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Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



22/398/CD

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SECRETARIAT:

Switzerland

SECRETARY:

Ms Chuanhong Zhao

OF INTEREST TO THE FOLLOWING COMMITTEES:

TC 8,TC 9,SC 17A,TC 18,TC 31,TC 44,TC 82,TC 88,TC 99,TC 114,TC 120

HORIZONTAL FUNCTION(S):

TC 22 Horizontal Group Safety

ASPECTS CONCERNED:

Safety

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TITLE:

Safety requirements for power electronic converter systems and equipment - Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SAFETY REQUIREMENTS FOR POWER ELECTRONIC
CONVERTER SYSTEMS AND EQUIPMENT –****Part 2: Power electronic converters from 1 000 V AC or
1 500 V DC up to 36 kV AC or 54 kV DC**

FOREWORD

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International Standard IEC 62477-2 has been prepared by IEC technical committee 22: Power electronic systems and equipment.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
22/290/FDIS	22/293/RVD

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

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

It has the status of a group safety publication in accordance with IEC Guide 104.

321 This International Standard is to be used in conjunction with IEC 62477-1:2012 and
322 IEC 62477-1:2012/AMD1:2016.

323 This document supplements or modifies the corresponding clauses in IEC 62477-1:2012 and
324 IEC 62477-1:2012/AMD1:2016. Where this document states "addition", "modification" or
325 "replacement", the relevant requirement, test specification or explanatory matter in
326 IEC 62477-1:2012 and IEC 62477-1:2012/AMD1:2016 is adapted accordingly. Where no
327 change is necessary, this document indicates that the relevant clause or subclause applies.
328 Where this document states "does not apply" this clause of the mentioned version of IEC 62477-
329 1 does not apply to any section of the equipment. Products that are designed to be compliant
330 to IEC 62477-1:2012 and IEC 62477-1:2012/AMD1:2016 are acceptable as components within
331 the equipment designed to this document. Additional subclauses, tables and figures are
332 numbered starting at 101. Additional annexes are numbered with double capital characters,
333 starting with AA.

334 A list of all the parts in the IEC 62477 series, published under the general title *Safety*
335 *requirements for power electronic converter systems and equipment* can be found on the
336 IEC website.

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

- 340 • reconfirmed,
- 341 • withdrawn,
- 342 • replaced by a revised edition, or
- 343 • amended.

344

345

INTRODUCTION

This part of IEC 62477 relates to products that include power electronic converters, with a rated system voltage from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC. It specifies requirements to reduce risks of fire, electric shock, thermal, energy and mechanical hazards, except functional safety as defined in IEC 61508 (all parts). The objectives of this document are to establish a common terminology and basis for the safety requirements of products that contain power electronic converters across several IEC technical committees.

This document has been developed with the intention

- to be used as a reference document for product committees inside TC 22 in the development of product standards for power electronic converter systems and equipment;
- to replace IEC 62103 as a product family standard providing minimum requirements for safety aspects of power electronic converter systems and equipment in apparatus for which no product standard exists, and

NOTE The scope of IEC 62103 contains reliability aspects, which are not covered by this document.

- to be used as a reference document for product committees outside TC 22 in the development of product standards of power electronic converter systems and equipment intended for renewable energy sources. Especially TC 82, TC 88, TC 105 and TC 114 have been identified as relevant technical committees at the time of publication.

Technical committees using this document should carefully consider the relevance of each paragraph in this document for the product under consideration and reference, add, replace or modify requirement as relevant. Product specific topics not covered by this document are in the responsibility of the technical committees using this document as reference document.

This document will not take precedence on any product specific standard according to IEC Guide 104. IEC Guide 104 provides information about the responsibility of product committees to use group safety standards for the development of their own product standards.

The most significant differences compared to IEC 62477-1:2012 and IEC 62477-1:2012/AMD1:2016 are the following:

- this document extends the range of rated system voltages for high-voltage (HV) up to 36 kV AC or 54 kV DC;
- this document adds arc fault rating label requirements with testing instructions.

SAFETY REQUIREMENTS FOR POWER ELECTRONIC CONVERTER SYSTEMS AND EQUIPMENT –

Part 2: Power electronic converters from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC

1 Scope

This part of IEC 62477 applies to power electronic converter systems (PECS) and equipment, their components for electronic power conversion and electronic power switching, including the means for their control, protection, monitoring and measurement, such as with the main purpose of converting electric power, with rated system voltages from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC.

This document can also be used as a reference standard for product committees producing product standards for

- adjustable speed electric power drive systems (PDS),
- standalone uninterruptible power systems (UPS), and
- stabilized DC power supplies.

For PECS for which no product standard exists, this document provides minimum requirements for safety aspects.

This document has the status of a group safety publication in accordance with IEC Guide 104 for power electronic converter systems and equipment for solar, wind, tidal, wave, fuel cell or similar energy sources.

According to IEC Guide 104, one of the responsibilities of technical committees is, wherever applicable, to make use of basic safety publications and/or group safety publications in the preparation of their product standards.

This document

- establishes a common terminology for safety aspects relating to PECS and equipment,
- establishes minimum requirements for the coordination of safety aspects of interrelated parts within a PECS,
- establishes a common basis for minimum safety requirements for the PEC portion of products that contain PEC,
- specifies requirements to reduce risks of fire, electric shock, thermal, energy and mechanical hazards, during use and operation and, where specifically stated, during service and maintenance,
- specifies minimum requirements to reduce risks with respect to pluggable and permanently connected equipment, whether it consists of a system of interconnected units or independent units, subject to installing, operating and maintaining the equipment in the manner prescribed by the manufacturer,
- establishes an arc fault rating label requirement with testing instructions for PEC and PECS, and
- covers power electronic converters and systems in open type design, which are catalog (pre-defined commercially available) power electronic converters and systems or engineered solutions from same.

This document does not cover

- telecommunications apparatus other than power supplies to such apparatus,
- functional safety aspects as covered by, for example, IEC 61508 (all parts),
- electrical equipment and systems for railways applications and electric vehicles, and
- power electronic converters and systems in open type design, which are – in their major part – dimensioned, designed and constructed according to the user's individual requirements and specifications and follow power installation standards, for example IEC 61936-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

IEC 60204-11, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV*

IEC 60417, *Graphical symbols for use on equipment* (available at <http://www.graphical-symbols.info/equipment>)

IEC 60617, *Graphical symbols for diagrams* (available at <http://std.iec.ch/iec60617>)

IEC 60730-1, *Automatic electrical controls – Part 1: General requirements*

IEC 61230, *Live working – Portable equipment for earthing or earthing and short-circuiting*

IEC 62271-102, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*
IEC 62477-1:2012/AMD1:2016

IEC Guide 104, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC Guide 51:2014, *Safety aspects – Guidelines for their inclusion in standards*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62477-1: 2022 apply, except as follows.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.24 mains supply

Replacement:

power distribution system that supply power to a PEC or PECS

Note 1 to entry: The voltage level can be any voltage within the range between 0 V and 36 kV AC or 54 kV DC.

3.27 open type

Addition:

Note 1 to entry: Open type HV equipment can also be installed behind a barrier, fence, building structure, etc. which is intended to provide the same protection as an enclosure.

Additional terms and definitions:

3.101 high voltage PEC or PECS HV PEC or PECS

PEC or PECS with a system voltage from 1 000 V AC or 1 500 V DC up to 36 kV AC or 54 kV DC

3.102 operator access area

area for which, under normal operating conditions,

- a) access is gained without the use of a tool, or
- b) the means of access is deliberately provided to the operator, or
- c) the operator is instructed to enter regardless of whether or not tools are needed to gain access

Note 1 to entry: In this document, the terms "access" and "accessible", unless qualified, relate to operator access as defined above.

4 Protection against hazards

4.1 General

4.1 of IEC 62477-1:2022 applies, except as follows.

Addition:

This document is written primarily addressing equipment contained within an enclosure. This document makes allowance for its usage with open type equipment. It is recommended when using this document for open type equipment to also use an installation standard (see IEC 61936-1).

If the manufacturer allows continued operation after a single fault, the manufacturer is responsible to provide all appropriate safety information in the product documentation (see 6.5.1.3).

4.2 Single fault conditions and abnormal operating conditions

4.2 of IEC 62477-1:2022 applies, except as follows.

Replacement of paragraph 3

This analysis shall include situations where a *single fault condition* in any *component*, *basic protection* (including *insulation systems*), *fault protection* or *port* would result in:

4.3 Short-circuit and overload protection

4.3.1 General

4.3.1 of IEC 62477-1:2022 does not apply.

Replacement:

To comply with the requirements defined in 4.2, the *PECS* shall not present a hazard under short-circuit or overload conditions (further referred as *fault*) at any power *port*, including phase to phase, phase to earth and phase to neutral. Adequate information shall be provided in the documentation to allow proper selection of *installation* wiring and protective devices external of the *PECS*, see IEC 61936-1, considering the automatic disconnection of supply in 4.4.4.4.

If a protective system or protective device is required for short-circuit or overload protection, it shall be provided or specified.

For marking, see 6.3.9.6.

Protection against *overcurrents* shall be provided for all *ports* except

- for *ports* that comply with the requirements for limited power sources in 4.6.5, or
- if the *PECS* complies with all normal operating conditions, *abnormal operating conditions* and *single-fault conditions* in this document without such protection provided.

NOTE 1 In this document, the term *overcurrent* covers both, short-circuit and overload.

NOTE 2 Local *installation* codes will still usually require provision of such protection for the purposes of protecting the input wiring in the *installation*. In some cases, it is possible local *installation* codes supersede requirements of this document.

When protection against *overcurrents* is required, this may be integral to the *PECS* or it may be provided in the *installation*, and details of the required *overcurrent* protective device shall be provided in the *PECS* installation instructions in accordance with 6.3.9.6.

No protection is required against *overcurrent* to earth on *ports* that have either

- no connection to earth, or
- *enhanced protection* between *live parts* and all conductive parts connected to earth.

NOTE 3 Under a *single-fault condition* in an IT-system, no short-circuit current or a limited short-circuit current will flow. A short-circuit current would flow in an IT-system, when a second fault occurs. Typically, only detection is done after the first fault in an IT-system.

NOTE 4 Where *enhanced protection* is provided, a short-circuit to earth would be considered to be two faults.

Testing is not required under a *single-fault condition* to earth in *PECS* installed on an IT-system.

