to traction and grid	R	N	Y	N
VI	+	–	0	+	0	Power source charging ESS	Y	Y	Y	N
VII	–	+	0	+	0	ESS to grid mode	R	N	Y	N
VIII	–	+	–	+	0	ESS and regenerative braking to grid	R	N	Y	N
IX	–	0	–	+	0	Pure regenerative braking	Y	N	Y	Y
X	–	–	–	+	0	Regenerative braking to ESS and power source	Y	N	Y	Y
XI	0	–	–	+	0	Regenerative braking to ESS only	Y	Y	Y	N
XII	+	–	–	+	0	Supplementary charging during braking	Y	Y	Y	N
XIII	+	0	0	+	0	Idling	Y	Y	Y	Y
XIV	0	+	0	+	0	Zero emission coasting	Y	Y	Y	N
XV	–	–	–	+	+	Rheostatic braking with ESS charging and source feedback	Y	N	Y	Y
XVI	–	0	–	+	+	Rheostatic braking with source feedback	Y	N	Y	Y
XVII	0	–	–	+	+	Rheostatic braking with ESS charging	Y	Y	Y	N
XVIII	0	0	–	+	+	Pure rheostatic braking	Y	Y	Y	Y
Y: The mode is applicable for the configuration. N: The mode is not applicable for the configuration. R: The mode is rarely applicable for the configuration.										

4.1.4 Typical configuration of the series hybrid systems

Figure 2 shows the block diagram of the most commonly seen configuration in series hybrid systems. In this figure, the five main subsystems, namely the PPS, the ESS, the traction equipment, the auxiliaries and the brake resistor, are all connected to the common DC link. The configurations of the examples given in 4.2.1, 4.2.2 and 4.2.3 have the same structure as shown in Figure 3.

However, there may be other configurations which do not share the same structure as shown in Figure 3. One such example is given in 4.2.4.

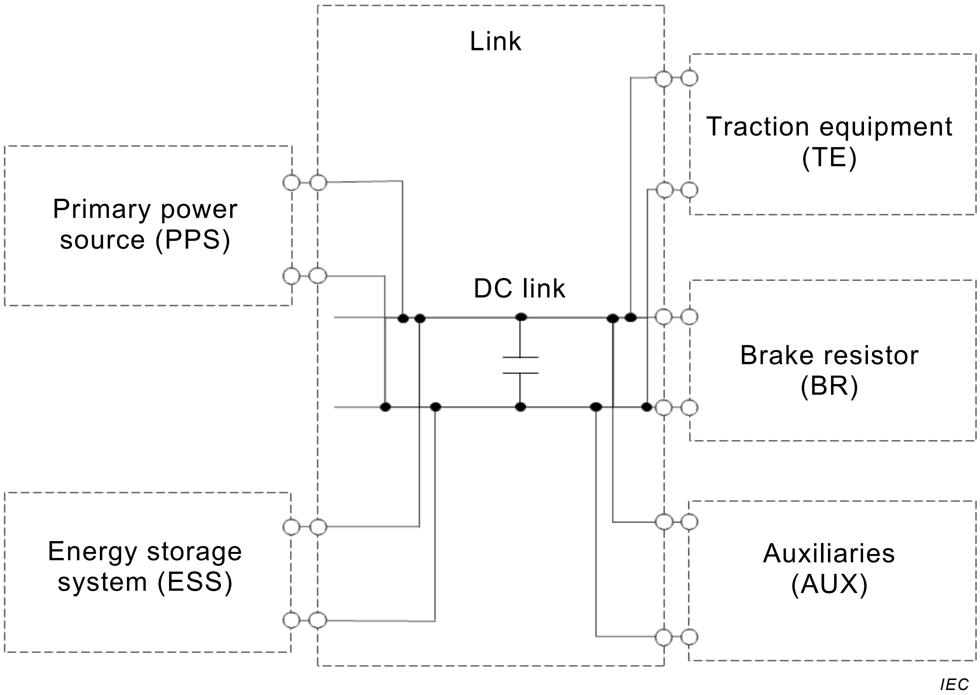
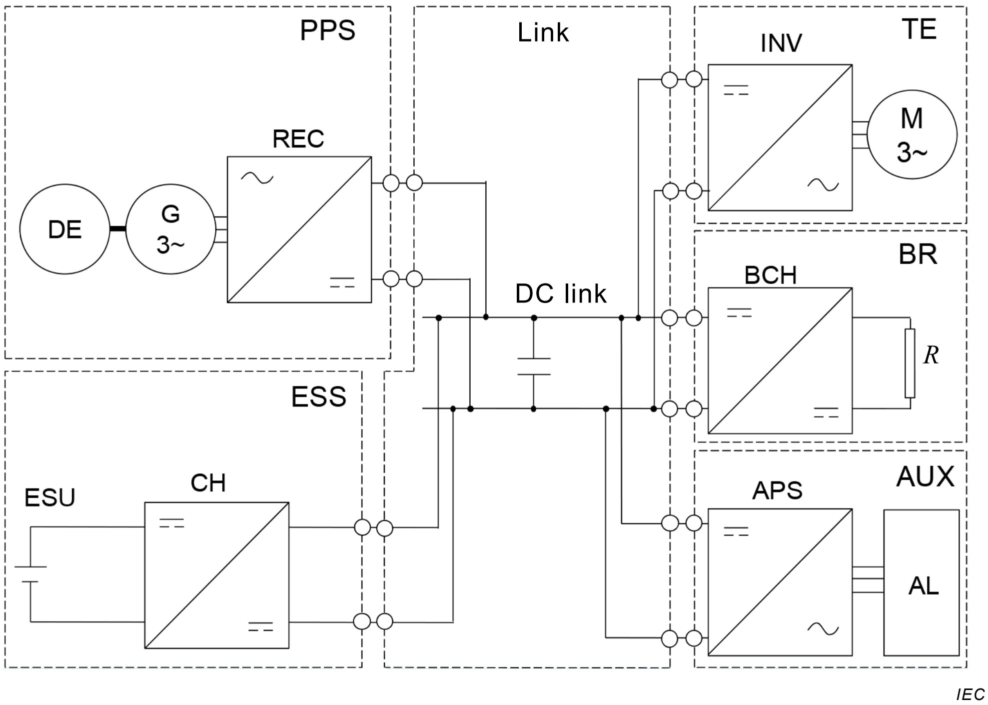


Figure 3 – Example configuration of a series hybrid system in which all main circuit subsystems are connected to the common DC link

4.2 Application examples

4.2.1 Diesel electric vehicles

Figure 4 shows an example configuration in which an ESS is integrated as part of the drive system of a diesel electric rail vehicle.



Key

PPS	Primary power source	ESS	Energy storage system	TE	Traction equipment
BR	Brake resistor	AUX	Auxiliaries		
DE	Diesel engine	REC	Rectifier	ESU	Energy storage unit
CH	Chopper (for ESS)	INV	Inverter (for TE)	BCH	Brake chopper (for BR)
R	Resistor	APS	Auxiliary power supply	AL	Auxiliary loads

Figure 4 – Series hybrid system in diesel electric vehicles

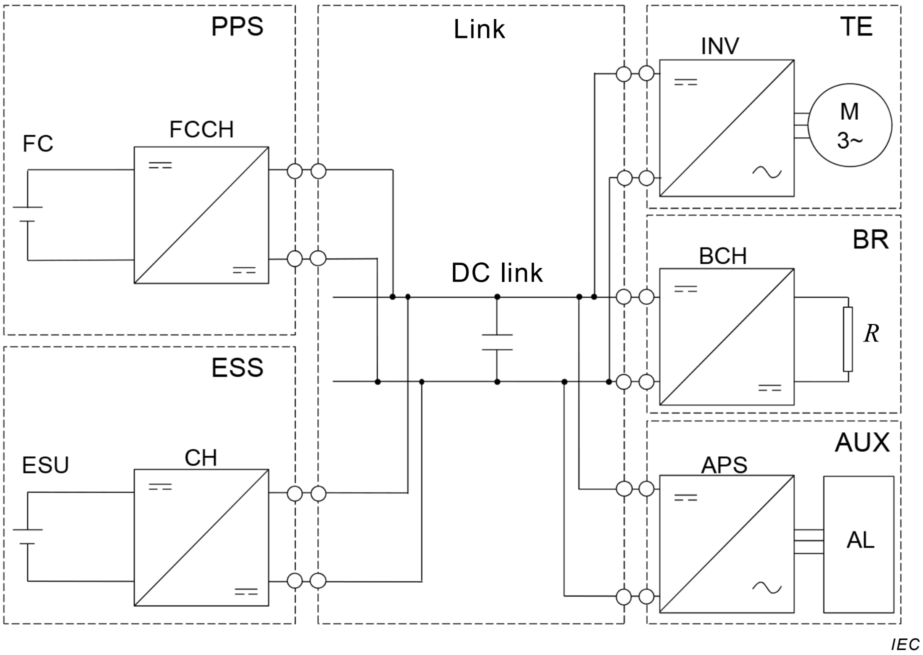
The ESS is charged by the energy recovered during regenerative braking (Mode XI in Table 1) or during partial or no-load operation if required (Modes I or VI in Table 1). The stored energy is then re-used during the next acceleration phase of the hybrid vehicle (Modes III or IV in Table 1) or otherwise determined by the energy management concept implemented for the specific application. During stops, the engine can be stopped automatically (idling stop) to reduce fuel consumption and noise emission by using the energy stored in the ESS for supplying the auxiliary loads.

If the regenerated power is greater than the maximum ESS charge power, either the engine or exhaust braking (Modes IX or X in Table 1) or the brake resistor (Modes XV, XVI, XVII or XVIII in Table 1) can be used to dissipate excess power.

In this configuration, using Modes V, VII and VIII in Table 1 may be appropriate in relatively rare operating situations for different applications. In Modes V, while the ESS supplies power required by the traction equipment and the auxiliary loads, the diesel engine and generator set also receives power from the ESS to dissipate energy. In Mode VII, while the ESS supplies power required by the auxiliary loads, the diesel engine and generator set also receives power from the ESS to dissipate energy. In Mode VIII, while the traction equipment regenerates power, the ESS discharges power at the same time, and the diesel engine and generator set receives power from both the ESS and the traction equipment and dissipates energy.

4.2.2 Fuel cell vehicles

Figure 5 shows an example configuration in which an ESS is integrated as part of the drive system of a fuel cell based rail vehicle. Its energy management strategy is similar to that for the diesel electric vehicles in 4.2.1; however, fuel cells generally have no ability to absorb power, and therefore Modes V, VII through X, XV and XVI in Table 1 are not applicable.



