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Fuel cell road vehicles — Safety specifications —

Part 3:
Protection of persons against electric shock

Véhicules routiers alimentés par pile à combustible — Spécifications de sécurité —

Partie 3: Protection des personnes contre les décharges électriques

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Foreword

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ISO 23273-3 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 21, *Electrically propelled road vehicles*.

ISO 23273 consists of the following parts, under the general title *Fuel cell road vehicles — Safety specifications*:

— *Part 1*: *Vehicle functional safety*

— *Part 2*: *Protection against hydrogen hazards for vehicles fuelled with compressed hydrogen*

— *Part 3: Protection of persons against electric shock*

Fuel cell road vehicles — Safety specifications —

Part 3:
Protection of persons against electric shock

1 Scope

This part of ISO 23273 specifies the essential requirements of fuel cell vehicles (FCV) for the protection of persons and the environment inside and outside the vehicles against electric shock.

It applies only to on-board electric circuits with working voltages between 25 V a.c. and 1 000 V a.c., or 60 V d.c. and 1 500 V d.c. respectively (for details on voltage class B, see Clause 5).

This International Standard does not apply to:

— FCV connected to an external electric power supply;

— component protection; or

— manufacturing, maintenance and repair.

2 Normative references

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

ISO 3864-2, *Graphical symbols — Safety colours and safety signs — Part 2: Design principles for product safety labels*

ISO 6469-1, *Electric road vehicles — Safety specifications — Part 1: On-board electrical energy storage*

ISO 20653, *Road vehicles — Degree of protection (IP-Code) — Protection of electrical equipment against foreign objects, water and access*

ISO 23273-1, *Fuel cell road vehicles — Safety specifications — Part 1: Vehicle functional safety*

IEC 60417, *Graphical symbols used on equipment — Annex K*

IEC 60479-1, *Effects of current on human beings and livestock — Part 1: General aspects*

IEC 60664-1, *Insulation coordination for equipment within low-voltage systems — Part 1: Principles, requirements and tests*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
air processing system
system that processes (e.g. that filters, meters, conditions and pressurizes) the incoming air for the fuel cell system

3.2
auxiliary electric circuit
electrical circuit supplying vehicle functions other than for propulsion, such as lamps, windscreen (windshield) wiper motors and radios

3.3
balance of fuel cell power system
remaining portion of the electric circuit of the fuel cell power system when the power sources (i.e. fuel cell stacks, batteries, etc.) are disconnected

3.4
barrier
part providing protection against direct contact from any usual direction of access

3.5
basic insulation
insulation applied to live parts for protection against direct contact under fault-free conditions

NOTE Basic insulation does not necessarily include insulation used exclusively for functional purposes.

3.6
basic protection
protection against direct contact with live parts under fault-free conditions

3.7
battery cell
basic rechargeable energy storage device, consisting of electrodes, electrolyte, container, terminals and usually separators, that is a source of electric energy obtained by direct conversion of chemical energy

3.8
battery pack
single mechanical assembly comprising battery cells and retaining frames or trays and possibly components for battery management

3.9
chassis-bonded
electric connection of one point of an electric circuit with the electric chassis

3.10
conductive part
part capable of conducting electric current

3.11
direct contact
contact of persons with live parts

3.12
double insulation
insulation comprising both basic insulation and supplementary insulation

3.13
electric chassis
conductive mechanical structure of the vehicle including all associated electric and electronic components, whose parts are electrically connected and whose potential is taken as reference

3.14
electric circuit
collection of connected devices through which electric current is intended to flow

3.15
dc/dc converter
set of equipment for the conversion of direct current of one voltage to direct current of another voltage and/or for isolating purposes

3.16
electric shock
physiological effect resulting from an electric current passing through a human body

3.17
enclosure
part providing protection of equipment against certain external influences and against direct contact from any direction

NOTE External influences can include the ingress of dust or water, prevention of mechanical damage.