For *pluggable equipment type A*, the protective device is provided in the *installation* and shall not require any specific characteristics other than that required in IEC 60364 or other local *installation* codes.

For *pluggable equipment type B* or *permanently connected equipment*, this protection may be provided by devices external to the *PECS*, in which case the installation instructions shall state the need for the protection to be provided in the *installation* and shall include the specifications for the required short-circuit and/or overload protection (see 6.3.9.6).

NOTE 5 IEC 60364 provides requirements for short-circuit and overload protection of the input wiring in the installation. The above requirement ensures that the user is informed about any special characteristics of the protective devices for the protection of the PECS, in addition to the requirements in IEC 60364 or other local installation codes.

If a protective device interrupts the neutral conductor, it shall also simultaneously interrupt all other supply conductors of the same circuit. It is permissible for the protective device to interrupt the neutral conductor after the other supply conductors of the same circuit.

Consideration shall be given to compliance with

- different type of earthing system (e.g. TN, TT, IT, star or corner-earthed in 4.4.7.1.5) as the short-circuit current to protective earth depends on the type of earthing system,
- automatic disconnection of supply in 4.4.4.4.1,
- disconnection time in 4.4.4.4.2 as required in IEC 60364-4-41:2005 and IEC 60364-4-41:2005/AMD1:2017, 411.3.2, (see Annex T), and
- alternative to automatic disconnection of supply in 4.4.4.4.3.

NOTE 6 IEC 60364-4-41:2005 and IEC 60364-4-41:2005/AMD1:2017, 411.3.2, provides more information about protection against indirect contact in case of a short-circuit between *hazardous live parts* and protective earth.

NOTE 7 The short-circuit fault current to earth is expected to be up to the rated short-circuit current of the output power *port* depending on earthing system.

4.3.2 Input short-circuit withstand strength and output short-circuit current ability

4.3.2.1 General

4.3.2.1 of IEC 62477-1:2022 applies.

4.3.2.2 Conditional short-circuit current (I_{cc}) on input ports

4.3.1 of IEC 62477-1:2022 applies, with additions.

After last paragraph:

If the available fault energy, either perspective short circuit current, or maximum let-thru from a protective device, is not achieved with the tests in 5.2.4.4 and 5.2.4.6, then the test of 5.2.4.4 shall be repeated at a location in the circuit upstream of the output port which creates the worst case condition on the input section of the PECS to ensure proper validation of the input short-circuit rating.

Note: the *minimum required prospective short circuit current* ($I_{cp,mr}$) may be zero for certain applications.

4.3.2.3 Short-time withstand current (I_{cw}) on input ports

4.3.2.3 of IEC 62477-1:2022 does not apply.

4.3.2.4 Output short-circuit current ability

4.3.2.4 of IEC 62477-1:2022 applies.

4.3.2.5 Combined input and output ports

4.3.2.5 of IEC 62477-1:2022 applies.

4.3.3 Short-circuit coordination (backup protection)

4.3.3 of IEC 62477-1:2022 only applies to LV supplied sections; however additional requirements are added for HV supplied sections below.

For HV PECS short-circuit coordination is provided by the site-installation. Please reference IEC 61936-1 for information on this topic.

The HV PECS manufacturer shall provide information within their documentation defining all protective devices required by the manufacturer to ensure safety of the PECS for installation, commissioning, operation, etc.

4.3.4 Protection by several devices

4.3.4 of IEC 62477-1:2022 applies with exception

Exception

It is allowed to use separate locations for these devices under the following condition. Proper documentation and labelling shall be provided which ensures the protective devices can be easily located, allowing appropriate manual replacement, or resetting steps, see 6.5.102, the marking of 6.5.6 of IEC 62477-1:2022 does not apply for the exception.

4.3.5 Replaceable fuses in neutral of single phase PECS

Applicable for LV PECS only:

Where both of the following conditions exist.

- a fuse is used in the neutral of single-phase *PECS* either *permanently connected* or provided with a non-reversible plug;
- after operation of the fuse, parts of the *PECS* that remain energized might represent a hazard during servicing.

A suitable marking shall be provided in the documentation to inform a *skilled person* of a possible hazard, see 6.5.6.

4.4 Protection against electric shock

4.4.1 General

4.4.1 of IEC 62477-1:2022 does not apply.

Replacement:

Protection against electric shock depends on the *decisive voltage class* from 4.4.2 and protection requirements from 4.4.2.7 and shall be provided by at least one of the following means:

- *basic protection* from 4.4.3 in combination with *fault protection* from 4.4.4; or
- *enhanced protection* from 4.4.5.

Protection under normal operating conditions is provided by *basic protection*, and protection under *single fault conditions* is provided by *fault protection*.

Enhanced protection provides protection under both normal operating conditions and *single fault conditions*.

For the use of means of *basic protection* in combination with *fault protection* and *enhanced protection*, see 4.4.6 for different constructions.

Basic protection, *fault protection* and *enhanced protection* may be achieved by means of

- *clearance* and *creepage distances* (4.4.7.4 and 4.4.7.5);
- *solid insulation* (4.4.7.8);
- *protection* by means of *enclosure* and barriers (4.4.3.3); or
- a combination of those means.

Clause A.6 provides an overview of the fundamental concept for protection against electric shock according to IEC 61140:2016.

Where not stated otherwise in this document, protection against electric shock is based on the body reaction *ventricular fibrillation*.

Additional protection according to IEC 61140:2016 can be provided by residual current-operated protective devices (RCD). For further information, see 4.4.8.

NOTE1 In this document, 4.4.1 to 4.4.6 have been harmonized with the concepts of the horizontal standard IEC 61140:2016 for protection against electric shock. *Basic protection*, *fault protection*, *enhanced protection* and the combination of those means have been implemented.

NOTE2 DVC D is added as clause 4.4.2.101 to preserve the existing numbering structure of IEC 62477-1:2022

4.4.2 Decisive voltage class

4.4.2.1 General

4.4.2.1 of IEC 62477-1:2022 applies, except as follows.

Addition:

DVC D is the fourth type.

4.4.2.2 DVC As

4.4.2.2 of IEC 62477-1:2022 applies.

4.4.2.3 DVC B

4.4.2.3 of IEC 62477-1:2022 applies.

4.4.2.4 DVC C

4.4.2.4 of IEC 62477-1:2022 applies.

4.4.2.101 DVC D

New clause:

DVC D circuit shall meet the requirements of:

- the voltage limits according to Table 2;
- protection of persons and protection to the surroundings and *adjacent circuits* according to Table ; and

- an *impulse withstand voltage* and *temporary overvoltage* according to Table 101 determined by the requirements of Table 3.

The protection requirements to other *DVC D* circuits shall be based on the consequence of a *single fault condition* (see 4.2). The protection shall be based on the highest *working voltage* and *impulse withstand voltage*.

4.4.2.5 Interconnection of external SELV/PELV to DVC As circuits

4.4.2.5 of IEC 62477-1:2022 applies.

4.4.2.6 Determination of decisive voltage class (DVC)

4.4.2.6 of IEC 62477-1:2022 replace with

4.4.2.6.1 General

The *decisive voltage class (DVC)* is used to determine the required level of protection from circuits to their surroundings in Table . For determination of the *working voltage*, see 4.4.7.1.2.

4.4.2.6.2 Limits of the working voltage for the DVC

Limits for the *working voltage* depending on the *DVC* for normal operating conditions, *abnormal operating conditions* and *single-fault conditions* are given in Table .

Examples for determination of the *DVC* are given in Clause A.5.1.

Table 2 – Voltage limits for the *decisive voltage classes DVC*

<i>DVC</i> ^e	Limits of <i>working voltage</i>				
	During normal operation conditions				During <i>single fault conditions</i> and <i>abnormal operating conditions</i>
	V				V
	AC voltage (RMS) U_{AC}	AC voltage (peak) U_{peak}	DC voltage (mean) U_{DC}	Impulse withstand voltage U_{peak}^c	Voltage (AC peak or DC) ^b
<i>DVC As</i> ^d (wet and salt water-wet)	6	8.5	15	800	see Figure and Figure 1b
<i>DVC As</i> ^f (dry)	25 (30)	35,4 (42,4)	60		
<i>DVC B</i>	50	71	120	According to Table 101 ^a	
<i>DVC C</i>	1 000	4 500 ^g	1 500	According to Table 101 ^a	
<i>DVC D</i>	No Limit	No Limit	No Limit	According to Table 101 ^a	--

- ^a For *non-mains supply*, see 4.4.7.2.4.
- ^b Single pulses relate to DC voltage limits and repetitive pulses relate to AC voltage limits.
- ^c Maximum transients with the 1,2/50 µs impulse characteristic as design criteria. Refer to Table 101.
- ^d Values are derived from IEC 61140:2016, 5.2.6.
- ^e For climatic conditions, refer to 4.9.
- ^f Values in brackets are permitted if only one circuit is provided or circuits are not simultaneously *accessible*.
- ^g The value of 4 500 V allows all low-voltage products to be covered by this document (possible reflections up to $3 \times \sqrt{2} \times 1\,000\text{ V} = 4\,242\text{ V}$).

673

674 Note: The values in Table 2 Row DVC As (wet and salt water-wet) are being further considered within IEC TC64 as
675 it has been determined that the 6V AC level is considered hazardous only under a combination of all of the following
676 conditions, which need to be more specifically delineated:

677 In a wet environment defined by AD7, and AD8 (immersed and submerged respectively), and

678 When a large portion of the human body can be exposed to the circuit, and

679 When the duration of time the body can be exposed is extended.

680 This JMT 10 will closely follow the pending change in standards like IEC 61140 and make the appropriate changes
681 as this new information defined in this note are released. Please see IEC documents 64/2678A/CD and 64/2694/DC.