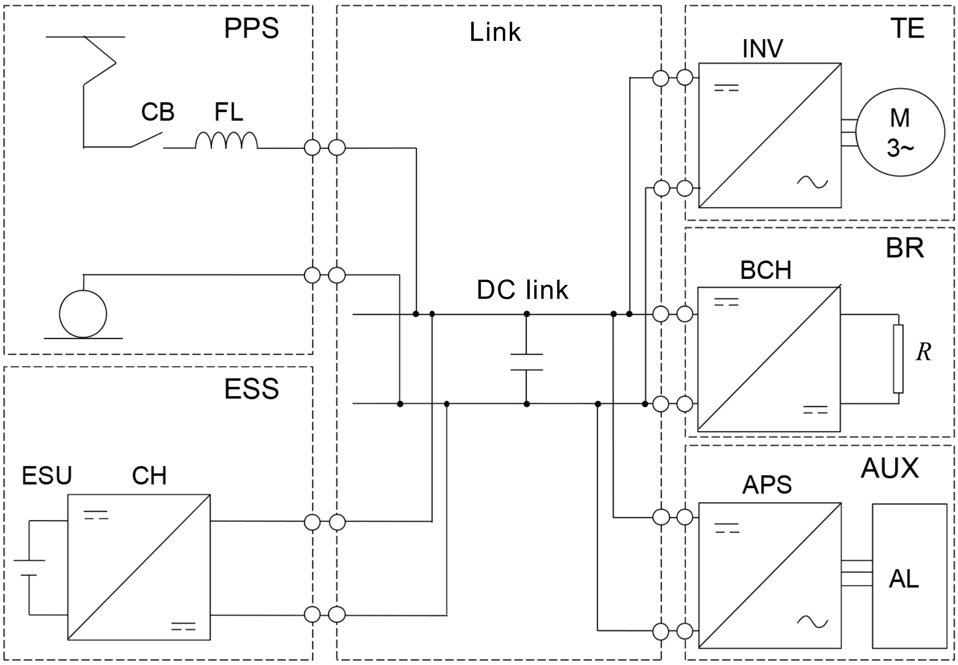
Key

PPS	Primary power source	ESS	Energy storage system	TE	Traction equipment
BR	Brake resistor	AUX	Auxiliaries		
FC	Fuel cells	FCCH	Chopper for fuel cells	ESU	Energy storage unit
CH	Chopper (for ESS)	INV	Inverter (for TE)	BCH	Brake chopper (for BR)
R	Resistor	APS	Auxiliary power supply	AL	Auxiliary loads

Figure 5 – Series hybrid system in fuel cell vehicles

4.2.3 DC contact line powered vehicles: parallel connection of ESS

Figure 6 shows an example configuration in which an ESS is connected in parallel to the DC contact line.



Key

PPS	Primary power source	ESS	Energy storage system	TE	Traction equipment
BR	Brake resistor	AUX	Auxiliaries		
ESU	Energy storage unit	CH	Chopper (for ESS)	CB	Circuit breaker
FL	Filter inductor	INV	Inverter (for TE)	BCH	Brake chopper (for BR)
R	Resistor	APS	Auxiliary power supply	AL	Auxiliary loads

Figure 6 – Series hybrid system in contact line powered vehicles with parallel connection of energy storage

The ESS can be charged both during braking (Modes X, XI or XII in Table 1) and during other operating modes (accelerating, coasting, etc.) as required (Modes I or VI in Table 1). Using Modes X or XI, regenerative braking can be used even under the feeding system with insufficient receptivity of regenerated power. All the power from the traction equipment goes back to the feeding circuit if the feeding system is fully receptive of the regenerated power (Mode IX in Table 1). If the power regenerated from the traction equipment during braking is greater than the sum of maximum ESS charge power and the maximum regenerative power, the brake resistor can be used to dissipate excess power (Modes XV, XVI, XVII or XVIII in Table 1).

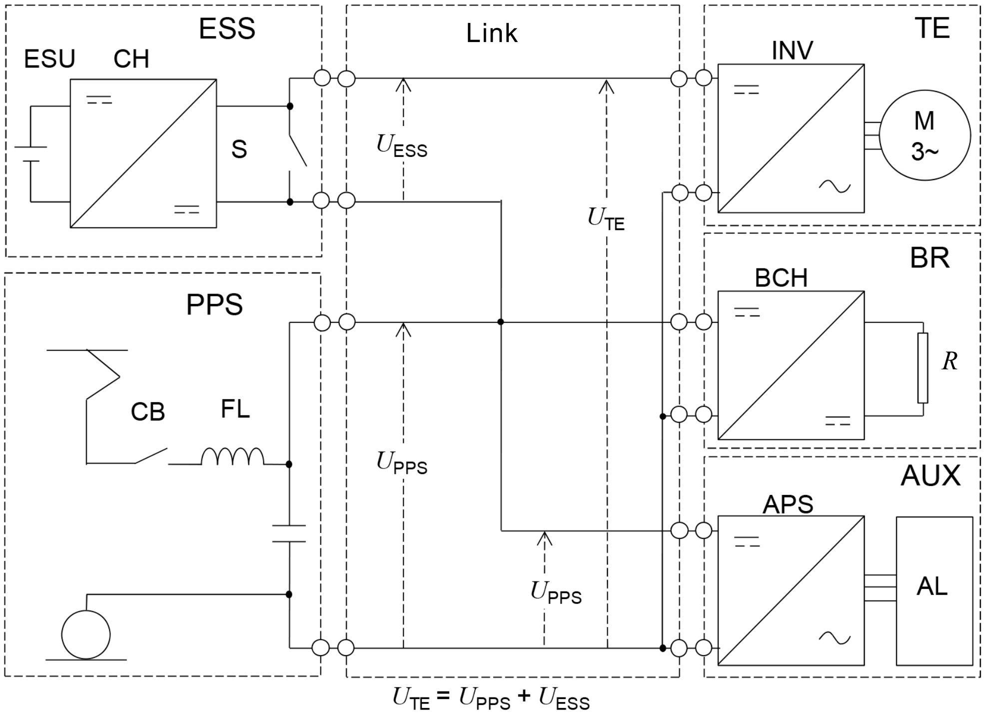
Similarly, the ESS can discharge the stored energy both during accelerating (Modes III, IV or V in Table 1) and during other operating modes (braking, coasting, etc.) as required (Modes VII or VIII in Table 1). Using Modes III or IV, the power input from the feeding system to the train during acceleration can be reduced without reducing the power consumed by the traction equipment, i.e. without influencing the accelerating performance.

The choice of operating modes should be based on a well-designed strategy to maximise the overall system efficiency or to attain the desired performance characteristics, such as the stabilisation of line voltage or autonomous operation, etc. The power flow within the system and the SOE of the ESS should be continuously monitored and regulated.

This system can be easily expanded to railway vehicles with the capability to operate under multiple voltages, including AC fed vehicles, by adding appropriate converters or transformers in the PPS block of Figure 6. Also, there are examples in which a chopper exists in the PPS block of the DC contact line powered vehicles and at the same time the chopper in the ESS block is replaced with circuit breakers.

4.2.4 DC contact line powered vehicles: series connection of ESS

Figure 7 shows an example configuration in which an ESS is connected in series with the contact line.



Key

PPS	Primary power source	ESS	Energy storage system	TE	Traction equipment
BR	Brake resistor	AUX	Auxiliaries		
ESU	Energy storage unit	CH	Chopper (for ESS)	CB	Circuit breaker
FL	Filter inductor	INV	Inverter (for TE)	BCH	Brake chopper (for BR)
R	Resistor	APS	Auxiliary power supply	AL	Auxiliary loads

S ESS bypass switch

U_{PPS} Primary power supply voltage, i.e. line voltage

U_{ESS} ESS output voltage

U_{TE} Traction equipment input voltage

Figure 7 – Series hybrid system in contact line powered vehicles with series connection of energy storage

Unlike examples in Figure 4, Figure 5 and Figure 6, this configuration has no common DC link to which main subsystems are connected, and therefore cannot be considered to have the same structure as shown in Figure 3. Nevertheless, it has the structure as shown in Figure 2.

In this configuration, the ESS is series connected to the DC contact line so the voltage at the input of traction inverter U_{TE} becomes the sum of the ESS voltage U_{ESS} and the line voltage U_{PPS}. This configuration allows the U_{TE} to be higher than the U_{PPS}, which means the traction equipment can handle higher power for a given current without increasing the power regenerated from the hybrid vehicle back to the feeding system. Thus, the range of regenerative brake is widened at higher vehicle speeds by increasing the motor voltage during braking.

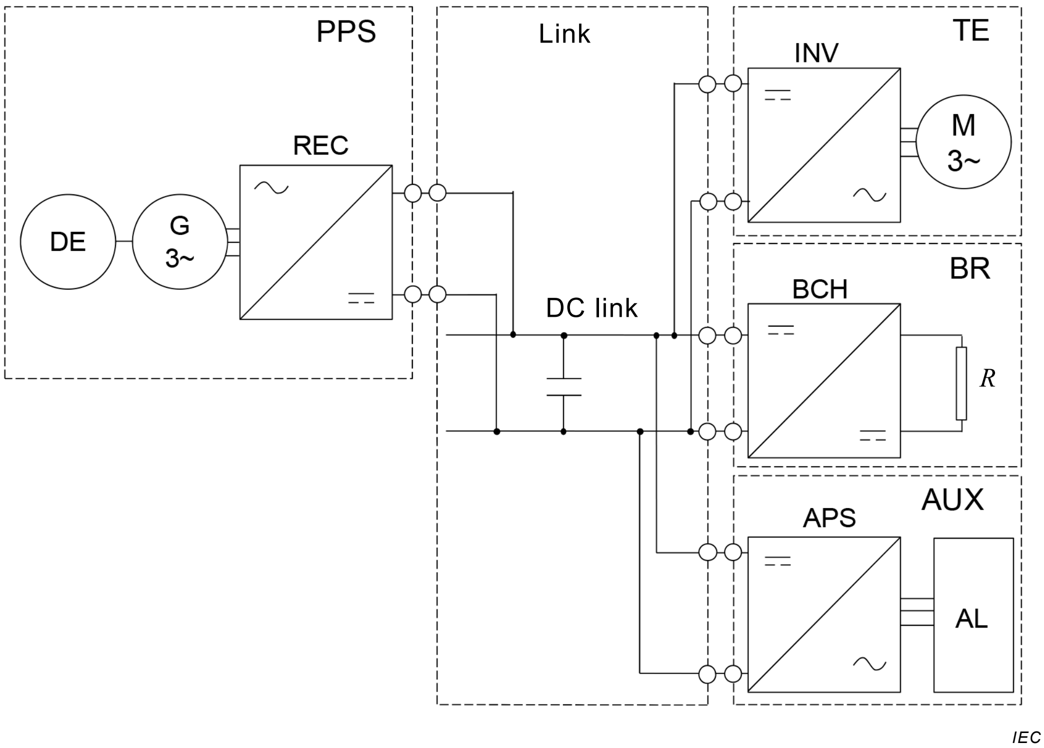
Assuming that U_{ESS} is non-negative, the ESS can be charged only during braking (Modes X and XV in Table 1), and the energy stored in the ESS can be discharged only during acceleration (Mode III in Table 1). Modes I, IV, V through VIII, XI, XII, XIV and XVII in Table 1 are not applicable.

4.3 Performance of the series hybrid systems

4.3.1 Improving efficiency

The series hybrid system can be designed to be more efficient than the non-hybrid systems through the use of regenerative braking.

For example, in diesel-electric system, the configuration of which is shown in Figure 8, it is not possible to use regenerative braking. By adding an ESS to the system, as shown in Figure 4, regenerative braking becomes available.