3.18
exposed conductive part
conductive part that can be touched by a test probe according to a protection degree as specified in ISO 20653

3.19
fuel cell
electrochemical device that generates electricity by the conversion of fuel and an oxidant without any physical or chemical consumption of the electrodes or electrolyte

3.20
fuel cell power system
combination of the fuel cell system, dc/dc converter(s), power unit and **RESS**, if any

3.21
fuel cell stack
assembly of two or more fuel cells, which are electrically connected

3.22
fuel cell system
system, typically containing the following subsystems: fuel cell stack, air processing system, fuel processing system, thermal management, water management, and their control system

3.23
fuel cell vehicle
FCV
vehicle that receives propulsion power from an on-board fuel cell power system

NOTE The general term FCV includes also vehicles with an additional other source of propulsion power.

3.24
fuel processing system
system that converts (if necessary), and/or conditions the fuel as stored in the on-board fuel storage into fuel suitable for operation in the fuel cell stack

3.25
insulation resistance monitoring system
system, which periodically or continuously monitors the insulation resistance between live parts and the electric chassis

3.26
live part
conductor or conductive part intended to be electrically energized in normal use

NOTE "electrically energized" means such conductor or conductive part can have an electric potential against the electric chassis.

3.27
maximum working voltage
highest value of a.c. voltage (rms) or of d.c. voltage which may occur in an electric system under any normal operating conditions, according to manufacturer's specifications, disregarding transients

3.28
potential equalization
electric connection of exposed conductive parts of the electric equipment to minimize differences in potential

3.29
protection degree
protection provided by a barrier/enclosure related to the contact with live parts by a test probe, such as a test finger (IPXXB), a test rod (IPXXC) or a test wire (IPXXD), as defined in ISO 20653

3.30
power unit
combination of electric motor, associated power electronics, and their associated controls for the purpose of vehicle propulsion

3.31
rechargeable energy storage system
RESS
system that stores energy and is rechargeable by on board and/or external energy sources and associated controls, if any

EXAMPLES These include batteries, capacitors and electromechanical flywheels.

3.32
reinforced insulation
insulation of live parts for protection against electric shock equivalent to double insulation

NOTE Reinforced insulation does not imply that the insulation must be a homogeneous piece. The reinforced insulation may comprise several layers which cannot be tested individually as supplementary or basic insulation.

3.33
supplementary insulation
independent insulation applied in addition to basic insulation for protection against electric shock in the event of a failure of the basic insulation

3.34
traction battery
collection of all battery packs, which are electrically connected for the supply of energy to the power unit and possibly auxiliary systems

3.35
voltage class A electric circuit
electric circuit with a maximum working voltage of $\leqslant$ 25 V a.c. or $\leqslant$ 60 V d.c. respectively

3.36
voltage class B electric circuit
electric circuit with a maximum working voltage of ($>$ 25 and $\leqslant$ 1 000) V a.c. or ($>$ 60 and $\leqslant$ 1 500) V d.c. respectively

4 Environmental and operational conditions

The requirements given in this part of ISO 23273 shall be met across the range of environmental and operational conditions for which the vehicle is designed to operate, as specified by the vehicle manufacturer.

5 Voltage classes of electric circuits

Depending on its maximum working voltage, U, an electric circuit belongs to one of the voltage classes specified in Table 1.

Table 1 — Voltage classes of electric circuits

Voltage class	Maximum working voltage	
	d.c. systems V	a.c. systems (15 Hz to 150 Hz) V (rms)
A	$0 < U \leqslant 60$	$0 < U \leqslant 25$
B	$60 < U \leqslant 1\,500$	$25 < U \leqslant 1\,000$

NOTE 1 The values 60 V d.c./25 V a.c. are selected taking into account humid weather conditions. For non a.c. but repetitive pulse voltages, if peak duration is above 10 ms, the considered working voltage is then the maximum peak value. If the peak duration is less than 10 ms, the working voltage is then the rms value. The reported a.c. voltage values are the most critical within the specified frequency range.