682

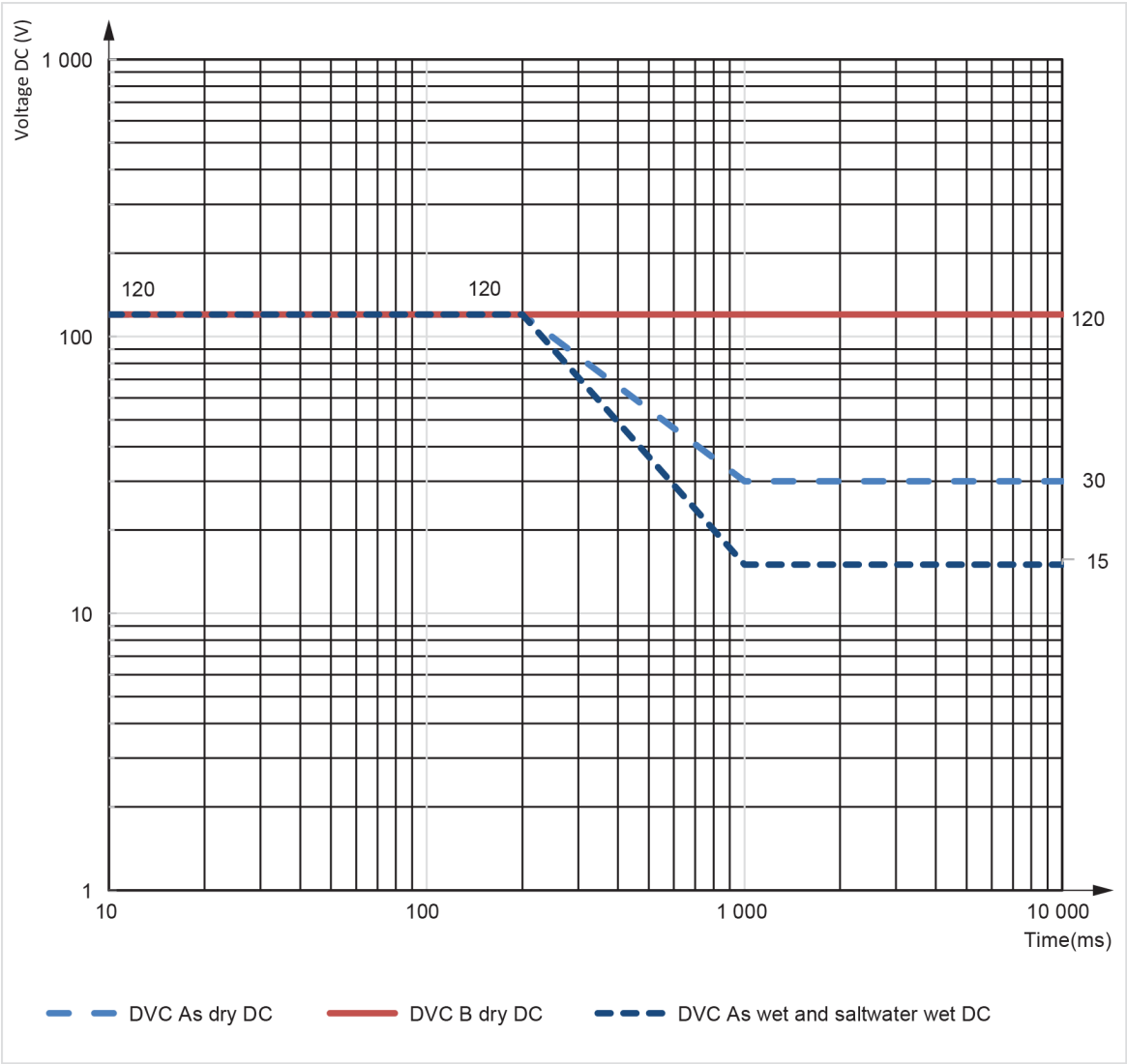


Figure 2a – Time-voltage zones for accessible circuits of DVC As and DVC B – DC during single fault conditions

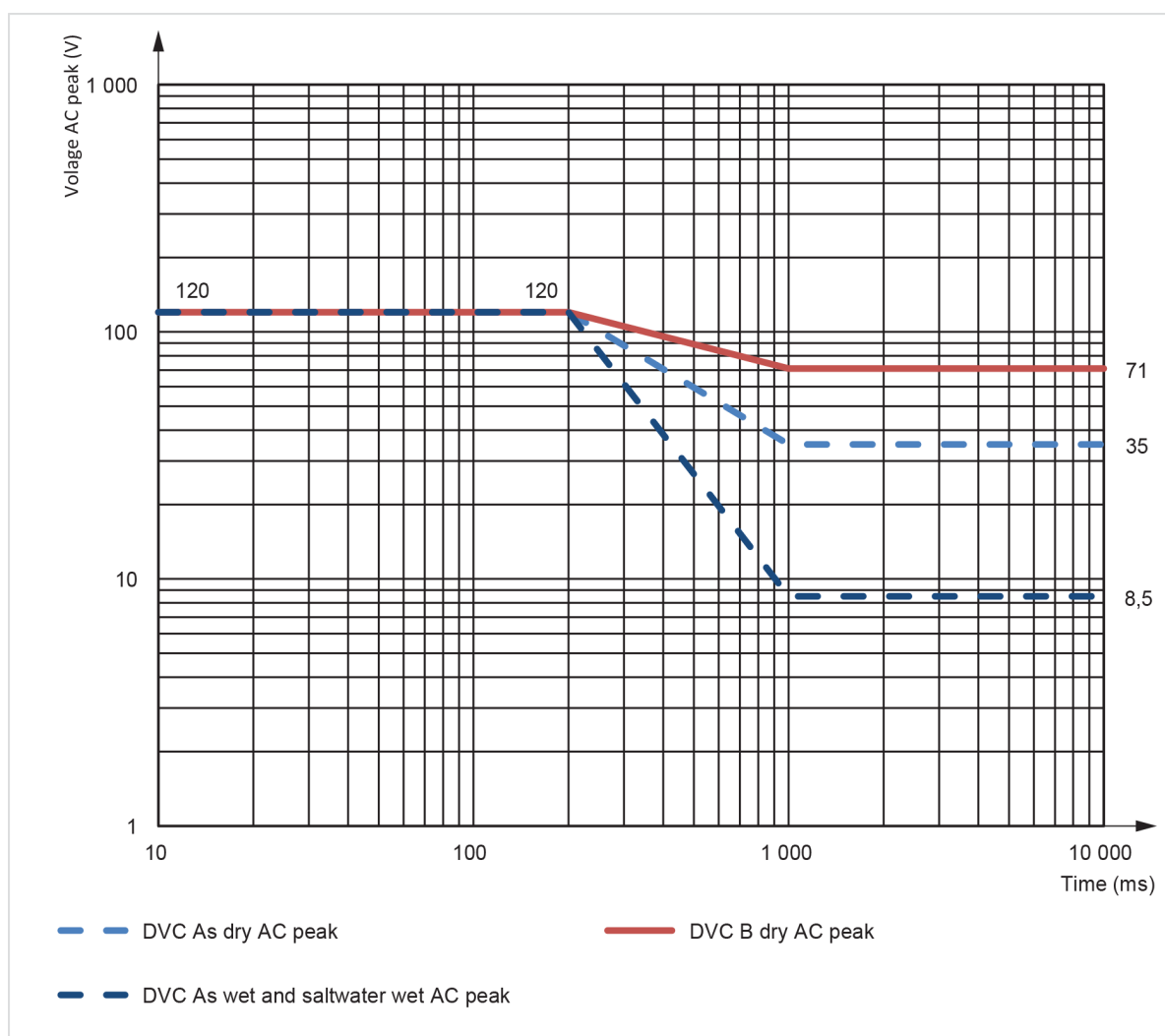
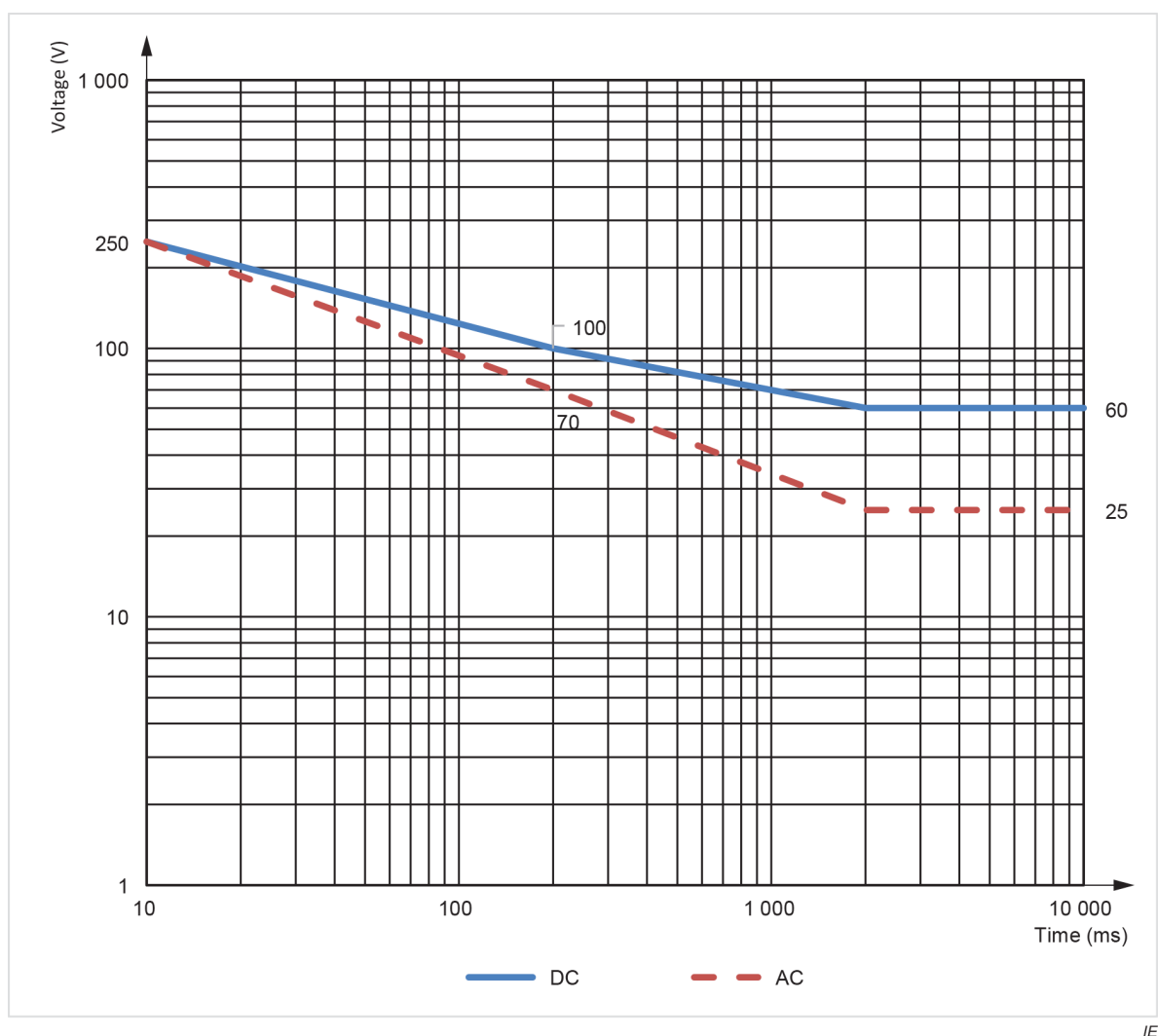


Figure 1b – Time-voltage zones for accessible circuits of DVC As and DVC B – AC peak during single fault conditions

NOTE DC voltage limits in Figure provide information about risk of internal burn of the human body considered just as harmful as the AC voltage. Figure 1b provides information about the limits for ventricular fibrillation which only apply to AC voltages.