Key

PPS	Primary power source	TE	Traction equipment		
BR	Brake resistor	AUX	Auxiliaries		
DE	Diesel engine	REC	Rectifier	INV	Inverter (for TE)
BCH	Brake chopper (for BR)	*R*	Resistor	APS	Auxiliary power supply
AL	Auxiliary loads				

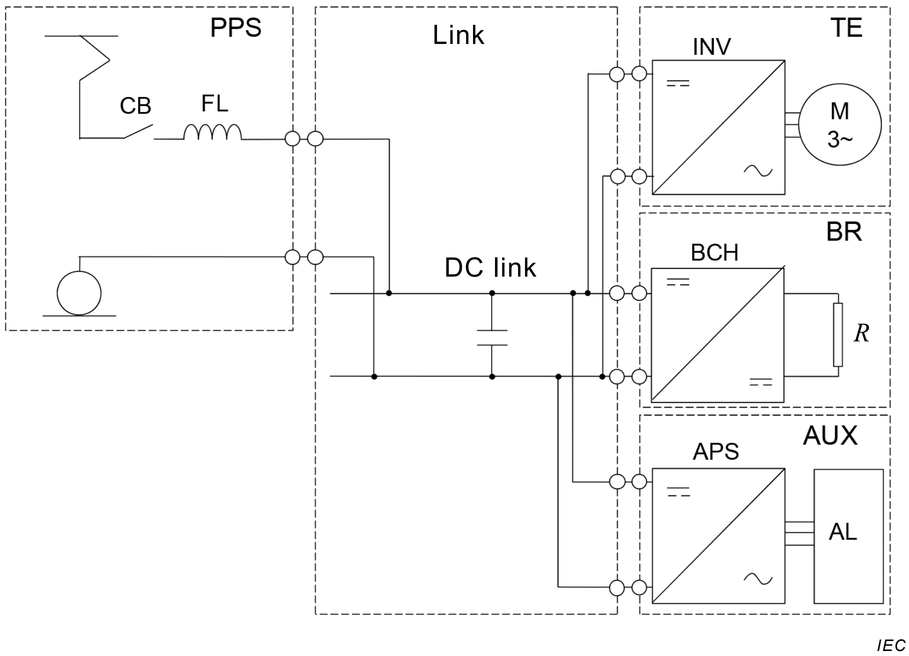
Figure 8 – Diesel electric propulsion system (without an ESS)

The onboard ESS can also enhance the availability of regenerative braking in the contact line powered vehicles. In such a system without an onboard ESS, the configuration of which is shown in Figure 9, it is not possible to use regenerative braking when the power feeding network is unreceptive of the power regenerated from the hybrid vehicle. By adding an ESS to the system, as shown in Figure 6, regenerative braking can be used in such circumstances by letting the onboard ESS absorb the power regenerated from the traction equipment.

In addition to regenerative braking, the series hybrid system can be designed to be more efficient than the non-hybrid systems through the use of PPS in the more efficient operating conditions.

For example, the diesel engine and generator set is most efficient when it works at certain operating point (e.g. engine speed, power); however, in the conventional diesel-electric system, the configuration of which is shown in Figure 8, the engine-generator set is forced to output power at some sub-optimal operating points. By adding an ESS to the system, as shown in Figure 4, the engine-generator set can be controlled to remain at the most efficient operating point.

As described above, there are various configurations and modes. It is important to evaluate the energy related definitions appropriately. Details are shown in Annex B.



Key

PPS	Primary power source	TE	Traction equipment	BR	Brake resistor
AUX	Auxiliaries				
CB	Circuit breaker	FL	Filter inductor	INV	Inverter (for TE)
BCH	Brake chopper (for BR)	R	Resistor	APS	Auxiliary power supply
AL	Auxiliary loads				

Figure 9 – Contact line powered propulsion system (without an ESS)

4.3.2 Boosting the motoring performance

When the power available from the PPS is limited in the series hybrid system, the ESS can be used to top up the power supplied to the traction equipment, thus boosting the motoring performance of the whole vehicle.

Figure 10 shows how boosting works. In the figure, it is assumed that:

- P_{BR} is 0;
- P_{AUX} is negligibly small; and

- $P_{TE} = P_{PPS} + P_{ESS}$

where P_{PPS}, P_{ESS}, P_{TE}, P_{BR} and P_{AUX} are as defined in Figure 2.

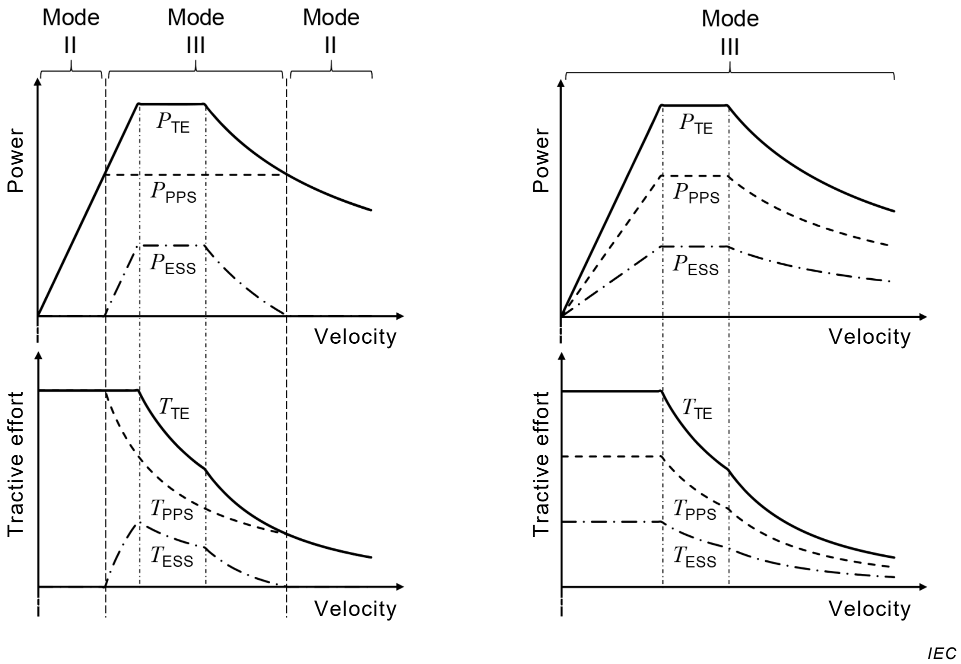
In the example shown in Figure 10 a), all the power required by the traction equipment (tractive power) is supplied by the PPS at low speed range (Mode II in Table 1). When the power exceeds the upper limit of the PPS in higher speed range, the ESS tops up the tractive power and boosts the tractive effort of the hybrid vehicle (Mode III in Table 1).

The following should be noted:

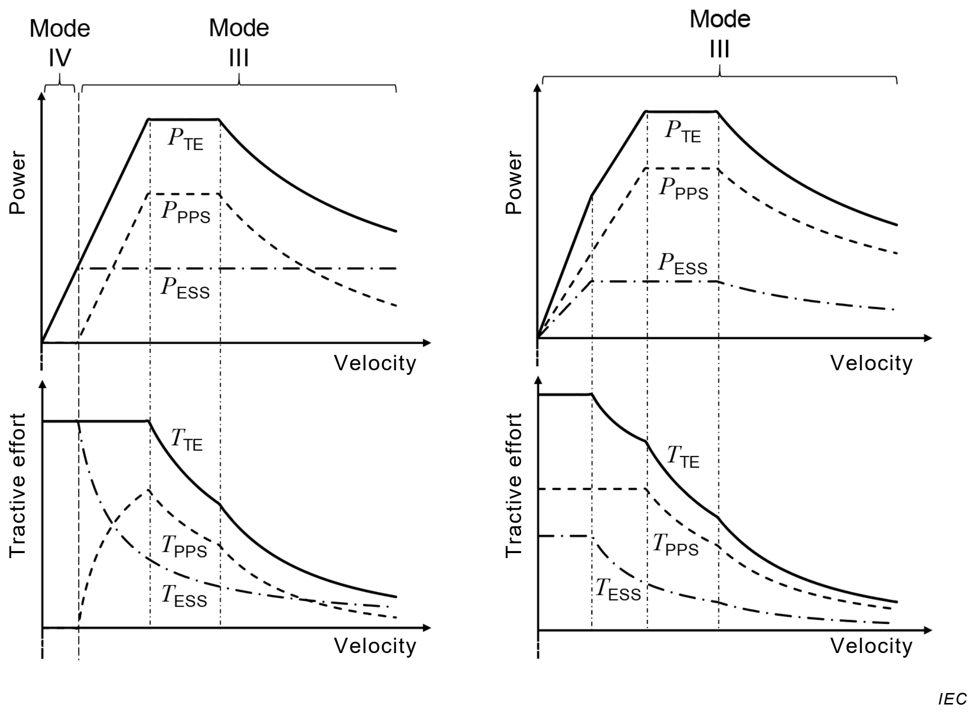
- The boosting is only available when there is enough energy remaining within the ESS. Therefore, a good energy management system is necessary for the system to be effective.
- Many different boosting control strategies can be devised for different purposes. Figure 10 b) through d) show examples of the possible cases, each of them resulting from a different strategy. In case b), the ratio of power from the PPS and the power from the ESS remains constant. Case c) is in contrast with case a), because in case c) ESS has the priority over PPS and supply all power at lower speed range; and in case d), P_{TE} is dependent on P_{PPS} and P_{ESS} unlike other cases in which P_{TE} is fixed. The choices of Modes in Table 1 are also different.

As described above, there are various configurations and modes. It is important to evaluate the energy related definitions appropriately. Details are shown in Annex B.

Not only accelerating performance, but also electric braking performance can be boosted similarly.



a) PPS priority over ESS **b) Proportional**



c) ESS priority over PPS **d) Combined power strategy**

Key

P_{PPS}	Power of primary power source (PPS)	P_{ESS}	Power of energy storage system (ESS)
P_{TE}	Power of traction equipment (TE)		
T_{PPS}	Part of T_{TE} contributed by PPS	T_{ESS}	Part of T_{TE} contributed by ESS
T_{TE}	Tractive effort, $T_{ESS} + T_{PPS} = T_{TE}$		

NOTE 1 For these examples the behavior of the power supply by ESS is assumed to be constant within a certain speed range, but can have different behaviour depending on ESS technologies.

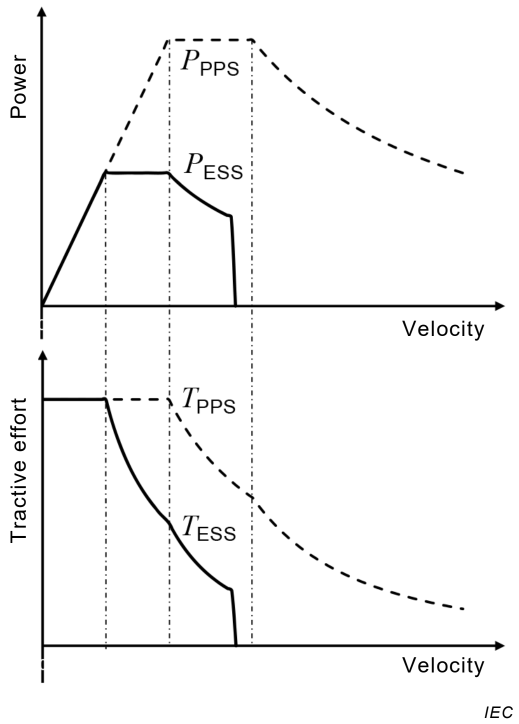
NOTE 2 For these examples SOC and/ or SOE of ESS are assumed to be sufficent to supply the power required for the operational pattern.

NOTE 3 The behavior of the power supply by ESS is assumed to be constant within speed range.

Figure 10 – Boosting of the motoring performance by onboard ESS

4.3.3 Degraded mode operation

In the series hybrid system, the vehicle can be designed to be able to move even when the PPS fails to function. In the example shown in Figure 11, if PPS fails, ESS is to output power to maintain the ability of the hybrid vehicle to move (shown as P_{ESS} and T_{ESS}, respectively). Generally, however, the energy and power available from the ESS are limited, and therefore the maximum power and maximum velocity are also limited in such degraded mode operation.



Key

P_{PPS}	Power of primary power source (PPS)	P_{ESS}	Power of energy storage system (ESS)
T_{PPS}	Part of T_{TE} contributed by PPS	T_{ESS}	Part of T_{TE} contributed by ESS

Figure 11 – An example of degraded mode performance by onboard ESS

5 Environmental conditions

5.1 General

The classes of service conditions described in IEC 62498-1:2010 shall be applied unless different classes are specified by the user. The user shall specify clearly in his specification the class to consider, otherwise class with suffix 1 shall be assumed.

In the event of other conditions applying these should be selected from IEC 60721-3-5 if appropriate.

5.2 Altitude

The altitude above sea-level, at which the equipment shall perform as specified, shall be as given in IEC 62498-1:2010, unless otherwise specified.

NOTE Altitude is relevant, in particular for air pressure level and its consequence on cooling systems and insulation.

5.3 Temperature

The class of ambient temperature, at which the vehicle, the hybrid system and its components will operate, shall be given according to IEC 62498-1:2010, Table 2 unless otherwise specified.