NOTE 2 The d.c. voltage is ⩽ 10 % ripple voltage (rms). The upper voltage of class B can be lower according to national requirements.

6 Marking

6.1 Electric equipment

The symbol shown in Figure 1 shall appear near voltage class B voltage sources, e.g. fuel cell stacks, batteries, super-capacitors. The same symbol shall be visible on barriers and enclosures which, when removed, expose live parts of class B circuits and/or basic insulation.

The symbol (background: yellow; bordering and symbol: black) shall be according to IEC 60417 and ISO 3864-2.

Figure 1 — Marking of voltage class B voltage equipment

6.2 Identification of voltage class B wiring

Harnesses containing voltage class B cables shall be visually identified with a permanent orange harness covering material.

7 Measures for the protection of persons against electric shock

7.1 General

Hazards of electric shock can occur when electric current passes through the human body (see IEC 60479-1). Such body current shall not exceed 10 mA continuously.

Protection against electric shock therefore means:

- either preventing a person from simultaneously coming into contact with two or more live parts having different electric potentials or a voltage between them; or
- limiting the current and its duration in case of such contact.

Protection against electric shock shall be comprised of:

- basic protection (protection against direct contact with live parts of any voltage class B electric circuit under normal operating (fault free) conditions); and
- protection under any first failure condition with respect to electric shock.

The protection measures described in 7.2 and 7.3 shall meet the requirements according to test methods specified in Clause 8.

NOTE 1 See IEC 60664-1 for guidance.

NOTE 2 For functional reasons, measures similar to those against electric shock may be also provided for voltage class A electric circuits. Such measures are not covered by this part of ISO 23273.

7.2 Basic protection measures

Persons shall be protected against direct contact with the live parts of any voltage class B electric circuit. Protection measures against direct contact shall be provided by either one or both of the following:

- basic insulation of the live parts;
- barriers/enclosures, preventing access to the live parts.

The barriers/enclosures may be electrically conductive or non-conductive.

Vehicle manufacturers should pay special attention to protection of basic insulation of live parts in passenger compartments and loading compartments.

7.3 Protection under first failure conditions

7.3.1 General

Protection under any first failure condition with respect to electric shock shall be achieved by the measures in either 7.3.2 or 7.3.3, depending on whether the voltage class B electric circuits are isolated from the chassis or chassis-bonded.

These measures can be different for the various live parts of one voltage class B electric circuit.

In any case, exposed conductive parts including exposed conductive barriers/enclosures shall be bonded to the electric chassis (for potential equalization).

7.3.2 Protection measures for isolated voltage class B electric circuits

Sufficient protection is provided with any of the basic protection measures (see 7.2), if they meet a 100 Ω/V minimum resistance requirement, based on the maximum working voltage of the electric circuit.

NOTE 100 Ω/V minimum insulation resistance corresponds to the required 10 mA maximum body current (see 7.1).

If the 100 Ω/V requirement cannot be maintained, then protection under any first failure condition shall be achieved by any of the following:

- double insulation or reinforced insulation;
- an additional layer of barriers/enclosures over the basic protection;
- monitoring periodically or continuously the resistance between the chassis and the live parts of any voltage class B electric circuit during operation of the vehicle (An appropriate warning shall be provided if loss of resistance is detected. Additionally, the ability to restart or use the vehicle may be limited if the loss of resistance recurs);
- providing an appropriate leakage current detection and shutdown system.

When the leakage current and time reaches a hazardous level (as defined in IEC 60479-1), the affected voltage class B circuit shall be shut off such that permanent or severe injury does not occur, considering the expected type and degree of human contact and the operational state of the vehicle as described in ISO 23273-1.

7.3.3 Protection measures for chassis-bonded voltage class B electric circuits

Protection shall be provided by any of the following, meeting the 100 Ω/V resistance requirement (see 7.1 and 7.3.2):

- double or reinforced insulation, of any class B equipment;
- an additional layer of barriers/enclosures over the basic class B protection.