IEC

Figure 2c – Time-voltage zones for conductive accessible parts during single fault conditions

4.4.2.7 Requirements for protection against electric shock

4.4.2.7 of IEC 62477-1:2022 applies with replacement of Table 3.

Table 3 – Minimum protection requirements for circuit under consideration

DVC of circuit under consideration	Protection to conductive accessible parts connected to PE	Protection to conductive accessible parts not connected to PE ^c	Protection to adjacent circuit				
			As Wet	As Dry	B	C	D
As Wet	None 1 or 3	None 1	1 ^a or 2 ^b	Basic protection	Basic protection	Enhanced protection	Enhanced protection
As Dry	None 1 or 3	None 1	--	1 ^a or 2 ^b	Basic protection	Enhanced protection	Enhanced protection

B	<i>Basic protection</i> ^d	<i>Basic protection</i> ^d	--	--	1 ^a or 2 ^b	<i>Enhanced protection</i> ^e	<i>Enhanced protection</i>
C	<i>Basic protection</i>	<i>Enhanced protection</i>	--	--	--	2	<i>Enhanced protection</i>
D	<i>Basic protection</i>	<i>Enhanced protection</i>	--	--	--	--	2
<i>Basic protection</i> , see 4.4.3.2.							
<i>Enhanced protection</i> , see 4.4.5.							
The row "As Wet" covers <i>DVC As wet</i> and <i>DVC As salt water wet</i> .							
1	Protection is not necessary for safety, but may be required for functional reasons according to 4.4.7.3.						
2	<i>Basic protection</i> for circuit of higher voltage.						
3	If the considered circuit is designated as a <i>SELV</i> circuit, <i>basic protection</i> is required from earth and from <i>PELV</i> circuits.						
1 or 2	Depending on separation with other circuits.						
NOTE The protection requirements in this table consider that <i>DVC C</i> and <i>DVC D</i> can be connected to mains supplies.							
^a Both circuits under consideration have the same voltage level.							
^b Both circuits under consideration have different voltage level.							
^c Also applies to conductive parts connected to functional earth.							
^d There are no protection requirement for <i>DVC B</i> to <i>accessible parts</i> in <i>service-access areas</i> or <i>restricted-access areas</i> , and refer to 4.4.3.3 and 4.11.1 for requirements about accessibility and <i>insulation</i> requirements for cable.							
^e For circuits within the voltage limits of <i>DVC B</i> which do not comply with 4.4.2.3 second bullet, it is permitted to use <i>basic protection</i> for the circuit of higher voltage if protection against direct contact is applied to the <i>DVC B</i> circuit.							

699

700 4.4.3 Means for *basic protection* (protection against direct contact)

701 4.4.3.1 General

702 4.4.3.1 of IEC 62477-1:2022 applies.

703 4.4.3.2 Protection by means of basic insulation of hazardous live parts

704 4.4.3.2 of IEC 62477-1:2022 replaced with

705 *Basic insulation* shall be provided by means of

- 706 • *solid insulation*; or
- 707 • *clearance and creepage distances* in combination with means of *enclosures* or barriers
- 708 according to 4.4.3.3.

709 The *insulation* shall be rated according to the *impulse withstand voltage*, *temporary overvoltage*

710 or *working voltage* (see 4.4.7.2.1), whichever gives the most severe requirement.

711 It shall not be possible to remove the *insulation* without the use of a tool or key.

712 A conductive *accessible part* is considered to be conductive if its surface is bare or is covered

713 by an insulating layer that does not comply with the requirements of at least *basic insulation*.

Any conductive *accessible part* is considered to be a *hazardous live part* if not separated from the *live parts* by at least the minimum protective requirements specified in Table and any additional applicable requirements in this document.

The *basic insulation* shall be designed and tested according to the *impulse withstand voltages* and *temporary overvoltages* for the circuits to which they are connected.

Compliance is shown by test of 5.2.3.2 and 5.2.3.4.

4.4.3.3 Protection by means of enclosures or barriers

4.4.3.3 of IEC 62477-1:2022 replace with

4.4.3.3.1 General

Hazardous live parts shall be arranged in *enclosures* or located behind barriers which comply at least with the requirements of IP2X according to IEC 60529.

NOTE The intention to require IP2X instead of IPXXB is to limit the size of openings to less than 12,5 mm in minor dimension, as otherwise openings of up to Ø 50 mm (or 20 mm minor dimension irrespective of length) can be permitted. 12,5 mm is required to protect against solid foreign objects.

It shall only be possible to open *enclosures* or remove barriers:

- with the use of a tool or key, or
- after de-energization of these *hazardous live parts*.

Examples for openings in *enclosures* are provided in **A.6.2** and **Table A.1**.

For testing, see 5.2.2.2 and 5.2.2.3.

4.4.3.3.2 Service-access areas

Products containing circuits of DVC B, DVC C or DVC D, where the protection against electric shock is provided by the service-access area, do not need to have protective measures for basic protection. It shall be required to use a tool or a key for access to the area, and compliance with a) or b) is required.

a) The marking requirements of 6.3.9.1.1 shall apply; and

– accessible hazardous live parts shall be protected by at least IPXXA; and

– hazardous live parts that are likely to be touched when making adjustments shall be protected by at least IPXXB.

b) The marking requirements of 6.3.9.1.1 and 6.3.9.1.2 shall apply.

4.4.3.3.3 Restricted access area

Products containing circuits of DVC B or DVC C and intended for installation in restricted access areas only do not need to have protective measures for basic protection, but require the use of a tool or a key for access to the area and shall be marked according to the requirements of 6.3.9.1.

Products containing circuits of DVC D and intended to be in a restricted-access area have additional requirements in 4.4.101.

4.4.3.3.4 Open type PEC and sub-assemblies

Open type PEC and sub-assemblies do not require protective measures for *basic protection*. This information provided with the *PEC* shall indicate that protection shall be provided in the *installation*.

For marking, see 6.2.1 and 6.3.6.

4.4.3.3.5 Top surfaces of enclosures or barriers

4.4.3.3.5.1 General

Top surfaces of *enclosures* or barriers, which are accessible when the *PECS* is energized and below which *hazardous live parts* are located, shall fulfill the requirements of IPXXC.

NOTE Top surfaces are the projection of surfaces from vertical.

For marking, see 6.3.2.

For *PECS* with no defined top surface or that are *movable*, the requirement of IPXXC applies to all reasonably possible top surfaces.

See 5.2.2.2 for test.

4.4.3.3.5.2 Protection against vertical falling objects

Openings in *enclosures* or barriers shall be located or constructed so that it is unlikely for vertical falling objects to enter the *enclosure* and create an electrical hazard.

Any opening shall be less than 2,5 mm in minor dimension unless an analysis according to 4.2 can prove that the construction provides adequate protection.

A ventilation opening in the top surface of a *PEC* that is not *open type* shall be covered by a hood or protective shield spaced above the opening when there are *uninsulated live parts* below the opening.

NOTE In USA and Canada, this applies to Type 1 *enclosure*.

For *movable PECS* with no defined top and bottom, this requirement applies to all sides.

Compliance is checked by *visual inspection* in 5.2.1.

For marking, see 6.3.2.

4.4.4 Means for fault protection (protection against indirect contact)

4.4.4.1 General

4.4.4.1 of IEC 62477-1:2022 applies.

4.4.4.2 Protective equipotential bonding (circuit)

4.4.4.2.1 General

4.4.4.2.1 of IEC 62477-1:2022 applies.

4.4.4.2.2 Rating of protective equipotential bonding

4.4.4.2.2 of IEC 62477-1:2012 applies with addition.

Third bullet added to b)

- to ensure no voltage drop exceeding the limits of *DVC* As in 4.4.2.2 and Figure 4 of IEC 62477-1:2022 during normal operating conditions and during a fault.

4.4.4.3 PE conductor**4.4.4.3.1 General**

4.4.4.3.1 of IEC 62477-1:2022 applies, except as follows.

Addition:

See IEC 61936 for HV installation.

For IT systems, the manufacturer may consider designing the PE conductor following 4.4.4.2.2.

NOTE 1 For IT systems not operating under earth fault condition, the prospective short-circuit current can be low, because the only path of the current is through parasitic capacitance and leakage resistance and is not driven by any shorted supply. This could allow for reducing the size of the earth conductor. Reduction of the earth conductor can be enhanced by monitoring of earth faults and appropriate circuit disconnection to avoid damage to the earth conductor.

NOTE 2 When considering the sizing of the PE conductor, the installer follows local regulations.

4.4.4.3.2 Means of connection for the PE conductor

4.4.4.3.2 of IEC 62477-1:2022 applies.

4.4.4.3.3 Requirements for reinforced PE conductor**4.4.4.3.3.1 General**

4.4.4.3.3.1 of IEC 62477-1:2022 applies.

4.4.4.3.3.2 PECS designed as pluggable equipment type A

4.4.4.3.3.2 of IEC 62477-1:2022 applies.

4.4.4.3.3.3 PECS designed as pluggable equipment type B and permanently connected equipment

4.4.4.3.3.3 of IEC 62477-1:2022 applies.

4.4.4.3.3.4 High leakage current conditions for permanently connected PECS

4.4.4.3.3.4 of IEC 62477-1:2022 applies with addition.

Inserted after “Note”

Local installation requirements apply in addition to this standard, e.g. IEC 61936-1.

4.4.4.4 Automatic disconnection of supply

4.4.4.4 of IEC 62477-1:2022 does not apply.