For lifetime calculations a temperature histogram should be provided by the user for the ambient air external to the vehicle. Otherwise the reference temperature TR1 according to IEC 62498-1:2010, Table 3 shall be applied.

A reference temperature is considered as being the permanent temperature for which the effects on material ageing are equivalent to those of the climatic temperature during the lifetime.

NOTE Thermal ageing is an exponential function of temperature (e.g. see IEC 60216-5 for insulating materials), i.e. the reference temperature is usually higher than the arithmetic mean temperature.

For altitude class AX (IEC 62498-1:2010), the dependency between altitude and temperature shall be provided by the user through a temperature histogram for each relevant altitude range (e.g. 0 m to 1 000 m and 1 000 m to 2 000 m).

Pre-heating or pre-cooling requirements for hybrid system components shall be agreed between the user and the manufacturer, if necessary.

6 Functional and system requirements

6.1 Mechanical requirements

6.1.1 Mechanical stress

6.1.1.1 Shock and vibration

The hybrid system, when supported at its designed fixings (including anti-vibration mounts when fitted), shall be able to withstand vibration and shock as stated in IEC 61373.

6.1.1.2 Other accelerations

When a vehicle is passing through a curve or is stopped on a curve, the allowable net acceleration components acting perpendicularly to the vertical axis of the vehicle shall not exceed the values given in IEC 61373. The hybrid system, including its auxiliary equipment, shall continue to perform as specified under transverse and longitudinal accelerations as specified in IEC 61373. These requirements shall be agreed between the user and the manufacturer.

6.1.2 Protection against external mechanical influences

The ingress protection category shall be defined according to IEC 60529 to fulfil the requirements for protection against direct contact and the conditions of installation environment.

6.2 Control requirement

A hybrid system shall have the following minimum functions:

- power flow control;
- energy and power flow monitoring; and
- monitoring the state of ESU.

6.3 Electrical requirement

6.3.1 External charge and discharge function

If required, the hybrid system shall be equipped with an external charge and discharge function. Specifications for the external charge and discharge function shall be agreed between the user and the manufacturer.

6.3.2 Operating with energy storage system only

If required, when power from the PSS, i.e. diesel gen-set, overhead contact line or third rail, is not available, the vehicle shall be able to operate with the traction performance and auxiliary loads as specified by the user.

6.4 Disconnecting requirement

Each ESU of the hybrid system shall be equipped with disconnecting devices to enable safe isolation or separation e.g. in the event of failure or maintenance purposes.

Each individual power source of the hybrid system should be equipped with disconnecting devices to enable safe separation of the power source from other subsystems.

6.5 Degraded mode

The concept for the degraded mode shall be specified and agreed between the user and the manufacturer. In case a part or all of an individual power source (e.g. ESU/ESS, diesel engine, fuel cell, external power source) fails, the remaining part shall fulfil these requirements for the concept of the degraded mode.

6.6 Safety requirements

6.6.1 Protection against electrical hazards

Protection against electrical hazards shall be considered for the driver, maintenance staff and passengers according to IEC 61991.

6.6.2 Fire behaviour and protection

Fire protection measures for fuel, ESU, etc. shall be specified by the user. Otherwise, see Annex C.

6.6.3 Protection against any other impacts

Protection against external mechanical impact shall be taken for the ESU according to IEC 62262.

Protection of environment, driver, maintenance staff and passenger against mechanical impact due to effects coming from the ESU, e.g. explosion, gas venting and/or releases, etc. shall be considered.

6.6.4 Short-circuit protection

The ESS shall be equipped with appropriate short-circuit protection.

The user shall define in the specification whether the parts of the hybrid system are short-circuit proof or not.

The test shall be performed as described in 8.9.

6.7 Lifetime requirements

Lifetime determination should be considered for the ESU. The data by the component supplier can be used. For the lifetime modelling the operational pattern shall be considered. The lifetime determination and modelling of the ESU depends on its usage and agreement between the subsupplier/component supplier or the ESU supplier and the system supplier and the user if necessary.

For definition of end of life (EOL) the following examples are given:

a) Component oriented for EDLC: Ageing causes decreasing capacitance and increasing internal resistance. Therefore, the manufacturer and the user can agree that "When the capacitance is below certain percentage 'X' of the initial capacitance or the internal resistance is 'Y' times higher than the initial resistance, then EOL is reached". The values of 'X', 'Y' or other parameters should be agreed between the user and the manufacturer according to the project.
b) Operational pattern oriented: Operational patterns should be supplied by system integrator or the user. The ESU supplier and/or the system integrator shall estimate the lifetime according to these patterns.

6.8 Additional requirement for noise emission of hybrid system

The measurement method refers to IEC 61133.

Where there is a specific noise emission requirement, emission shall be determined upon agreement between the user and the manufacturer.

7 Kinds of tests

7.1 General

Tests are classified in the following three categories:

a) type tests;
b) optional tests; and
c) routine tests.

The routine tests for individual equipment that constitutes a system shall be performed in accordance with the relevant standards. Some minimum routine tests are specified.

The test locations are broken down as follows:

a) vehicle/system interface (level 1): logic interface (to auxiliaries, overall vehicle control unit, to infrastructure and signalling interface, etc.) working together, hardware interfaces (cables, etc.);

   EXAMPLE Interfaces of hybrid system control unit, auxiliary and overall vehicle control unit.

b) systems and interfaces (level 2): physical and control interfaces between the vehicle and the traction (propulsion) chain;

   EXAMPLE Interfaces of ESS/ESS, link, traction equipment, brake resistor and PPS and hybrid system control unit (either part of the control unit of the subsystem or dedicated unit which is applicable).

c) components (level 3): ESU, converter, motors, etc. as shown in Figure 2;
d) subcomponents (level 4): lithium ion battery, EDLC, etc within ESU.

See 7.5 and Table 2 therein.

7.2 Type test

A type test is conducted to verify the ratings, characteristics and performance of a new system. This type test shall be conducted on a system/interface (level 2) and vehicle/system interface (level 1) for each new design. The suppliers for subcomponent, component, system and/or vehicle are responsible for type tests for their appropriate level or scope of supply. Component and subcomponent tests (level 3 and 4) are expected to have been performed in advance according to the relevant component standards.

If the design or manufacturing process of equipment included in the combined system is changed after a type test is conducted on the system, the impact of the change on the combined system shall be evaluated. The decision on whether to conduct the type test or conduct only part of that test is based on the agreement between the user and the manufacturer. If the manufacturer previously prepared a report on a type test that covers all test items for a similar system, the type test can be omitted upon agreement between the user and the manufacturer.

Simulation results based on reliable modelling (successfully verified with previous measurement) can be applied under agreement.

7.3 Optional test

Optional test can be performed to obtain additional information about the hybrid system. Optional test is not mandatory and shall be carried out only upon agreement between the user and the manufacturer. If no specific agreement is made between the user and the manufacturer, this test result shall not be treated as acceptance criteria for the system.

7.4 Routine test

Routine tests are carried out to verify that the system or vehicle is correctly assembled and that all components, system and/or vehicle functions properly and safely operating. Routine tests shall be performed by the manufacturer on each item of a given type. The manufacturer and the user may agree to adopt an alternative test procedure. This may permit reduced routine testing of all components, system and/or vehicle or may require the full routine tests on a portion of all components, system and/or vehicle chosen at random from those produced on the order.

Routine tests which are subject to agreement between the manufacturer and the user are to be carried out only if it is so stated in the specification.

7.5 Test categories

The test categories refer to Table 2.

The test locations are categorised as component tests, combined tests and vehicle tests.

Special requirements from the user shall be agreed between the user and the manufacturer.

The location of the tests listed in Table 2 can be discussed and agreed between the manufacturer and the user.

Table 2 – List of tests *(1 of 3)*

Test item	Location of the test	Type of tests	Level[a]	Clause/sub clause number
Combined test at test bench				
ESS charge/discharge control function	B	T	2	8.3.1
External charge test	B	O	2	8.3.2
Disconnection test	C or B	T	2.3	8.3.3
Degraded mode test	B	O	2	8.3.4
SOC/SOE test	B	O	2	8.3.5
Sweeping speed under full torque test	B	T	2	8.4.1
Output torque test with energy storage system only	B	T	2	8.4.2

Table 2 *(2 of 3)*

Test item	Location of the test	Type of tests	Level[a]	Clause/sub clause number
System sequence test	–	–	–	8.5
a) start up of the system	B	T	2	–
b) motoring operation including power limitation according to the protection conditions	B	T	2	–
c) regenerative operation including power limitation according to the protection conditions	B	T	2	–
d) disconnection of one or more ESS and/or ESU	B	T	2	–
e) reconnection of one or more ESS and/or ESU	B	T	2	–
f) disconnection of one or more PPS	B	T	2	–
g) reconnection of one or more PPS	B	T	2	–
h) shut down of the system	B	T	2	–
i) redundancy, degraded mode	B	T	2	–
Energy efficiency and consumption measurement	B	O	2	8.6.2
Determination of fuel consumption	B	O	2	8.6.3.1
Determination of the exhaust gas emission levels	B	O	2	8.6.3.2
Duration measurement of ESS	B	O	1	8.7.2
Low-temperature operation test	B or C	O	2 or 3	8.8.2
High-temperature operation test	B or C	O	2 or 3	8.8.3
Short-circuit protection test	B or C	O	2 or 3	8.9
ESU endurance test	C	O	4	8.10
Vehicle level				
ESS disconnection test	V	R	1	9.2
Vehicle sequence test	–	–	–	9.3
a) start up of the system	V	R	1	–
b) motoring operation	V	R	1	–
c) electric braking operation	V	R	1	–
d) disconnection of one or more ESS and/or ESU	V	R	1	–
e) reconnection of one or more ESS and/or ESU	V	R	1	–
f) disconnection of one or more PPS	V	R	1	–
g) reconnection of one or more PPS	V	R	1	–
h) shut down of the system	V	R	1	–
i) redundancy, degraded mode	V	R	1	–
Drive system energy consumption measurement	V	O	1	9.4
Determination of fuel consumption	V	O	1	9.5.1
Determination of the exhaust gas emission levels	V	O	1	9.5.2
Auxiliary circuit energy consumption measurement	V	O	1	9.6
Duration of vehicle operation by ESS	V	O	1	9.7
Determination of acoustic noise emission	V	O	1	9.8

Table 2 *(3 of 3)*

NOTE 1 It is preferable that the “optional” type tests in the table be conducted through agreement between the user and the manufacturer. An “optional” type test and an optional test are not in the same test category. NOTE 2 Abbreviation of location of test is as follows: C: Component test B: The test is made at the test bench during the combined test. V: Vehicle NOTE 3 Abbreviation of type of tests is as follows: T: Type test O: Optional test R: Routine test
[a] For levels, see 7.1.

7.6 Acceptance criteria

Unless stated in Clause 8 and 9, acceptance criteria shall be as follows:

- for function it shall be verified that the system works properly as specified;
- for performance or characteristics test it shall be verified that the performance or characteristics complies with the specifications. The specifications shall be agreed between the user and the manufacturer.

8 Combined tests

8.1 General

For test items other than those specified in Clause 8, refer to IEC 61287-1, IEC 60349-2, IEC 60349-4, and IEC 61377.

8.2 Test conditions

Test conditions refer to IEC 61377.

8.3 ESS control

8.3.1 ESS charge/discharge control function

Charging and discharging of the ESS at rated power shall be carried out according to the requirements agreed between the user and the manufacturer. Power flow, e.g. of the PPS, ESS and converters shall be monitored to verify appropriate control.

8.3.2 External charge test

If the external charging function is equipped, time, current and voltage during the specified charging rate shall be measured. The starting temperature and cooling conditions are determined based on the agreement between the user and the manufacturer. However, the lower and upper limits of the charging rate are set within a range where constant-current charging is possible.