If a conductive cover is used for basic protection, then the additional layer of barriers/enclosures shall be non-conductive.

NOTE Chassis-bonded voltage class B systems are currently not supported by the SAE in the USA.

7.4 Complementary or alternative approach to protection measures against electric shock

Complementarily to the selection of the protection measures as prescribed in 7.2 and 7.3, the following approach may be applied to establish sufficient protection for persons against electric shock. This approach may also be applied to develop alternative protection measures more specific to the conditions of a given fuel cell vehicle design.

The vehicle manufacturer shall conduct an appropriate hazard analysis in respect to electric shock and establish a set of measures which give sufficient protection against electric shock. This analysis may use a FMEA (failure mode and effect analysis), a FTA (fault tree analysis), or another appropriate method, and shall consider normal (fault free) and any first failure conditions relevant for electric shock hazards. The failure conditions shall not only comprise the normal operational and environmental conditions of the vehicle, but also specific conditions as exposure to water.

This approach also makes it possible to determine the requirements for components and systems being integrated into the vehicle during assembly as units, so that such components and systems can be designed, manufactured and tested accordingly.

8 Test methods and requirements for the protection measures against electric shock

8.1 General

The verification of the protection measures according to Clause 7 shall be performed on each voltage class B electrical circuit on the vehicle.

If the safety aspects in relation to the whole vehicle are not affected, the tests may be performed on components or parts of the circuits individually instead.

8.2 Insulation

8.2.1 General

If protection is provided by insulation, the live parts of the electric system shall be totally encapsulated by insulation which can be removed only by destruction.

The insulating material shall be suitable to the maximum working voltage and temperature ratings of the FCV and its systems (see also Clause 4).

The insulation shall have sufficient insulation resistance, if required, and withstand voltage capability. Compliance is checked by tests in 8.2.2, 8.2.3 and 8.2.5.

8.2.2 Insulation resistance measurement of the balance of fuel cell power system

For the measurement of the insulation resistance between the balance of power system of the voltage class B circuits and their conductive parts, the electric power sources of these circuits (fuel cell stacks, traction batteries) shall be disconnected at their terminals, and the live parts shall be disconnected from the electric chassis, if the circuits are chassis-bonded.

Prior to the measurement, the equipment shall be subjected to a preconditioning period of at least 8 h at (5 ± 2) °C, followed by a conditioning period of 8 h at a temperature of (23 ± 5) °C, a humidity of ($90\ ^{+10}_{-5}$) %, and an atmospheric pressure between (86 to 106) kPa.

Alternative preconditioning and conditioning parameters may be selected, provided transition across the dew point occurs shortly after the beginning of the conditioning period.

The insulation resistance shall be measured periodically throughout the conditioning period.

For each voltage class B electric circuit, the test voltage shall be applied as follows:

— connecting the live parts of the balance of fuel cell power system to each other;

— connecting all conductive parts, including the electric chassis, to each other;

— applying the test voltage between the connected live parts and the connected conductive parts.

NOTE Measurements on exposed insulation layers are normally performed on the affected components outside the vehicles, according to procedures as specified in e.g. ISO 6722 or in ISO 14572 for cables.

For the measurement of the insulation resistance between the balance of fuel cell power system of the voltage class B circuits and the auxiliary electric circuits, the batteries of the auxiliary electric circuits shall be disconnected, and the live parts of the auxiliary electric circuits shall be connected.

The test voltage shall be applied between the connected live parts of the voltage class B circuits and the connected live parts of the auxiliary electric circuits.

The measurements shall be performed using suitable instruments.

The test voltage shall be at least the open circuit voltage of the fuel cell power system and be applied for a time long enough to obtain stable reading.

8.2.3 Insulation resistance measurement of the voltage class B electric power sources

For the measurement of the insulation resistance of the fuel cell stack, the entire mechanical structure of the fuel cell system (including the cooling system with its cooling medium) shall be considered.