Replacement:

4.4.4.4.1 General

For automatic disconnection of supply in case of a failure of *basic insulation*,

- a *protective equipotential bonding system* shall be provided, and

- a protective device, for example fuse, circuit breaker, RCD, operated by the fault current shall disconnect one or more of the phase conductors supplying the *PECS*, as part of the *system* or *installation*.

The automatic disconnection of supply depends on an operable *protective equipotential bonding* (see 4.4.4.2) during the *expected lifetime*.

4.4.4.4.2 Interruption of the fault current within the required time

The protective device shall interrupt the fault current within a time as specified in 4.4.2.6.2 and 411.3.2.2, 411.3.2.3 and 411.3.2.4 of IEC 60364-4-41:2005 and IEC 60364-4-41:2005/AMD1:2017, which are reproduced in Clause T.1.

If the protective device is not part of the *PECS*, information for selection shall be given in the installation manual.

For test, see 5.2.4.5 (see also 4.3.1).

For marking, see 6.3.9.6.

Where it is not feasible for a protective device to interrupt the supply in accordance with IEC 60364-4-41:2005 and IEC 60364-4-41:2005/AMD1:2017, 411.3.2, or where the use of an RCD for this purpose is not appropriate, see 4.4.4.4.3.

However, disconnection may be requested for reasons other than protection against electric shock.

4.4.4.4.3 Automatic disconnection of supply is not feasible

In case that automatic disconnection is not feasible in conditions where

- PEC* with limited short-circuit current at the output power *port* is installed, or
 - the required disconnection times as specified in 4.4.4.4.2 cannot be achieved by a protective device, or
 - protection against other hazards is required (e.g. protection against thermal hazards in 4.6),
- one of the following means are applicable:

- 1) for *installations* with *PEC*, the voltage at the output power *port* shall be reduced to AC 50 V or DC 120 V or less by an electronic protection circuitry, which *trips* within the time specified in 4.4.4.4.2 in the event of a fault between a live conductor and the *PE conductor* or earth and the electronic protection circuitry is tested with a *type test* according to 5.2.4.5 and the verification according to 5.2.4.7,

NOTE 1 One example for "electronic protection circuitry, which *trips*" is an *electronic power output short-circuit protection circuitry*.

- 2) supplementary *protective equipotential bonding* shall be provided in accordance with 415.2 of IEC 60364-4-41:2005 and IEC 60364-4-41:2005/AMD1:2017, in which the voltage between simultaneously conductive *accessible parts* shall not exceed AC 50 V or DC 120 V.

NOTE 2 See Clause T.2.

NOTE 3 As an example, a motor is not supplied from a *mains supply*, but from a *PEC* output power *port* via a long motor cable. In case of a failure in the motor, the current can be too low to operate the automatic disconnection of supply in a required time due to either limitation of the output current at the output power *port* of the *PEC* by a current limiting circuitry or by the impedance of the motor cable.

NOTE 4 Typically, the maximum available continuous current at the output power *port* against earth can be used as value for I_a (see Clause T.2) for calculating the resistance of the supplementary *protective equipotential bonding*, to meet the voltage limits.

For marking, see 6.3.9.6.

872

873 **4.4.4.5 Supplementary insulation**

874 4.4.4.5 of IEC 62477-1:2022 applies.

875 **4.4.4.6 Basic protection between circuits**

876 4.4.4.6 of IEC 62477-1:2022 applies with addition.

877 Addition:

878 Paragraph 3 and 4 are only valid if one of the circuits being compared is accessible to persons.

879 **4.4.4.7 Electrically protective screening**

880 4.4.4.7 of IEC 62477-1:2022 applies.

881 **4.4.5 Means for enhanced protection**882 **4.4.5.1 General**

883 4.4.5.1 of IEC 62477-1:2022 applies with addition.

884 *Addition inserted as second sentence in first paragraph:*885 *Enhanced protection* shall be fully and effectively maintained under all conditions of intended
886 use of the PEC.887 **4.4.5.2 Double insulation**

888 4.4.5.2 of IEC 62477-1:2022 does not apply.

889 *Replacement:*890 *Double insulation* shall have two or more *insulations*, where at least one *insulation* shall meet
891 the requirement of *basic insulation* in 4.4.3.2 and another *insulation* shall meet the requirement
892 of *supplementary insulation* in 4.4.4.5.893 **4.4.5.3 Reinforced insulation**

894 4.4.5.3 of IEC 62477-1:2022 applies.

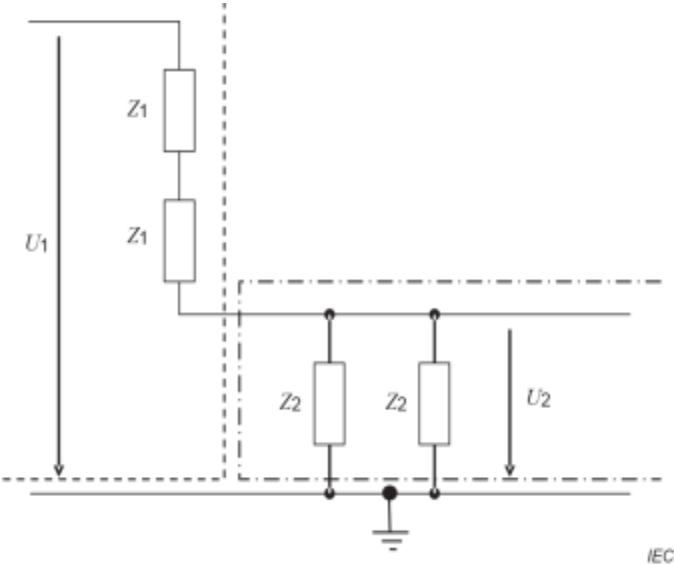
895 **4.4.5.4 Enhanced protection between circuits**

896 4.4.5.4 of IEC 62477-1:2022 applies.

897 **4.4.5.5 Protection by means of protective impedance**

898 4.4.5.5 of IEC 62477-1:2022 applies.

4.4.5.101 Protection by using limited voltages (source IEC 61800-5-1 clause A.4)



Key

- Z resistor
- U₁ hazardous voltage, earthed
- U₂ ≤ DVC As from Table 2.

To provide protection in *single-fault conditions*, use the following formulae:

$$U_2 = \frac{U_1 Z_2}{2Z_1 + Z_2}$$

or

$$U_2 = \frac{U_1 Z_2}{2(Z_1 + \frac{Z_2}{2})}$$

Figure 7A - Protection by using limited voltages

4.4.6 Protective means for equipment classes

4.4.6.1 General

4.4.6.1 of IEC 62477-1:2022 applies.

4.4.6.2 Protective means for PECS designed as class I equipment

4.4.6.2 of IEC 62477-1:2022 applies.

4.4.6.3 Protective means for PECS designed as class II equipment

4.4.6.3 of IEC 62477-1:2022 applies.

4.4.6.4 Protective means for PECS designed as class III equipment

4.4.6.4 of IEC 62477-1:2022 applies.

4.4.7 Insulation**4.4.7.1 Influencing factors****4.4.7.1.1 General**

4.4.7.1.1 of IEC 62477-1:2022 applies.

4.4.7.1.2 Working voltage

4.4.7.1.2 of IEC 62477-1:2022 applies.

4.4.7.1.3 Pollution degree

4.4.7.1.3 of IEC 62477-1:2022 applies.

4.4.7.1.4 Overvoltage category (OVC)

4.4.7.1.4 of IEC 62477-1:2022 applies.

4.4.7.1.5 Supply system earthing

4.4.7.1.5 of IEC 62477-1:2022 applies.

4.4.7.1.6 Determination of impulse withstand voltage and temporary overvoltage

4.4.7.1.6 of IEC 62477-1:2022 applies, except as follows.

Addition:

Table 101 applies.

Table 101 – Impulse withstand voltage and temporary overvoltage versus system voltage up to 36 kV AC or 54 kV DC

Column 1	2	3	4	5	6
System voltage (see 4.4.7.1.6) V AC	Impulse withstand voltage V				Temporary overvoltage ^a V Crest value/RMS
	Overvoltage category				
	I	II	III	IV	
≤ 50	330	500	800	1500	1770/1250
≤ 100	500	800	1500	2500	1840/1300
≤ 150	800	1500	2500	4000	1910/1350
≤ 300	1500	2500	4000	6000	2120/1500
≤ 600	2500	4000	6000	8000	2550/1800
≤ 1000	4000	6000	8000	12000	3110/2200
➤ 1000	4000	6000	8000	12000	4250/3000
3600	9000	16000	20000	40000	14150/10000
7200	17500	29000	40000	60000	28300/20000

12000	29000	42500	60000	75000	39600/28000
17500	40000	55000	75000	95000	53750/38000
24000	52000	75000	95000	125000	70700/50000
36000	75000	95000	125000	145000	99000/70000
Interpolation: ≤ 1000: Interpolation of <i>system voltage</i> is not permitted when determining the <i>impulse withstand voltage</i> for <i>mains supply</i>. Interpolation of <i>system voltage</i> is permitted when determining the <i>temporary overvoltage</i> for <i>mains supply</i>. Interpolation of <i>system voltage</i> is permitted when determining the <i>impulse withstand voltage</i> for <i>non-mains supply</i>. Interpolation of <i>system voltage</i> is permitted when determining the <i>temporary overvoltage</i> for <i>non-mains supply</i>. > 1000: Interpolation is permitted. SOURCE: IEC 62477-2:2018, Table 101.					
^a The RMS values are derived using the formula (1 200 V + <i>system voltage</i>) from IEC 60664-1:2020.					

4.4.7.1.7 Determination of the system voltage for mains supply and non-mains supply

4.4.7.1.7.1 For mains supply

4.4.7.1.7.1 of IEC 62477-1:2022 applies, except as follows.

Addition:

For HV PEC and PECS supplied by an AC mains supply, the system voltage is the r.m.s. value of the supply voltage between phases.

Exception:

Replace

“For *PECS* having series-connected rectifier bridges (12-pulse, 18-pulse, etc.), the *system voltage* for the determination of *impulse withstand voltages* is the highest RMS value of the AC voltage before rectification at the rectifier bridge taking into account the supply *system* earthing (TN, TT or IT).”

With

“For *PECS* having series-connected diode bridges (12-pulse, 18-pulse, etc.), the system voltage is the sum of the a.c. voltages at the diode bridges.” From the second to last paragraph of the clause.

Information regarding insulation coordination for HV systems can be found in IEC 60071 -5.