8.3.3 Disconnection test

In the event of any power source failure, it shall be possible to disconnect the failed device without damage or causing safety concerns. Manual disconnection shall be tested if installed, e.g. for maintenance purpose.

8.3.4 Degraded mode test

If a degraded mode is specified, the vehicle shall have the capability to operate with no permanent damage or safety concerns to any component with partially or fully disconnected power source, e.g. ESU/ESS, diesel engine, fuel cell, or external power source.

The specific operating range under the degraded mode shall be determined upon agreement between the user and the manufacturer.

8.3.5 SOC/SOE test

SOC or SOE of ESS shall be determined at the beginning. The changes in SOC or SOE shall be monitored continuously throughout an assumed operational pattern by measuring time and energy in order to facilitate a charge or energy balance calculation and return the calculated SOC or SOE to the same level at the end of the normal operation (e.g. by charging from the engine output).

If repeated operational patterns are required, SOC or SOE at the beginning and at the end of operational pattern should be balanced with a post operation. The post operation may be performed by off-line charging/discharging, e.g. external/internal power source or catenary or overhead contact line or third rail.

Acceptance criteria of this test shall be agreed between the user and the manufacturer.

8.4 Output torque

8.4.1 Sweeping speed under full torque test

For the series hybrid system the torque characteristics shall be verified according to the design. Contribution of each power source (PPS or ESS) should be measured.

Measurement is carried out according to IEC 61377:2016, Clause 7.

The test is performed by gradually increasing and decreasing the speed with the maximum torque command over the entire speed range in motoring and electric braking at motor "hot". At this time, abnormal interruption of the system shall not occur. The speed change rate should be appropriate for each application and each system.

When the maximum motoring or brake control command is applied, the series hybrid system shall provide as much power as possible automatically and independently of the state of the ESS.

Full performance may not be available due to limitation of power/energy from the ESS and/or PPS.

The boosted or limited characteristics due to the ESS shall be measured.

8.4.2 Output torque test with energy storage system only

If operation is required with the ESS only, the specified output torque shall be achieved by the power from the ESS with the PPS disconnected.

8.5 System sequence test

The purpose of the system sequence test is to check the combination of the devices works as intended in a sequence of operation, with no connection to operational pattern. The following sequence of operation shall be checked:

a) start up of the system

Control power supply is switched on and necessary actions are carried out for the system to start up for operation;

b) motoring operation including power limitation according to the protection conditions

Motoring command is turned on, traction circuit is configured for motoring and starts motoring. Several kinds of tractive effort commands within specified speed range shall be tested.

See IEC 61377:2016, Clause 7;

c) regenerative operation including power limitation according to the protection conditions

Braking command is turned on, traction circuit is configured for braking and starts braking. Several kinds of braking effort commands within the specified speed range shall be tested.

See IEC 61377:2016, Clause 7;

d) disconnection of one or more ESS and/or ESU

One or more ESS and/or ESU are disconnected. This sequence shall be operated under the specified conditions. If this sequence is carried out when ESS/ESU or converter are working, ESS/ESU or converter shall be stopped safely before disconnection.

See 8.3.3;

e) reconnection of one or more ESS and/or ESU

ESS and/or ESU disconnected in procedure d) can be reconnected. This sequence shall be operated under the specified conditions. After this, the reconnected ESS/ESU or converter shall start operation correctly and as specified;

f) disconnection of one or more PPS

One or more PPS are disconnected. This sequence shall be operated under the specified conditions. If this sequence is carried out when the converter is working, the converter shall be stopped safely before disconnection.

See 8.3.3;

g) reconnection of one or more PPS

PPS disconnected in procedure f) can be reconnected. This sequence shall be operated under the specified conditions. After this, the reconnected PPS shall start operation correctly and as specified;

h) shut down of the system

After operation, the system can be turned off using the sequences of commands to switch off power circuit, control circuit, etc.;

i) redundancy, degraded mode

The test of redundancy and degraded modes shall be performed as specified. See 8.3.4.

No abnormal behaviour (e.g. over voltages, over currents, unintended system shutdown, etc.) shall be observed.

8.6 Energy efficiency and consumption

8.6.1 General

The system shall be operated in combination with an equivalent load and measurement shall be performed in accordance with IEC 61377:2016, 8.3.

The load condition may be different from an actual one due to limitations of the test facilities.

Tests shall be performed at stabilized conditions, e.g. thermal conditions of converter, motor, ESS, etc.

Simulation results based on reliable modelling (successfully verified with previous measurements) can be applied instead of a test under agreement between the user and the manufacturer.

For the measuring procedure refer to IEC 61377. Acceptance criteria specified in IEC 61377 excludes energy consumption of the ESS. Acceptance criteria of energy consumption including the ESS shall be agreed between the user and the manufacturer. The manufacturer is responsible for choosing the pertinent accuracy of the measuring equipment for devices described in Annex B, e.g., PPS (including fuel consumption), ESS.

This standard is applicable to bench test measurement and tests on completed vehicles for factory and field tests. Temporary measurement equipment may be used, which is different from on board energy measurement system for revenue service.

For methods and definitions of energy measurement on board trains in revenue service, IEC 62888 series may be referred to and used for field tests under agreement between the user and the manufacturer. E.g., root mean square can be used for calculation of accuracy of energy measurement equipment; voltage meter, current meter and power meter as defined in IEC 62888-2.

8.6.2 Energy efficiency and consumption measurement

8.6.2.1 General

Energy efficiency and consumption in a specified operation (duration, distance, speed, etc.) shall be measured.

To determine the energy efficiency and consumption, voltage and current on every subsystem in Figure 2 shall be measured simultaneously and integrated for the specified operation. If required, some components may also be measured upon agreement between the user and the manufacturer.

8.6.2.2 Preparation

The initial level of energy in the ESS before starting the specified operation shall be determined.

8.6.2.3 Measuring equipment

The accuracy of the measuring equipment shall be in conformance with IEC 61377:2016, 6.4.

8.6.2.4 Measurement locations

The measurement methods shall minimize the power losses in terminals and wirings. The measurement locations are shown below.

a) PPS

   Measurement is taken at the output terminal of the power source. Current and voltage sensors for DC or AC power supply can be used to determine the energy consumption of the PPS. Flow meters can be used for diesel or gas fuel consumption, if required.

b) ESS

   Measurement is taken at the output terminal of the ESS.

c) Traction equipment

   Measurement is taken at the input terminals.

d) Brake resistor

   Measurement is taken at the input terminals of the brake resistors.

e) AUX

If major power for auxiliary circuits is supplied by the auxiliary converter, measurement is taken at the input terminals of the auxiliary converter.

f) Components of the subsystem

If required, measurement for the components may be carried out under agreement between the user and the manufacturer in order to determine the efficiency of such component of the subsystem, e.g. dedicated converter, transformer for AC contact line powered PPS, etc.

8.6.2.5 Measurement

The specified operation for the specified number of times to measure the energy for motoring and regenerative brake shall be repeated.

After testing, the stored energy in the ESS and the difference from the initial level shall be measured and calculated.

SOC/SOE at the beginning and at the end of each operational pattern (duty cycle) or at the end of all repeated duty cycles should be balanced with post operation. Post operation may be performed by off-line charging/discharging, e.g. external/internal power source, or catenary line.

The operational pattern and load conditions for the tests shall be agreed upon between the user and the manufacturer.

8.6.2.6 Calculating the system energy consumption to ensure the profile

At the end of the test the system energy consumption shall be calculated by subtracting the difference in energy stored in the ESS from the energy supplied by the power source. The system energy consumption incorporates traction equipment, braking resistor and auxiliaries.

Where there is an imbalance in the level of charge or energy in the ESS (ΔSOC/ΔSOE) the difference in charge or energy can be adjusted via energy consumption.

8.6.2.7 Specific energy consumption calculation

With respect to the energy consumption measured in 8.6.2.5, the specific energy consumption from the running distance and load that correspond to the relevant operational pattern shall be calculated.

8.6.3 Determination of fuel consumption and exhaust gas emission (in case of engine or fuel cell)

8.6.3.1 Determination of fuel consumption

The fuel consumption for the specified operational patterns and load conditions shall be measured or calculated. The operational patterns and load conditions are determined based on the agreement between the user and the manufacturer.

Depending on the agreement between the user and the manufacturer, the fuel consumption is determined either by the actual fuel consumption measured in the fuel tank, or through the conversion of data obtained by monitoring the running state of the engine based on the fuel consumption data obtained from stationary tests conducted in advance.

8.6.3.2 Determination of the exhaust gas emission levels

The emissions of the exhaust gas shall be measured or calculated. Their components shall be analyzed.

Depending on the agreement between the user and the manufacturer, the gas emissions are determined either by the actual measurement or through the conversion of data obtained by monitoring the running state of the engine based on the gas emission data obtained from stationary tests conducted in advance.

8.7 Duration of vehicle operation by ESS

8.7.1 General

This test is carried out to verify the performance of the ESS to supply energy for required operation.

Simulation results based on reliable modelling (successfully verified with previous measurements) can be applied instead of the tests under agreement between the user and the manufacturer, e.g. due to certain limitation of test facilities.

8.7.2 Duration measurement of ESS

With the PPS disconnected the specified operation (duration, distance, speed, etc.) shall be achieved using the power from the ESS.

With the PPS disconnected the running duration shall be checked when only the ESS is used.

This measurement is not required for systems that are not capable of running with power from an ESS only.

8.8 Environmental test

8.8.1 General

The system shall be operated in the range of specified temperature (low and high temperature). The main focus of this test is on ESU.

Component level tests or reliable test results of similar existing systems can be used upon agreement between the user and the manufacturer.

8.8.2 Low-temperature operation test

After operation has started at the lower limit temperature of the specified temperature class (e.g., ambient temperature of −25° C for T1; IEC 62498-1:2010, Table 2) for the ESU, the time needed to reach the state where the specified operational pattern can be supplied by the ESU shall be measured. Stabilized operating conditions concerning temperature such as heating, cooling, etc. for the ESU should be considered.

A partial subsystem test is acceptable if there is an agreement between the user and the manufacturer.

If there are restrictions due to the testing infrastructure, the test method shall be defined by agreement between the user and the manufacturer.

8.8.3 High-temperature operation test

The specified operational pattern at the upper limit temperature (e.g., 50 °C in the equipment box for T1; IEC 62498-1:2010, Table 2) for the ESU shall be measured. Stabilized operating conditions concerning temperature such as heating, cooling, etc. for the ESU should be considered.

A partial subsystem test is acceptable if there is an agreement between the user and the manufacturer.

If there are restrictions due to the testing infrastructure, the test method shall be defined by agreement between the user and the manufacturer.

NOTE E.g. if the test is not performed at the specified maximum ambient temperature, temperature measurement results are corrected linearly (between 10 °C and 40 °C) or by thermal simulation model (e.g. considering changes in internal resistance) to extrapolate the results to maximum operating temperature.

8.9 Short-circuit protection test

The specified terminals of the ESS shall be short-circuited according to the proper means as agreed between the manufacturer and the user.

It is permitted to perform this test by creating the fault condition in the off-state, before start-up of the system.

In the event of short-circuit, the ESS shall react according to the definitions in the protection concept of the hybrid system as agreed between the user and the manufacturer.

If there is restriction due to possibility of damage to the test bench facilities, the test method shall be defined by agreement between the user and the manufacturer.

8.10 ESU endurance test

Endurance test shall be performed at subcomponent level according to the relevant standards:

- for EDLC, endurance cycling test shall be performed according to IEC 61881-3;
- for lithium-ion battery, endurance in cycles test is specified in IEC 62928.

Simulation results for endurance based on reliable modelling (successfully verified with previous measurements) can be applied under agreement between the user and the manufacturer, e.g. especially for the duty cycle of revenue operation.