Prior to the measurement, power generation shall be stopped after operation at maximum output according to the manufacturer's specification. The voltage across the fuel cell stack power terminals shall be discharged. All cables shall be disconnected from the fuel cell stack power terminals, and all other cables from other electric terminals of the fuel cell stack. All cooling pipes, fuel pipes, air pipes shall remain connected.

Apart from these specific conditions, the procedure shall be performed as given in 8.2.2.

The measurement of the insulation resistance of a traction battery, if any, shall be conducted as specified in ISO 6469-1.

8.2.4 Insulation resistance requirements

If the protection means chosen requires a minimum insulation resistance, it shall be a minimum of 100 Ω/V for each voltage Class B circuit. To meet this requirement, it may be necessary to have higher insulation resistance for each component, depending on the number of the components and the structure of the circuit they belong to.

8.2.5 Voltage withstand capability

8.2.5.1 General

The voltage class B systems shall be designed according to IEC 60664-1 or a voltage withstand test shall be performed as described below.

8.2.5.2 Voltage withstand test

8.2.5.2.1 Purpose

This test is intended to demonstrate the adequacy of the protection measures to isolate live parts under normal conditions for the following components: harnesses, bus bars and connectors.

8.2.5.2.2 Test description

An a.c. voltage of a frequency between 50 Hz and 60 Hz or an equivalent d.c. voltage (see below) shall be applied for one minute

- between terminals and housing with electrically conductive surface with galvanic isolation, and
- between terminals and an electrode wrapped around the housing (for example metal foil, sphere bath) in the case of plastic housing.

Neither dielectric breakdown nor flashover shall occur during the test.

The a.c. test voltage shall be V rms 2 U + 1 000 where U (in V) is the maximum working voltage across the isolating parts.

NOTE This test voltage may be subject to reduction pending further investigation of the voltage transients in the systems of vehicles with a fuel cell propulsion system.

The equivalent d.c. test voltage is 1,41 times the a.c. rms value.

8.3 Requirements for barriers/enclosures

8.3.1 General

If protection is provided by barriers/enclosures, live parts shall be placed inside enclosures or behind barriers, preventing access to the live parts from all sides.

The barriers/enclosures shall provide sufficient mechanical resistance under normal operating conditions, as specified by the manufacturer.

If barriers/enclosures are accessible directly, they shall be opened or removed only by use of special tools or maintenance keys.

The insulation resistance and voltage withstand tests as in 8.2.2 through 8.2.5 shall include barriers/enclosures, if affected, unless evaluations prove otherwise.

Continuity of the connections to the vehicle chassis shall meet the requirements of 8.3.3.

Depending on the size of (intended) openings in the barriers/enclosures (e.g. for venting purposes) and the distance to the live parts, a certain degree of protection (IP Code) as specified in ISO 20653 shall be met (see 8.3.2).

See 6.1 for marking of barriers/enclosures.

8.3.2 Protection degrees for barriers/enclosures

Barriers/enclosures accessible directly shall at least comply with the requirements of IPXXD, if they cover components of voltage class B circuits. In other cases, lower IP degrees (IPXXC or IPXXB) may be sufficient, if a risk analysis applied to the barrier/enclosure shows only a minimal shock risk.

8.3.3 Continuity requirements for potential equalization

A current of 25 A d.c. derived from a source having a no-load voltage not exceeding 60 V d.c. shall be passed between any two exposed conductive parts for at least 5 s.

The voltage drop between any two exposed conductive parts shall be measured.

The resistance calculated from the current and this voltage drop shall not exceed 0,1 Ω.

Bibliography

[1] ISO 6722, *Road vehicles — 60 V and 600 V single-core cables — Dimensions, test methods and requirements*

[2] ISO 14572, *Road vehicles — Round, unscreened 60 V and 600 V multicore sheathed cables — Test methods and requirements for basic and high performance cables*

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