For *PECS* supplied by an DC mains supply, the system voltage (in column 1 of Table 7) is:

- For a symmetric monopole -- the rated DC voltage between a pole and earth;
- For an unsymmetric monopole -- the rated DC voltage between poles;

4.4.7.1.7.2 For non-mains supply

4.4.7.1.7.2 of IEC 62477-1:2022 applies with addition.

Addition:

For PECS having series-connected diode bridges (12-pulse, 18-pulse, etc.), the system voltage is the sum of the a.c. voltages at the diode bridges.

Voltages generated within the *PECS* by the secondaries of transformers providing galvanic isolation from the *mains supply* are also considered to be *system voltages* for the determination of *impulse withstand voltages*.

4.4.7.1.8 Components bridging insulation

4.4.7.1.7 of IEC 62477-1:2022 applies.

4.4.7.2 Insulation to the surroundings

4.4.7.2.1 General

4.4.7.2.1 of IEC 62477-1:2022 applies.

4.4.7.2.2 SPD Monitoring

4.4.7.2.2 of IEC 62477-1:2022 applies.

4.4.7.2.3 Circuits connected directly to mains supply

4.4.7.2.2 of IEC 62477-1:2022 applies.

4.4.7.2.4 Circuits connected directly to non-mains supply

4.4.7.2.3 of IEC 62477-1:2022 does not apply.

Replacement:

Insulation between the surroundings and circuits connected directly to a *non-mains supply* shall be designed according to:

- a) the *impulse withstand voltage* determined from Table 101 using the *system voltage*;
 - b) the *working voltage*; or
 - c) the *temporary overvoltage* if known to exist due to the nature of the supply;
- whichever gives the most severe requirement.

Note: if temporary overvoltage is unknown, then the design can only consider a) and b).

In determination of *temporary overvoltages* on *non-mains supply*, the following situations should be considered:

- loss of the neutral in a *non-mains supply system*;
- accidental earthing of a *non-mains supply IT system*; and
- short-circuit in the *non-mains supply installation*.

For further information, see IEC 60364-4-44:2007, Clause 442 and IEC 61936-1.

The *insulation* between the surroundings and circuits connected directly to a *non-mains supply* *insulation* is normally evaluated to withstand impulse voltages of *overvoltage category II* except a higher *overvoltage category* shall be used when control of overvoltage is not provided. Overvoltage category IV shall be used if non mains supply is provided by or transmitted through outdoor lines for both LV and HV systems. For LV applications and circuits with a *low*

level of impulse voltages and for which it can be shown that the impulse voltages remain on a low level even under *single fault condition*, *overvoltage category I* may be used. This requirement is considered to be met if the expected *impulse withstand voltages* do not exceed the values given in Table 101 for *overvoltage category I* at the appropriate *system voltage*.

NOTE 1 The *overvoltage category* for *non-mains supplies* does not differ between *permanently connected equipment* in fixed *installations* and *non permanently connected equipment* to the fixed *installation*.

If means are provided which reduce impulse voltages of *overvoltage category III* to values of category II, or values of *overvoltage category II* to values of category I, *basic insulation* and/or *supplementary insulation* downstream of the *SPD* may be designed for the reduced value. The requirements for *double insulation* and/or *reinforced insulation* shall not be reduced to values less than those required for *basic insulation* designed to withstand impulses without these means being present.

If the devices used for this purpose can be damaged by overvoltages or repeated impulses, thus decreasing their ability to reduce impulses, they shall be monitored and an indication of their status provided according to 4.4.7.2.2.

NOTE 2 The determined *impulse withstand voltage* based on the *system voltage* can be reduced by means of inherent protection or *SPD* internal in the *PECS* or as part of the *installation*. IEC 61643-12 provides information on the selection and use of such *SPD*.

4.4.7.2.5 PECS connected to both mains supply and non-mains supply

4.4.7.2.5 of IEC 62477-1:2022 applies.

4.4.7.2.6 DVC As or DVC B circuits supplied from mains supply or non-mains supply

4.4.7.2.6 of IEC 62477-1:2022 applies.

4.4.7.2.7 Insulation between circuits

4.4.7.2.4 of IEC 62477-1:2022 applies.

4.4.7.3 Functional insulation

4.4.7.3 of IEC 62477-1:2022 does not apply.

Replacement:

If the failure of *functional insulation* does not produce a hazard (electrical, thermal, fire), no specific requirements apply for the dimensioning of *functional insulation*. In other cases, the following requirements apply.

Testing is not required, except where the circuit analysis required by 4.2 shows that failure of the *insulation* could result in a hazard.

For parts or circuits that are significantly affected by external transients, *functional insulation* shall be designed according to the *impulse withstand voltage* of *overvoltage category II*, except that *overvoltage category III* shall be used when the *PECS* is connected at the origin of the *installation*.

Where measures are provided that reduce transient overvoltages within the circuit from category III to values of category II, or values of category II to values of category I, *functional insulation* may be designed for the reduced values.

1038 Where the circuit characteristics can be shown by testing (see 5.2.3.2) to reduce impulse
1039 withstand voltages, *functional insulation* may be designed for the highest *impulse withstand*
1040 *voltage* occurring in the circuit during the tests.

1041
1042 For parts or circuits that are not significantly affected by external transients, *functional*
1043 *insulation* shall be designed according to the *working voltage* across the *insulation*.
1044

1045 The requirements of 4.4.7.7 apply.

1046 **4.4.7.4 Clearance distances**

1047 **4.4.7.4.1 General**

1048 4.4.7.4.1 of IEC 62477-1:2022 applies, except as follows.

1049 *Addition:*

1050 The clearance for HV is provided in Table 102, see IEC 60071-1 and IEC 60071-2 for additional
1051 information.

1052

1053
1054**Table 102 – Clearance distances for functional, basic or supplementary insulation**

Impulse withstand voltage d (from Table 101)	Temporary overvoltage f (crest value) h (from Table 101)	Working voltage f (recurring peak) a	Minimum clearance distances in air up to 2 000 m above sea level mm			
V	V	V	Pollution degree			
			1	2	3	4
N/A	≤ 110	≤ 88	0,01			
N/A	225	180	0,01			
330	330 ^e	260 ^e	0,01	0,2 ^{b, c}	0,8 ^c	1,6 ^c
500	500 ^e	400 ^e	0,04			
800	710 ^e	560 ^e	0,10			
1 500	1 270 ^e	1 010 ^e	0,5	0,5		
2 500	2 220 ^e	2 000 ^e	1,5	1,5	1,5	
4 000	3 430 ^e	3 090 ^e	3,0	3,0	3,0	3,0
6 000	4 890 ^e	4 410 ^e	5,5	5,5	5,5	5,5
8 000	6 060 ^e	5 460 ^e	8,0	8,0	8,0	8,0
12 000	9 500 ^e	8 550 ^e	14	14	14	14
20 000	15000	13500	25			
40 000	32300	29000	60			
60 000	45700	41100	90			
75 000	59700 ^g	53700 ^g	120			
95 000	78800 ^g	70900 ^g	160			
125 000	107000 ^g	96000 ^g	220			
145 000	130000 ^g	117000 ^g	270			

NOTE For determination of reinforced and double insulation, refer to 4.4.7.4.2.

a This voltage is approximately 0,8 times the voltage required to break down the associated clearance for impulse withstand voltages below 2 500 V and 0,9 times the voltage required to break down the associated clearance for impulse withstand voltages above 2 500 V.

b For printed wiring board (PWB), the values for pollution degree 1 apply except that the value shall not be less than 0,04 mm.

c The minimum clearance given for pollution degrees 2, 3 and 4 are based on the reduced withstand characteristics of the associated creepage distance under humidity conditions (see IEC TR 63040:2016).

d Interpolation is permitted for non-mains supply but not for mains supply. Clearances for impulse withstand voltage is derived from IEC 60664-1:2020, Table F.2.

e Clearances for temporary overvoltage and working voltage are derived from IEC 60664-1:2020, Table F.8.

f Interpolation is permitted when clearance is determined from temporary overvoltage and working voltage.

g Values are extrapolated from IEC 60664-1:2020.

h Only relevant for determining insulation between surroundings and circuits.

1055

4.4.7.4.2 Clearances for reinforced insulation

4.4.7.4.2 of IEC 62477-1:2022 does not apply.

Replacement:

Clearances for reinforced insulation shall be dimensioned to withstand

- for low-voltage PECS, the value corresponding to the next higher impulse voltage, or 1,6 times the temporary overvoltage, or twice the working voltage shall be used;

- for high-voltage PECS, the value corresponding to 1,6 times the impulse voltage, temporary overvoltage or working voltage shall be used.

Clearances for reinforced insulation between circuits connected directly to the supply mains and other circuits shall not be reduced when measures to reduce transient overvoltages are provided.

For values not covered in Table 8 of IEC 62477-1:2022, refer to IEC 60664-1:2020, Table F.2 and Table F.7.

4.4.7.4.3 Clearances for use above 2 000 m and/or above 30 kHz

4.4.7.4.3 of IEC 62477-1:2022 applies with addition

For HV altitude correction calculation, See IEC 60071-2:2023

4.4.7.4.4 Clearances for homogeneous fields

4.4.7.4.4 of IEC 62477-1:2022 applies with addition.

Addition to paragraph 4:

The requirements defined in paragraph 4 are only required in cases where the spacing and insulation are close to the minimum acceptable level and the layer of insulating material has a higher insulation property than air. In other cases, it is not required or recommended to remove this layer.

4.4.7.4.5 Clearance to conductive enclosures

4.4.7.4.5 of IEC 62477-1:2022 applies with addition.

Addition:

Also refer to 4.12.1.

4.4.7.5 Creepage distances**4.4.7.5.1 Insulating material groups**

4.4.7.5.1 of IEC 62477-1:2022 applies.

4.4.7.5.2 Determination of creepage distance

4.4.7.5.2 of IEC 62477-1:2022 applies with addition.