9 Vehicle test

9.1 General

The tests to be conducted on hybrid vehicles as completed vehicles are shown below.

The tests, unless otherwise specified below, for testing completed vehicles refer to IEC 61133.

Simulation results based on reliable modelling (successfully verified with previous measurements) can be applied instead of the tests under agreement between the user and the manufacturer, e.g. due to certain limitations of test facilities.

9.2 ESS disconnection test

The ESS shall be instantly and safely disconnected either automatically or manually in an emergency or in the event of a failure. Manual and/or automatic disconnection shall be tested if installed, e.g. for maintenance purpose.

NOTE This test is carried out as part of vehicle sequence test.

9.3 Vehicle sequence test

The purpose of the vehicle sequence test is to check the completed vehicle works as intended in a sequence of operation. The following sequence of operation shall be checked:

a) start up of the system

Control power supply is switched on and necessary actions are carried out for the vehicle to start up for operation;

b) motoring operation

Motoring command is turned on, traction circuit is configured for motoring and starts motoring. Several kinds of tractive effort commands within specified speed range, including power boosting (see Figure 10) and/ or power limitations (see Figure 11) if any, shall be tested.

See IEC 61133:2016, 9.2;

c) electric braking operation

Braking command is turned on, traction circuit is configured for braking and starts braking. Several kinds of braking effort commands within the specified speed range, including power boosting (see Figure 10) and/ or power limitations (see Figure 11) if any, shall be tested.

See IEC 61133:2016, 9.2;

d) disconnection of one or more ESS and/or ESU

One or more ESS and/or ESU are disconnected. This sequence shall be operated under the specified conditions. If this sequence is carried out when ESS/ESU or converter are working, ESS/ESU or converter shall be stopped safely before disconnection.

See 9.2;

e) reconnection of one or more ESS and/or ESU

ESS and/or ESU disconnected in procedure d) can be reconnected. This sequence shall be operated under the specified conditions. After reconnection, ESS/ESU or converter shall start operation correctly if failures are removed or the failed component/system is safely disconnected;

f) disconnection of one or more PPS

One or more PPS are disconnected. This sequence shall be operated under specified conditions. If this sequence is carried out when the converter is working, the converter shall be stopped safely before disconnection;

g) reconnection of one or more PPS

PPS disconnected in procedure f) can be reconnected. This sequence shall be operated under the specified conditions. After reconnection, the vehicle shall start operation correctly if failures are removed or the failed component/system is safely disconnected;

h) shut down of the system

After operation, the vehicle can be turned off by the commands according to sequences of switching off power circuit, control circuit, etc.;

i) redundancy, degraded mode

The test of redundancy and degraded modes shall be performed as specified.

No abnormal behaviour (e.g. over voltages, over currents, unintended system down, etc.) shall be observed.

9.4 Drive system energy consumption measurement

The energy consumption shall be measured for the sections, operational patterns and load conditions specified by the user. The operational patterns and load conditions are determined based on the agreement between the user and the manufacturer.

The measurement method refers to 8.6.2.

NOTE Altitude of start and end positions is taken into account to evaluate the measured results.

9.5 Determination of fuel consumption and exhaust gas emission (in case of engine or fuel cell)

9.5.1 Determination of fuel consumption

Determination of the fuel consumption refers to 8.6.3.1, applicable to the vehicle level.

9.5.2 Determination of the exhaust gas emission levels

Determination of the exhaust gas levels refers to 8.6.3.2, applicable to the vehicle level.

9.6 Auxiliary circuit energy consumption measurement

The amount of energy consumption of the auxiliary circuit shall be measured because the auxiliaries (e.g. comfort auxiliaries) as a main consumer of energy can have significant influence on the operation of the hybrid system.

If the APS supplies all the power for the auxiliary circuits, measurement is taken at the input terminal of the APS.

If there are circuits other than the load on the APS, measure the energy consumption in each one.

9.7 Duration of vehicle operation by ESS

Determination of duration for ESS refers to 8.7.2, applicable to the vehicle level.

9.8 Determination of acoustic noise emission

The noise in the running and stationary states of the vehicle shall be determined.

The determination of acoustic noise emission refers to IEC 61133:2016, 9.17.

But considering intermittent operation of the engine and the radiator specific to the hybrid system, noise shall be determined in combination with start/stop of the PPS, e.g. diesel engine or radiator under certain kinds of conditions.

If necessary, noise measurement of component or subsystem at component test or at bench test may be performed upon agreement between the user and the manufacturer.

Annex A
(informative)

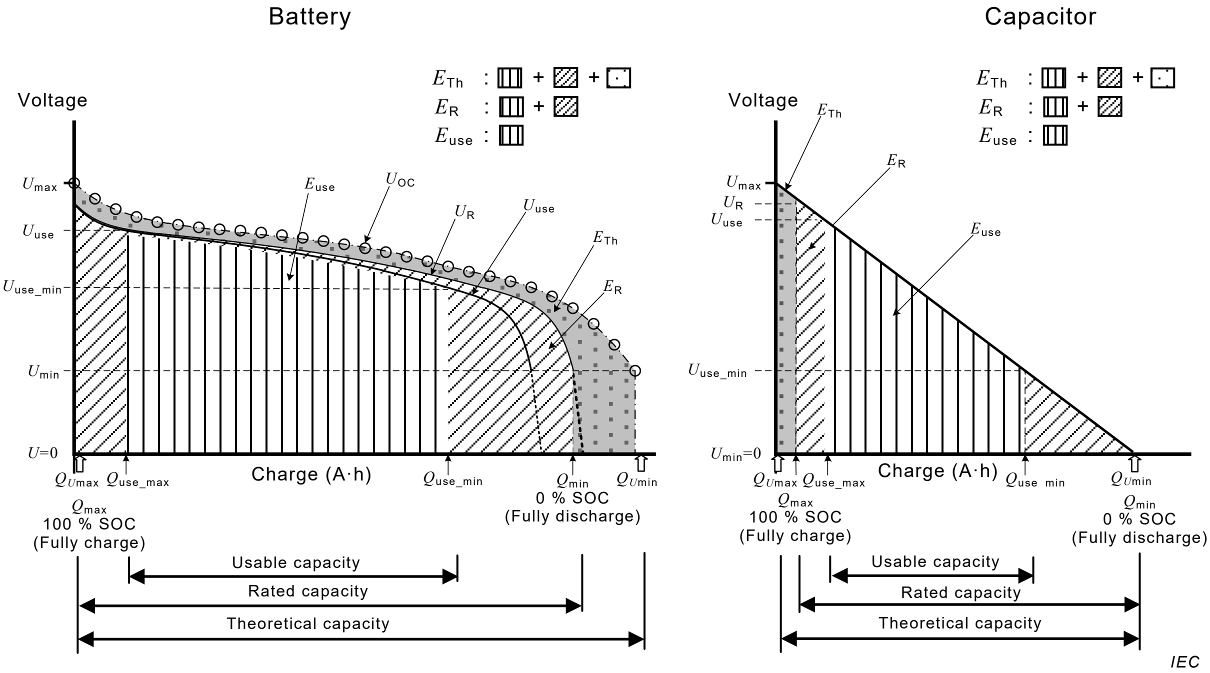
State of charge (SOC) and state of energy (SOE) for batteries and capacitors

A.1 Content of capacity and energy

A.1.1 General

In this international standard, capacity and energy are defined in three distinct contexts: theoretical, rated, and usable. The primary purpose of Annex A is to detail and clarify the definitions or relations applied in the ESU with batteries and/or capacitors as the adopted storage technologies.

For example Figure A.1 illustrates the difference of each definition containing capacity and energy for the battery and the capacitor.



Key

E_{Th}	Theoretical energy	E_R	Rated energy	E_{use}	Usable energy
Q_{max}	Maximum charge			Q_{min}	Minimum charge
Q_{Umax}	Charge at the maximum voltage			Q_{Umin}	Charge at the minimum voltage
Q_{use_max}	Maximum usable charge			Q_{use_min}	Minimum usable charge
U	Voltage			U_{OC}	Voltage at the open circuit
U_R	Rated voltage	U_{max}	Maximum voltage	U_{min}	Minimum voltage
U_{use}	Maximum usable voltage			U_{use_min}	Minimum usable voltage

NOTE For batteries: for very small currents, the usable energy content is similar to the rated energy.

Figure A.1 – Difference of capacity and energy content

A.1.2 Theoretical energy

Theoretical energy, E_{Th}, is defined in 3.1.18.1. It is the amount of energy at a very low value of discharging current (that can be discharged from the energy storage device without energy loss, for example, via joule or ohmic heating) representing the maximum amount of energy being stored in the ESU.

For the capacitor, the theoretical energy is based on the maximum voltage:

$$E_{\mathrm{Th}} = \frac{1}{2} C U_{\mathrm{max}}{}^{2}$$

where

E_{Th} is the theoretical energy;

C is the capacitance;

U_{max} is the maximum voltage.

NOTE For measurement of capacitance, refer to IEC 61881-3.

For the capacitor technology, all electric charge can be removed or discharged from the electrode pair and the corresponding theoretical minimum voltage is therefore zero, i.e., $U_{\mathrm{min}} = 0$.

A.1.3 Rated energy

Rated energy is defined in 3.1.18.2. It is the amount of energy that can be discharged from the ESU under the “rating” conditions.

For the battery, the rated energy is the integral of the product of constant current in discharge test and measured voltage (e.g. C_5 rate).

For example, a lithium-Ion battery, refer to result of IEC 62928 for the rated energy and according to IEC 62620.

For the capacitor, the rated energy is practically based on the rated voltage:

$$E_{\mathrm{R}} = \frac{1}{2} C U_{\mathrm{R}}{}^{2}$$

where

E_{R} is the rated energy;

C is the capacitance;

U_{R} is the rated voltage.

NOTE For EDLC E_{R} is not fully obtained due to loss of ESR.

A.1.4 Usable energy

The usable energy is defined in 3.1.18.3. It is the usable portion of available energy within a pre-defined range of SOC or voltage limits. The maximum and minimum limits are parameters typically defined by the user or the manufacturer.

For example, parameters such as power, current or maximum and minimum voltage limit for the equipment used may be defined.

For the battery, the usable energy is the energy which can be used without limiting the duty cycle initially agreed between the user and the manufacturer.

For the capacitor, the usable energy is effectively the difference between energies at charged voltage and minimum usable voltage:

$$E_{\text{use}} = \frac{1}{2} C U_{\text{use}}{}^2 - \frac{1}{2} C U_{\text{use\_min}}{}^2$$

where

E_{use} is the usable energy;

C is the capacitance;

U_{use} is the maximum usable voltage;

$U_{\text{use\_min}}$ is the minimum usable voltage.

NOTE For EDLC E_{use} is not fully obtained due to loss of ESR.

A.2 Content of SOC and SOE

A.2.1 General

As several definitions of capacity and energy exist, state of charge (SOC) and state of energy (SOE) as a combination of the contents of capacity and energy can also be defined as discussed herein.

An appropriate definition should be selected by the user for the intended purposes and applications.

In general, SOC is a relative ratio of the amount of capacity remaining in the ESU to the maximum amount available per definition (i.e., theoretical, rated, or usable). The quantity of SOC is typically expressed in decimals (0,0 to 1,0) or percentage (%). A SOC value of 1,0 or 100 % represents the fully charged state, whereas 0,0 or 0 % represents the fully discharged state. Similarly, SOE is a measure of relative energy available in the ESU, and also expressed in decimals or percentage.

A.2.2 Theoretical purpose

For the theoretical purpose the following definitions are appropriate:

$$\text{SOC}_{\text{Th}} = \frac{CH_{\text{Th\_remaining}}}{CH_{\text{Th}}}$$

$$\text{SOE}_{\text{Th}} = \frac{E_{\text{Th\_remaining}}}{E_{\text{Th}}}$$

where

CH_{Th} is the theoretical capacity, in Ah;

$CH_{\text{Th\_remaining}}$ is the remaining theoretical capacity, in Ah;

E_{Th} is the theoretical energy, in Wh;

$E_{\text{Th\_remaining}}$ is the remaining theoretical energy, in Wh.

A.2.3 Common purpose

For the common purpose the following definitions are appropriate:

$$\text{SOC} = \frac{CH_{\text{R\_remaining}}}{CH_{\text{R}}}$$

$$\text{SOE} = \frac{E_{\text{R\_remaining}}}{E_{\text{R}}}$$

where

CH_{R}	is the rated capacity, in Ah;
$CH_{\text{R\_remaining}}$	is the remaining rated capacity, in Ah;
E_{R}	is the rated energy, in Wh;
$E_{\text{R\_remaining}}$	is the remaining rated energy, in Wh.

A.2.4 Effective or practical purpose

For the effective or practical purpose the following definitions are appropriate:

$$\text{SOC}_{\text{Ef}} = \frac{CH_{\text{use\_remaining}}}{CH_{\text{use}}}$$

$$\text{SOE}_{\text{Ef}} = \frac{E_{\text{use\_remaining}}}{E_{\text{use}}}$$

where

CH_{use}	is the usable capacity, in Ah;
$CH_{\text{use\_remaining}}$	is the remaining usable capacity, in Ah;
E_{use}	is the usable energy, in Wh;
$E_{\text{use\_remaining}}$	is the remaining usable energy, Wh.

A.2.5 Coefficient of usage

For the coefficient of usage purpose the following definitions are appropriate, applicable for both beginning of life (BOL) and end of life (EOL).

$$\text{COU}_{\text{SOC}} = \frac{CH_{\text{use}}}{CH_{\text{R}}}$$

$$\text{COU}_{\text{SOE}} = \frac{E_{\text{use}}}{E_{\text{R}}}$$

where

CH_{R}	is the rated capacity, in Ah;
CH_{use}	is the usable capacity, in Ah;
E_{R}	is the rated energy, in Wh;
E_{use}	is the usable energy, in Wh.

NOTE Other combinations as ratios of different contents of capacity or energy can be used if needed.

$$\text{COU}_{\text{SOC\_R\_Th}} = \frac{CH_{\text{R}}}{CH_{\text{Th}}}$$

$$\mathrm{COU}_{\mathrm{SOE\_R\_Th}} = \frac{E_{\mathrm{R}}}{E_{\mathrm{Th}}}$$

$$\mathrm{COU}_{\mathrm{SOC\_use\_Th}} = \frac{CH_{\mathrm{use}}}{CH_{\mathrm{Th}}}$$

$$\mathrm{COU}_{\mathrm{SOE\_use\_Th}} = \frac{E_{\mathrm{use}}}{E_{\mathrm{Th}}}$$

Annex B
(informative)

Energy related terms and definitions

B.1 General

This Annex describes energy related definitions, terms and detailed calculation methods.

It should be noted that different definitions are widely used for the same word “regenerative efficiency”. Take an example of system architecture shown in Figure 9 (contact line powered non-hybrid system). It is common to evaluate the regenerative performance of this system by measuring the power transmitted between the vehicle and the power supply network through the current collectors (e.g. pantographs or shoegears). However, this generally means that the power flow may be positive, i.e. from the power supply network to the vehicle, when the traction equipment is regenerating power that is smaller than the power supplied to the auxiliary loads.

Therefore, even when the losses at the PPS subsystem of Figure 9 are ignored, the supplied, regenerated and consumed energy, the regeneration coefficient and many other performance indices of the vehicle can differ significantly from those defined for the traction equipment under this definition.

It should also be noted that the appropriate interpretation of energy indices are significantly different for individual configurations. For example, in the configuration of Figure 6, the regenerated energy to the PPS is basically returned to the power supply network. However, in Figure 4, it is absorbed by engine or exhaust braking, and therefore should be treated differently.

Therefore, the energy efficiency performance indices should be clearly defined and handled appropriately depending on the configuration of the system.

B.2 Terms and definitions for regenerative indices

B.2.1
power source subsystem
any constituent of a series hybrid system the primary activity of which is to supply power to other parts of the system

Note 1 to entry: An ESS can be viewed both as power source and power sink under different context.

B.2.2
power sink subsystem
any constituent of a series hybrid system the primary activity of which is to receive power from other parts of the system and consume it to fulfil any specific purpose

Note 1 to entry: See note to entry B.2.1.

B.2.3
supplied energy
<power source subsystem in a series hybrid system> amount of energy transmitted from the power source subsystem to other parts of the system during a specified operational pattern

<power sink subsystem in a series hybrid system> amount of energy transmitted from other parts of the system to the power sink subsystem during a specified operational pattern

<railway vehicle using contact lines> amount of energy transmitted from the contact lines to the vehicle during a specified operational pattern

B.2.4
regenerated energy
<power source subsystem in a series hybrid system> amount of energy transmitted from other parts of the system to the power source subsystem during a specified operational pattern

<power sink subsystem in a series hybrid system> amount of energy transmitted from the power sink subsystem to other parts of the system during a specified operational pattern

<railway vehicle using contact lines> amount of energy transmitted from the vehicle to the contact line during a specified operational pattern

B.2.5
consumed energy
amount of energy obtained by subtracting regenerated energy from supplied energy

B.2.6
regenerative efficiency
ratio of regenerated energy to supplied energy

B.3 Energy-related performance indices of the series hybrid systems

B.3.1 General

In evaluating the energy efficiency of the series hybrid systems, the most important performance index is the energy consumption, as defined in 3.1.8.

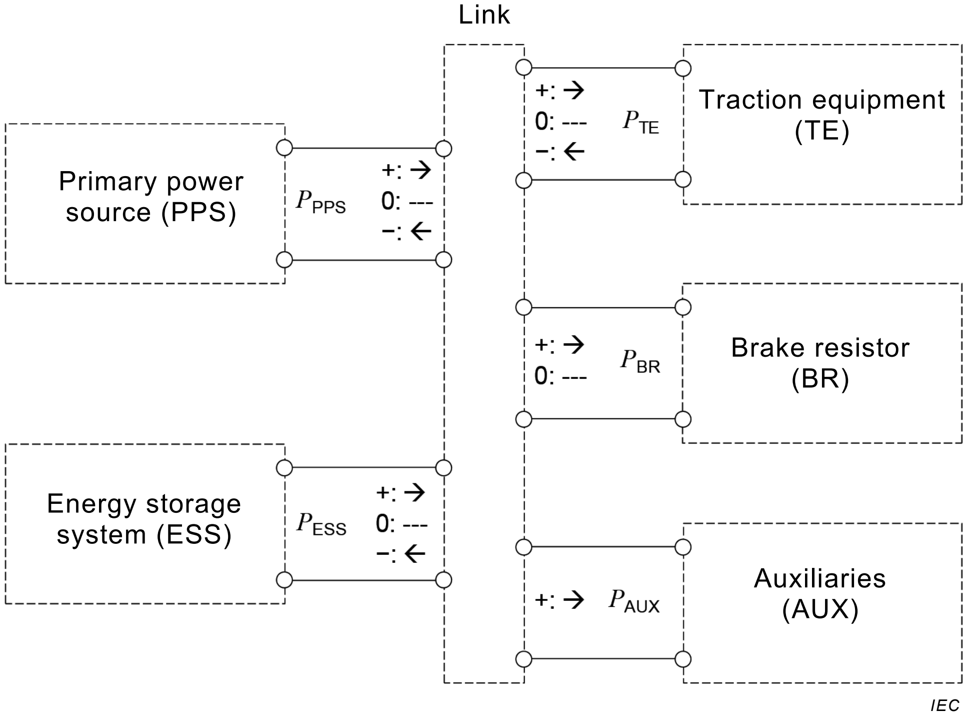
Other performance indices, such as supplied, regenerated and/or consumed energy of each subsystem in the series hybrid system and/or of the whole series hybrid system, regenerative efficiency, of the traction equipment and/or of the whole series hybrid system, etc. can be used and should be considered where appropriate.

The possible objectives of the indices defined in this annex include, but are not limited to the investigation into the contribution of each of the subsystems in a hybrid system to energy saving.

B.3.2 Measuring locations

In the calculation of indices described in this annex, it is necessary to measure power flows between the link block and the subsystems in the hybrid system. In the example configuration of Figure B.1, these power flows are shown as P_{PPS}, P_{ESS}, P_{TE}, P_{BR} and P_{AUX}.

NOTE Inevitably, there are losses in the link block of Figure B.1. However, these losses are generally small and therefore ignored in the following parts of this annex.



Key

P_{PPS} Power of primary power source (PPS)

P_{TE} Power of traction equipment (TE)

P_{ESS} Power of energy storage system (ESS)

P_{BR} Power of brake resistor (BR)

P_{AUX} Power of auxiliaries (AUX)

Figure B.1 – Example block diagram of a series hybrid system

In addition to these, it is necessary to measure the following:

- for the vehicle powered by the contact line, the electric power taken in by the vehicle through current collectors; and
- for the vehicle powered by the PPS that consumes fuel or gas, the consumption of fuel or gas by flow meters.

As stated in 8.6.2.4, measurements shall be taken at the terminals linking each subsystem and the link block in Figure B.1.

B.3.3 Class of primary power source

For the convenience of the description in this annex, the primary power sources in the hybrid system can be classified into the following two classes:

- Class 0: the primary power source that either:
  - has no ability to absorb regenerative power; or
  - can absorb and dissipate regenerative power but has no ability to reuse the returned energy.
- Class 1: the primary power source that can absorb regenerative power and reuse the returned energy effectively.

Out of the examples in Clause 4, diesel-electric PPS and fuel-cell PPS are categorized in Class 0, and contact line PPS is categorized in Class 1·

B.3.4 Energy consumption

B.3.4.1 Energy consumption by traction equipment

The supplied, regenerated and consumed energy of the traction equipment in Figure B.1 can be expressed by the following equations:

$$E_{\mathrm{S,TE}} = \int_{t=T_{\mathrm{S}}}^{T_{\mathrm{E}}} \max(P_{\mathrm{TE}}(t),0)dt \tag{B.1}$$

$$E_{\mathrm{R,TE}} = \int_{t=T_{\mathrm{S}}}^{T_{\mathrm{E}}} \max(-P_{\mathrm{TE}}(t),0)dt \tag{B.2}$$

$$E_{\mathrm{C,TE}} = E_{\mathrm{S,TE}} - E_{\mathrm{R,TE}} \tag{B.3}$$

where $E_{\mathrm{S,TE}}$, $E_{\mathrm{R,TE}}$ and $E_{\mathrm{C,TE}}$ are supplied, regenerated and consumed energy of the traction equipment, t is time, $P_{\mathrm{TE}}(t)$ is P_{TE} as denoted in Figure 3 at time t, T_{S} and T_{E} are the start and end times of the operational pattern given as the condition of evaluation, and max(a, b) equals to a if $a > b$ and b otherwise. Similar definitions can be done to the supplied, regenerated and consumed energy of other subsystems in the series hybrid system, or the series hybrid system as a whole (especially the series hybrid systems for contact line powered vehicles).

B.3.4.2 Energy consumption at current collectors

For contact line powered railway vehicles (including vehicles without hybrid systems), the supplied and returned energy at the current collectors (e.g. pantographs if the contact line is the overhead line) can be expressed by the following equations:

$$E_{\mathrm{S,CC}} = \int_{t=T_{\mathrm{S}}}^{T_{\mathrm{E}}} \max(P_{\mathrm{CC}}(t),0)dt \tag{B.4}$$

$$E_{\mathrm{R,CC}} = \int_{t=T_{\mathrm{S}}}^{T_{\mathrm{E}}} \max(-P_{\mathrm{CC}}(t),0)dt \tag{B.5}$$

$$E_{\mathrm{C,CC}} = E_{\mathrm{S,CC}} - E_{\mathrm{R,CC}} \tag{B.6}$$

where t, T_{S}, T_{E} and max(a, b) are same as in B.3.4.1, $E_{\mathrm{S,CC}}$, $E_{\mathrm{R,CC}}$ and $E_{\mathrm{C,CC}}$ are supplied, regenerated and consumed energy at the current collector, and $P_{\mathrm{CC}}(t)$ is the power input at the current collector (when $P_{\mathrm{CC}} < 0$ then the power is flowing back from the vehicle to the contact line) at time t.