1088 *Addition:*

1089 Creepage distances for PEC and PECS shall be dimensioned according to Table 103.

1090

Table 103 – Creepage distances (in millimetres)

Column 1	2	3	4	5	6	7	8	9	10	11	12
Working voltage (AC RMS or DC mean) ^e	PWBs ^a		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
	All material groups	All material groups except IIIb	All material groups	Insulating material group				Insulating material group			
				I	II	IIIa	IIIb	I	II	IIIa	IIIb
V	mm	mm	mm	mm	mm	mm		mm	mm	mm	
≤ 2	0,025	0,04	0,056	0,35	0,35	0,35		0,87	0,87	0,87	
5	0,025	0,04	0,065	0,37	0,37	0,37		0,92	0,92	0,92	
10	0,025	0,04	0,08	0,40	0,40	0,40		1,0	1,0	1,0	
25	0,025	0,04	0,125	0,50	0,50	0,50		1,25	1,25	1,25	
32	0,025	0,04	0,14	0,53	0,53	0,53		1,3	1,3	1,3	
40	0,025	0,04	0,16	0,56	0,80	1,1		1,4	1,6	1,8	
50	0,025	0,04	0,18	0,60	0,85	1,20		1,5	1,7	1,9	
63	0,04	0,063	0,20	0,63	0,90	1,25		1,6	1,8	2,0	
80	0,063	0,10	0,22	0,67	0,95	1,3		1,7	1,9	2,1	
100	0,10	0,16	0,25	0,71	1,0	1,4		1,8	2,0	2,2	
125	0,16	0,25	0,28	0,75	1,05	1,5		1,9	2,1	2,4	
160	0,25	0,40	0,32	0,80	1,1	1,6		2,0	2,2	2,5	
200	0,40	0,63	0,42	1,0	1,4	2,0		2,5	2,8	3,2	
250	0,56	1,0	0,56	1,25	1,8	2,5		3,2	3,6	4,0	
320	0,75	1,6	0,75	1,6	2,2	3,2		4,0	4,5	5,0	
400	1,0	2,0	1,0	2,0	2,8	4,0		5,0	5,6	6,3	
500	1,3	2,5	1,3	2,5	3,6	5,0		6,3	7,1	8,0	
630	1,8	3,2	1,8	3,2	4,5	6,3		8,0	9,0	10,0	
800	2,4	4,0	2,4	4,0	5,6	8,0		10,0	11	12,5	b
1 000	3,2	5,0	3,2	5,0	7,1	10,0		12,5	14	16	
1 250	4,2	6,3	4,2	6,3	9	12,5		16	18	20	
1 600	c	c	5,6	8,0	11	16		20	22	25	
2 000			7,5	10,0	14	20		25	28	32	
2 500			10,0	12,5	18	25		32	36	40	
3 200			12,5	16	22	32		40	45	50	
4 000			16	20	28	40		50	56	63	
5 000			20	25	36	50		63	71	80	
6 300			25	32	45	63		80	90	100	
8 000			32	40	56	81		100	110	125	
10 000			40	50	71	100		125	140	160	
12 500			50	63	90	125		d	d	d	b, d
16 000			63	80	110	150					
20 000			80	100	140	200					
25 000			100	125	180	250					
32 000			125	160	220	320					
40 000			160	200	280	400					
50 000			200	250	360	500					
63 000			250	320	450	600					

Interpolation is permitted.

- ^a These columns also apply to *components* and parts on PWBs, and to other *creepage distances* with a comparable control of tolerances.
- ^b Insulating materials of group IIIb are not normally recommended for *pollution degree* 3 above 630 V.
- ^c Above 1 250 V, use the values from columns 4 to 11, as appropriate.
- ^d Values for creepage distances are not determined for this range. For values, see IEC 60071-2:1996, Table 1.

1091

1092 **4.4.7.6 Coating or potting**

1093 4.4.7.6 of IEC 62477-1:2022 applies.

1094 **4.4.7.7 Decreased spacings for functional insulation**

1095 4.4.7.7 of IEC 62477-1:2022 does not apply.

1096 *Replacement:*

1097 *Clearance and creepage distances for functional insulation on PWB and components*
 1098 *assembled on PWB shall comply with the requirements of 4.4.7.4 and 4.4.7.5.*

1099 Decreased *clearance and creepage distances* on PWB are permitted when all the following are
 1100 satisfied:

- 1101 a) the PWB has minimum flammability rating of V-0 (see IEC 60695-11-10:2013);
- 1102 b) the PWB base material has a minimum CTI of 100;
- 1103 c) the PWB complies with the PWB short-circuit test (see 5.2.4.7).

1104 *Decreased clearance and creepage distances for components assembled on PWB are*
 1105 *permitted when*

- 1106 d) used in pollution degree 1 or 2 environment,
- 1107 e) used in overvoltage category I, and
- 1108 f) the assembled PWB complies with the PWB short-circuit test (see 5.2.4.7).

1109 In this case, the *component* manufacturer specification may be used.

1110 **4.4.7.8 Solid insulation**

1111 **4.4.7.8.1 General**

1112 4.4.7.8.1 of IEC 62477-1:2022 applies.

1113 **4.4.7.8.2 Material requirements**

1114 4.4.7.8.2 of IEC 62477-1:2022 applies.

1115 **4.4.7.8.3 Thin sheet or tape material**

1116 **4.4.7.8.3.1 General**

1117 4.4.7.8.3.1 of IEC 62477-1:2022 applies.

1118 **4.4.7.8.3.2 Thin sheet material thickness and number of layers**

1119 4.4.7.8.3.2 of IEC 62477-1:2022 applies.

1120 **4.4.7.8.4 Printed wiring boards (PWBs)**

1121 **4.4.7.8.4.1 General**

1122 4.4.7.8.4.1 of IEC 62477-1:2022 applies with addition.

1123 Addition:

1124 Refer to Table 12 and IEC 60695-11-10 for flammability information.

1125 **4.4.7.8.4.2 Inner layers of multi-layer printed wiring boards (see Figure D.14)**

1126 4.4.7.8.4.2 of IEC 62477-1:2022 applies.

1127 **4.4.7.8.4.3 Use of coating materials**

1128 4.4.7.8.4.3 of IEC 62477-1:2022 applies.

1129 **4.4.7.8.5 Potting materials**

1130 4.4.7.8.6 of IEC 62477-1:2022 applies.

1131 **4.4.7.9 Connection of parts of solid insulation (cemented joints)**

1132 4.4.7.9 of IEC 62477-1:2022 applies.

1133 **4.4.7.10 Requirements for electrical withstand capability**

1134 **4.4.7.10.1 General**

1135 4.4.7.10.1 of IEC 62477-1:2022 applies with addition.

1136 Addition:

1137 Refer to 5.2.2.1 for rules about allowance of testing.

1138 *In addition to using system voltage for insulation coordination and deriving test voltages (see*
1139 *Table 106 and Table 107), Care shall be taken when considering higher voltage levels internal*
1140 *to the product. Additional impulse testing shall be performed following 4.4.7.10.2 and 4.4.7.10.3*
1141 *for higher voltage levels, as explained in 4.4.7.2.*

1142 *Details regarding additional testing levels and concept may be found in IEC 60071 series.*

1143 *Some examples where System Voltage may not be appropriate for deriving test voltages are:*

- 1144 • Inductive coupling elements having a relevant voltage drop which requires PEC to
- 1145 generate much higher voltage than system voltage.
- 1146 • Some circuits like Modular Multilevel Converters or voltage multipliers may generate DC
- 1147 voltages much higher than peak AC.
- 1148 • When faults on AC side may lead to significant voltage increase.

1149 **4.4.7.10.2 Basic insulation or supplementary insulation**

1150 4.4.7.10.1 of IEC 62477-1:2022 applies.

4.4.7.10.3 Double insulation or reinforced insulation

4.4.7.10.2 of IEC 62477-1:2022 applies with addition.

Addition to paragraph 2 and 3.

The example in Figure D.14 represents the most simplistic possible example. In examples with more than one layer of insulation, it is possible that the voltage stress is not linear due to the different material properties of the layers. Consideration shall be given to this condition.

4.4.8 Compatibility with residual current-operated protective devices (RCD)

4.4.8 of IEC 62477-1:2022 only applies to LV section.

4.4.9 Capacitor discharge

4.4.9 of IEC 62477-1:2022 does not apply.

Replacement:

For protection against electric shock hazard, capacitors within a PECS shall be discharged either to a voltage less than UDCL of DVC As, or to a residual energy less than 0,5 mJ, after the removal of energy from the PECS. The requirements for the discharge of a capacitor for electrical energy hazard is located in clause 4.5 and shall be used in addition to these requirements.

a) For *PECS of pluggable equipment type A and pluggable equipment type B*, the discharge time shall not exceed 1 s or the *hazardous live parts* shall be protected against direct contact by at least IP2X (see 4.4.3.3).

b) For *permanently connected PECS*, the discharge time shall not exceed 5 s.

c) For pluggable and *permanently connected PECS* with a control system that prevents access to the capacitors, until discharged as described above, no discharge time is required.

For *PECS*, which do not meet the above requirements a), b) or c), access shall only be possible by means of a tool or key, and the information and marking requirements of 6.5.2 apply.

This requirement also applies to capacitors used for power factor correction, filtering, etc.

NOTE The requirement of 4.4.9 only consider the stored energy related to internal capacitors of the *PEC*. For the final application where the *PEC* is used as a *component*, and other sources of energy can be present, further considerations of stored charge can apply. See also 4.8 for multiple sources of supply.

Compliance is checked by test of 5.2.3.8.

See 6.5.2 for information and marking requirements.

New Clause:

4.4.101 Access conditions for HV PEC or PECS**4.4.101.1 General**

The high-voltage sections shall be protected with respect to personnel safety.

- Personnel shall be prevented from accessing the high-voltage sections of a *PECS*. This protection is either provided by an appropriate *enclosure* according to IEC 60204-11:2018 with respect to personnel safety or will be governed by the rules of the *installation* (example IEC 61936-1).

- If an *enclosure* is used, *interlocks* shall be used to prevent any access inside the *enclosure* of the high-voltage section when *mains supply* circuit breaker(s) providing the high-voltage to the circuit are on (see b) below). *Interlocks* are required on all *doors*. *Interlocks* are not required on *hinged panels* or *covers*.

NOTE 1 Requirement is taken from UL 347A.

NOTE 2 A *hinged panel* can be three bolted sides and a bolted, welded or similarly secured hinge.

a) Operating conditions

Interlocking *doors* shall prevent any access inside the *enclosure* of the high-voltage converter section when *mains supply* circuit breaker(s) providing the high-voltage to the circuit are on, and if *hazardous live parts* have not been earthed (see b).

b) Access for maintenance – Earthing instructions

The earthing operation is performed after the normal discharge time stated by the *PECS* manufacturer. Care shall be taken to ensure that this operation is safe even in case of failure of the discharge circuit. Care shall also be taken that, on the input and output side of the *PECS*, the stray capacitance of cables, motor and/or transformer shall be discharged before possible access to *live parts*. The requirements of 4.4.9 apply.

Earthing devices (earthing switches and/or earthing cables) shall be provided in sufficient quantity to facilitate work being carried out in safety on the *live parts* of the high-voltage equipment of the *PECS*. The earthing devices shall comply with the relevant requirements of IEC 62271-102:2018 or IEC 61230:2008. The earthing contacts, or an indication that the contacts of the switches are closed, shall be visible by the maintenance personnel before they access the equipment.

NOTE 3 In particular cases, (for example, load-commutated inverters), two earthing devices (one supply side, one load side) can be required.

For parts which are not directly earthed by an earthing switch, the *component* manufacturers shall provide safe instructions to perform earthing.

For test, see 5.2.2.101

For marking, see 6.5.101.

4.4.101.2 Isolating means for high-voltage PECS

4.4.101.2.1 PECS with isolating means

4.4.101.2.1.1 General

The isolating means shall be an externally-operable, gang-operated power circuit isolating means with position indication that complies with 4.4.101.2.1.1 to 4.4.101.2.1.5.

For test, see 5.2.2.101.

The following are examples of possible isolating means:

- a) three-pole isolating switch;
- b) three-pole isolating switch in mechanical combination with high-voltage motor circuit fuses;
- c) three-pole load break switch;
- d) draw out three-pole contactor (with or without fuse assembly);
- e) draw out three pole circuit breaker.

4.4.101.2.1.2 Operating location

The isolating mechanism indicated in 4.4.101.2.1.1 shall be arranged to be operated from a location where the operator is not exposed to energized parts and shall be arranged to be operated from a

1232 ungrounded conductors of the circuit simultaneously with one operation. When a disconnecting
1233 means disconnects a permanent *PE conductor*, it shall open all energized conductors and the
1234 *PE conductor* in the same operation.

1235 **4.4.101.2.1.3 Visibility of isolating gap**

1236 The isolating means shall provide visible indication of an isolating gap in the circuit.

1237 The isolation gap or a mechanically operated indicator shall be visible through a window. The
1238 mechanical operator shall be actuated by the movement of the actual isolating switch assembly,
1239 the shutter of a draw-out assembly, etc. The action of the mechanical indicator shall not be
1240 dependent on the movement of the operating handle or mechanism alone.

1241 **4.4.101.2.1.4 Interlocking and locking**

1242 The high-voltage isolating means shall be interlocked as indicated in 4.4.101.1.

1243 The high-voltage isolating means shall have provision for being locked by mechanical means
1244 in the open position.

1245 **4.4.101.2.1.5 De-energisation of switch blades**

1246 All load side switch blades shall be de-energized when the switch is in the open position, except
1247 switches that are intended to be energized from both sides (for example, bus tie, loop
1248 sectionalizing). These switches shall not have energized blades in the open position unless

- 1249 a) barriers or *enclosures* are installed over the switches for protection against contact with the
1250 energized switch blades, and
- 1251 b) the switch is marked in accordance with 6.5.101.

1252 **4.4.101.2.2 PECS without isolating means**

1253 *PECS* that is not provided with the isolating means noted in 4.4.101.2.1.1 shall comply with a)
1254 and b) below:

- 1255 a) the *PECS* shall be marked in accordance with 6.5.101;
- 1256 b) instructions shall be provided with respect to external isolating means and interlocking in
1257 accordance with 6.5.101.

1258 **4.5 Protection against electrical energy hazards**

1259 **4.5.1 General access areas**

1260 **4.5.1.1 General**

1261 4.5.1.1 of IEC 62477-1:2022 applies.

1262 **4.5.1.2 Determination of hazardous electrical energy level**

1263 4.5.1.2 of IEC 62477-1:2022 applies.

1264

1265 *New Clause:*

1266 **4.5.1.101 Limited power sources**

1267 Where a limited power source is required, the source shall comply with Table or Table as
1268 applicable.

1269 A limited power source shall comply with one of the following requirements:

- 1270 a) the output is inherently limited in compliance with Table ; or

- a) a linear or non-linear impedance limits the output in compliance with Table . If a positive temperature coefficient device (e.g. PTC) is used, it shall pass the applicable tests specified in IEC 60730-1:2013, IEC 60730-1:2013/AMD1:2015 and IEC 60730-1:2013/AMD2:2020; or
- b) a regulating network limits the output in compliance with Table , both with and without a *single fault condition* in the regulating network; or
- c) an *overcurrent protective device* is used and the output is limited in compliance with Table .

Where an *overcurrent protective device* is used, it shall be a fuse or a non-adjustable, non-autoreset, electromechanical device.

A limited power source operated from an *AC mains supply*, or a battery-operated limited power source that is recharged from an *AC mains supply* while supplying the load, shall incorporate an isolating transformer.

Compliance to determine the maximum available power is checked by test of 5.2.3.9.

Table 104 – Limits for sources without an overcurrent protective device

Output voltage ^a U_{oc}		Output current ^{b, d} I_{sc} A	Apparent power ^{c, d} S VA
V AC RMS	V DC		
≤ 30	≤ 30	≤ 8	≤ 100
-	$30 < U_{oc} \leq 60$	$\leq 150 / U_{oc}$	≤ 100
^a Output voltage measured in accordance with 5.1.5.3 with all load circuits disconnected. Voltages are for substantially sinusoidal AC and ripple-free DC. For non-sinusoidal AC and DC with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V. ^b Maximum output current with any non-capacitive load, including a short-circuit. ^c Maximum output apparent power in VA with any non-capacitive load. ^d Measurement of I_{sc} and S are made 5 s after application of the load if protection is by an electronic circuit or a positive temperature coefficient device (e.g. PTC), and 60 s in other cases.			

Table 105 – Limits for power sources with an overcurrent protective device

Output voltage ^a U_{oc}		Output current ^{b, d} I_{sc} A	Apparent power ^{c, d} S VA	Current rating of overcurrent protective device ^e A
V AC RMS	V DC			
≤ 20	≤ 20	$\leq 1\,000 / U_{oc}$	≤ 250	≤ 5,0
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$			$\leq 100 / U_{oc}$
–	$30 < U_{oc} \leq 60$			$\leq 100 / U_{oc}$

- ^a Output voltage measured in accordance with 5.1.5.3 with all load circuits disconnected. Voltages are for substantially sinusoidal AC and ripple free DC. For non-sinusoidal AC and for DC with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V.
- ^b Maximum output current with any non-capacitive load, including a short-circuit, measured 60 s after application of the load.
- ^c Maximum output VA with any non-capacitive load measured 60 s after application of the load.
- ^d Current limiting impedances remain in the circuit during measurement, but *overcurrent protective devices* are bypassed. The reason for making measurements with *overcurrent protective devices* bypassed is to determine the amount of energy that is available to cause possible overheating during the operating time of the *overcurrent protective devices*.
- ^e Current ratings of *overcurrent protective devices* that break the circuit within 120 s with a current equal to 210 % of the current rating specified in the table.

1285 NOTE The limited power source concept is intended for usage in operator access area. For more information, see
1286 IEC 60730-1.

1287 **4.5.2 Service access areas**

1288 4.5.2 of IEC 62477-1:2022 applies.

1289 **4.6 Protection against fire and thermal hazards**

1290 **4.6.1 Circuits representing a fire hazard**

1291 4.6.1 of IEC 62477-1:2022 applies.

1292 **4.6.2 Components representing a fire hazard**

1293 **4.6.2.1 General**

1294 4.6.2.1 of IEC 62477-1:2022 applies.

1295 **4.6.2.2 Components within a circuit representing a fire hazard**

1296 4.6.2.2 of IEC 62477-1:2022 applies.

1297 **4.6.2.3 Components within a circuit not representing a fire hazard**

1298 4.6.2.3 of IEC 62477-1:2022 applies.

1299 **4.6.3 Fire enclosures**

1300 **4.6.3.1 General**

1301 4.6.3.1 of IEC 62477-1:2022 applies.

1302 **4.6.3.2 Flammability of enclosure materials**

1303 4.6.3.2 of IEC 62477-1: 2022applies.

1304 **4.6.3.3 Openings in fire enclosures**

1305 **4.6.3.3.1 General**

1306 4.6.3.1 of IEC 62477-1: 2022applies.

1307 **4.6.3.3.2 Openings in the top and side of fire enclosures**

1308 4.6.3.3.2 of IEC 62477-1: 2022applies.

1309 **4.6.3.3.3 Openings in the bottom of a fire enclosure**

1310 4.6.3.3.3 of IEC 62477-1: 2022 applies.

1311 **4.6.3.3.4 Doors or covers in fire enclosures**

1312 4.6.3.3.4 of IEC 62477-1:2022 applies.

1313 **4.6.4 Temperature limits**

1314 **4.6.4.1 Internal parts**

1315 4.6.4.1 of IEC 62477-1: 2022 applies.

1316 **4.6.4.2 Accessible parts**

1317 4.6.4.2 of IEC 62477-1: 2022 applies.

1318 **4.6.5 Limited power sources**

1319 4.6.5 of IEC 62477-1: 2022 does not apply (see 4.5.1.101).

1320 **4.7 Protection against mechanical hazards**

1321 **4.7.1 General**

1322 4.7.1 of IEC 62477-1:2022 applies.

1323 **4.7.2 Specific requirements for liquid cooled PECS**

1324 **4.7.2.1 Coolant**

1325 4.7.2.1 of IEC 62477-1:2022 applies.

1326 **4.7.2.2 Design requirements**

1327 **4.7.2.2.1 General**

1328 4.7.2.2.1 of IEC 62477-1:2022 applies with modification.

1329 *Replace second paragraph with.*

1330 *PECS* using liquids shall be so constructed that it is unlikely that either a hazardous
1331 concentration of these materials or a hazard listed in 4.2 will be created by condensation,
1332 vaporization, leakage, spillage or corrosion during normal operation, storage, filling or
1333 emptying.

1334 **4.7.2.2.2 Corrosion resistance**

1335 4.7.2.2.2 of IEC 62477-1:2022 applies with modification.

1336 *Replace first paragraph with and addition of the note below:*

1337 All cooling *system components* shall be suitable for use with the specified coolant. They shall
1338 be corrosion resistant.

1339 NOTE: Experience in the field has shown that electrolytic corrosion based on DC currents is a potential concern.