It should be noted that the sign (+, 0 or -) of the power supplied to the traction equipment P_{TE} and the sign of P_{CC} do not always coincide, even for non-hybrid vehicles.

In evaluating this, if there is an onboard ESS, its SOC and/or the SOE shall be equal at times $t = T_{\mathrm{S}}$ and $t = T_{\mathrm{E}}$, as specified in 8.6.2.5.

B.3.4.3 Electric energy consumption of the hybrid system

The supplied and returned electric energy of the primary power source in the hybrid system can be expressed by the following equations:

$$E_{\text{S,PPS}} = \int_{t=T_\text{S}}^{T_\text{E}} \max(P_{\text{PPS}}(t),0)dt \tag{B.7}$$

$$E_{\text{R,PPS}} = \int_{t=T_\text{S}}^{T_\text{E}} \max(-P_{\text{PPS}}(t),0)dt \tag{B.8}$$

$$E_{\text{C,PPS}} = E_{\text{S,PPS}} - E_{\text{R,PPS}} \tag{B.9}$$

where t, T_S, T_E and max(a, b) are same as in B.3.4.1, $E_{\text{S,PPS}}$, $E_{\text{R,PPS}}$ and $E_{\text{C,PPS}}$ are supplied, regenerated and consumed electric energy at the primary power source, and $P_{\text{PPS}}(t)$ is P_{PPS} as denoted in Figure B.1 at time t.

In evaluating this, if there is an onboard ESS, its SOC and/or the SOE shall be equal at times $t = T_\text{S}$ and $t = T_\text{E}$, as specified in 8.6.2.5.

If the primary power source is Class 1 according to the definition in B.3.3, then the electric energy consumption of the hybrid system is equal to $E_{\text{C,PPS}}$ defined in equation (B.9).

If the primary power source is Class 0 according to the definition in B.3.3, then the electric energy consumption of the hybrid system is equal to $E_{\text{S,PPS}}$ defined in equation (B.7).

B.3.4.4 Losses in the ESS

Considering an ESS as the power sink subsystem, its supplied, regenerated and consumed energy can be expressed by the following equations:

$$E_{\text{S,ESS}} = \int_{t=T_\text{S}}^{T_\text{E}} \max(-P_{\text{ESS}}(t),0)dt \tag{B.10}$$

$$E_{\text{R,ESS}} = \int_{t=T_\text{S}}^{T_\text{E}} \max(P_{\text{ESS}}(t),0)dt \tag{B.11}$$

$$E_{\text{C,ESS}} = E_{\text{S,ESS}} - E_{\text{R,ESS}} \tag{B.12}$$

where t, T_S, T_E and max(a, b) are the same as in B.3.4.1, $E_{\text{S,ESS}}$, $E_{\text{R,ESS}}$ and $E_{\text{C,ESS}}$ are the supplied, regenerated and consumed energy of the ESS, and $P_{\text{ESS}}(t)$ is the P_{ESS} as denoted in Figure B.1 at time t. The $E_{\text{C,ESS}}$ as defined here shows the losses within the ESS during the given operational pattern.

In evaluating this, the SOC and/or the SOE of the ESS shall be equal at times $t = T_\text{S}$ and $t = T_\text{E}$, as specified in 8.6.2.5.

B.3.5 Regenerative efficiency

B.3.5.1 General

The appropriate definition of regenerative efficiency of a hybrid system as a whole depends on its configuration.

Regenerative efficiency may become greater than 100 % depending on the operational pattern, e.g. when the vehicle is descending the slope.

B.3.5.2 Regenerative efficiency of the traction equipment

The regenerative efficiency of the traction equipment RE_{TE} in % can be expressed by the following equation:

$$RE_{\mathrm{TE}} = \frac{E_{\mathrm{R,TE}}}{E_{\mathrm{S,TE}}} \times 100 \quad \text{(B.13)}$$

where $E_{\mathrm{S,TE}}$ and $E_{\mathrm{R,TE}}$ are as defined in B.3.4.1.

B.3.5.3 Regenerative efficiency of the contact line powered vehicle

The regenerative efficiency of the contact line powered vehicle (including non-hybrid vehicles) RE_{CC} in % can be expressed by the following equation:

$$RE_{\mathrm{CC}} = \frac{E_{\mathrm{R,CC}}}{E_{\mathrm{S,CC}}} \times 100 \quad \text{(B.14)}$$

where $E_{\mathrm{S,CC}}$ and $E_{\mathrm{R,CC}}$ are as defined in B.3.4.4.

It should be noted that the RE_{CC} of the hybrid vehicle (vehicle with onboard ESS) is generally lower than that of the non-hybrid vehicle (vehicle without onboard ESS) running under the same operational pattern.

NOTE In evaluating this, if there is an onboard ESS, its SOC and/or the SOE is considered to be balanced as described above.

B.3.5.4 Regenerative efficiency of the hybrid system

The generic definition of regenerative efficiency can be given as follows, using the concept of the Class of primary power source defined in B.3.3.

For hybrid systems powered by Class 1 PPS, their regenerative efficiency RE_1 in % can be given as follows:

$$RE_1 = \frac{E_{\mathrm{R,TE}} - E_{\mathrm{S,BR}}}{E_{\mathrm{S,TE}}} \times 100 \quad \text{(B.15)}$$

where $E_{\mathrm{S,TE}}$ and $E_{\mathrm{R,TE}}$ are as defined in B.3.4.1, and $E_{\mathrm{S,BR}}$ is as defined in the following equation:

$$E_{\text{S, BR}} = \int_{t=T_\text{S}}^{T_\text{E}} P_{\text{BR}}(t)dt \qquad \text{(B.16)}$$

For hybrid systems powered by Class 0 PPS, their regenerative efficiency RE_0 in % can be given as follows:

$$RE_0 = \frac{E_{\text{R, TE}} - E_{\text{R, PPS}} - E_{\text{S, BR}}}{E_{\text{S, TE}}} \times 100 \qquad \text{(B.17)}$$

where $E_{\text{S,TE}}$ and $E_{\text{R,TE}}$ are as defined in B.3.4.1, $E_{\text{S,BR}}$ is as defined above in Equation (B.16), and $E_{\text{R,PPS}}$ is as defined in B.3.4.3.

NOTE In evaluating this, if there is an onboard ESS, its SOC and/or the SOE is considered to be balanced as described above.

Annex C
(informative)

Laws and regulations for fire protection applicable for this standard

C.1 General

Laws and regulations for fire protection in some countries are listed as below.

The list is for information only.

C.2 China

GB 6771-2000, *Regulations relating to fire preventive and fighting measures for electric locomotives*

C.3 Europe

EN 45545, *Railway applications — Fire protection on railway vehicles*

C.4 Japan

Ministerial Ordinance and its approved specification of Ministry of Land, Infrastructure, Transport and Tourism

Chapter 8. Rolling Stock

Section 5. Fire Prevention Measures for Rolling Stock, Article 83 – Article 85.

Section 6. Rolling Stock Facilities for One Man Operation, Article 86

Chapter 10. Train Operation

Section 2. Train Operation, Article 108.

C.5 Russia

VNPB – 03, *Passenger Cars. Fire Safety Requirements, GOST*

C.6 United states of America

NFPA 130, *Standard for Fixed Guideway Transit and Passenger Rail Systems*

Annex D
(informative)

List of subclauses requiring agreement between the user and the manufacturer

The agreements needed between the user and the manufacturer in this standard are listed in Table D.1.

In this standard four levels of the test are specified. Depending on the level, the user may be the purchaser.

Table D.1 – List of subclauses requiring agreement between the user and the manufacturer *(1 of 2)*

Subclause	Title	Comment
3.1.15	End of life	Required functionality or operational pattern
5.3	Temperature	Requirements of pre-heating or pre-cooling
6.1.1.2	Other accelerations	Requirements under transverse and longitudinal accelerations
6.3.1	External charge and discharge function	Specifications for the external charge and discharge function
6.5	Degraded mode	Concept for the degraded mode
6.7	Lifetime requirements	– Lifetime determination and modelling of the ESU – EOL for EDLC and parameters
6.8	Additional requirement for noise emission of hybrid system	Specific noise emission requirement
7.2	Type test	– Decision on whether to conduct the type test or conduct only part of that test – Omitting the type test – Applying simulation results
7.3	Optional test	– Optional test – Acceptance criteria for the system
7.4	Routine test	– Routine tests – Adoption of an alternative test procedure
7.5	Test categories	– Special requirements – Location of the tests – Conducting optional" type tests
7.6	Acceptance criteria	Specifications
8.3.1	ESS charge/discharge control function	Requirements of charging and discharging of the ESS
8.3.2	External charge test	Starting temperature and cooling conditions
8.3.4	Degraded mode test	Specific operating range under the degraded mode
8.3.5	SOC/SOE test	Acceptance criteria
8.6.1	General	– Applying simulation results – Acceptance criteria of energy consumption including the ESS – Using IEC 62888 series for field tests

Table D.1 *(2 of 2)*

Subclause	Title	Comment
8.6.2.1	General	Measurements of some components
8.6.2.4	Measurement locations	Measurement for the components
8.6.2.5	Measurement	Operational pattern and load conditions
8.6.3.1	Determination of fuel consumption	– Operational patterns and load conditions – Actual fuel consumption measured in the fuel tank, or through the conversion of data obtained by monitoring
8.6.3.2	Determination of the exhaust gas emission levels	Actual measurement or through the conversion of data
8.7.1	General	Applying simulation results
8.8.1	General	Using of component level tests or reliable test results of the existing system
8.8.2	Low-temperature operation test	– Partial subsystem test – Test method due to restrictions of the testing infrastructure
8.8.3	High-temperature operation test	– Partial subsystem test – Test method due to restrictions of the testing infrastructure
8.9	Short-circuit protection test	– Proper means of short-circuiting – Protection concept – Test method due to possibility of damage to the test bench facilities
8.10	ESU endurance test	Applying simulation results
9.1	General	Applying simulation results
9.4	Drive system energy consumption measurement	Operational patterns and load conditions
9.8	Determination of acoustic noise emission	Noise measurement of component or subsystem at component test or at bench test
A.1.4	Usable energy	Duty cycle

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IEC 60254-1:2005, *Lead-acid traction batteries – Part 1: General requirements and methods of test*

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IEC 60721-3-5, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 5: Ground vehicle installations*

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IEC 62278, *Railway applications – Specification and demonstration of reliability, availability, maintainability and safety (RAMS)*

IEC 62497-1, *Railway applications – Insulation coordination – Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment*

IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*[2]

IEC 62620, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for use in industrial applications*

IEC 62888 (all parts), *Railway applications – Energy measurement on board trains*[3]

IEC 62888-2, *Railway applications – Energy measurement on board trains – Part 2: Energy measuring*[4]

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1 This publication was withdrawn.

2 Under consideration.

3 Under consideration.

4 Under consideration.

IEC 62928, *Railway applications – Rolling stock equipment – Onboard lithium-ion traction batteries*[5]

IEC 62973, *Railway applications – Batteries for auxiliary power supply systems*[6]

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EN 1986-2:2001, *Electrically propelled road vehicles – Measurement of energy performances – Part 2: Thermal electric hybrid vehicles*

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5 Under consideration.

6 Under consideration.

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