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**Electrical safety and lightning protection of
medium voltage input and up to ± 400 V DC
output power system in ICT data centre and
telecommunication centre**

Recommendation ITU-T K.151

ITU-T



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Electrical safety and lightning protection of medium voltage input and up to ± 400 V DC output power system in ICT data centre and telecommunication centre

Summary

Recommendation ITU-T K.151 provides guidelines for electrical safety and lightning protection requirements for medium voltage power electronic converter systems, which have medium voltage input with rated system voltages from 1 000 V AC up to 36 kV AC and low voltage output with rated voltages up to ± 400 V DC, used in information and communication technology (ICT) data centres, telecommunication centres, or other application environments.

With the development of big data and cloud computing technology, the quantity and total capacity of the data centres and telecommunication centres together with ICT equipment power densities are increasing rapidly. In this condition, it was found that the traditional power distribution equipment and power systems had the disadvantages of low energy efficiency, high energy consumption, high maintenance difficulties, and high costs in many existing data centres and telecommunication centres. In order to solve these problems, it is necessary to develop a new structure of a whole power system, which may be powered directly by medium voltage and based on power electronic conversion.

From the perspective of electrical safety and lightning protection, there are lots of differences between the data centre and telecommunication centre powered by traditional low-voltage alternating current (AC) and that powered by medium voltage. This Recommendation focuses mainly on electrical insulation, partial discharge, electrical safety, resistibility and lightning surge protection.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
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Keywords

Electrical safety, ICT data centre, lightning protection, medium voltage, power electronic converter systems, telecommunication centre.

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Recommendation ITU-T K.151

Electrical safety and lightning protection of medium voltage input and up to ± 400 V DC output power system in ICT data centre and telecommunication centre

1 Scope

This Recommendation addresses electrical safety, earthing and bonding, and lightning protection requirements for medium voltage power electronic converter systems, which have medium voltage input with rated system voltages from 1 000 V AC up to 36 kV AC and low voltage output with rated voltages up to ± 400 V DC, used in information and communication technology (ICT) data centres, telecommunication centres, or other application environments.

This Recommendation does not include the requirements of traditional -48 V DC or lower output voltage systems.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T K.20] Recommendation ITU-T K.20 (2021), *Resistibility of telecommunication equipment installed in a telecommunication centre to overvoltages and overcurrents.*
- [ITU-T K.27] Recommendation ITU-T K.27 (2015), *Bonding configurations and earthing inside a telecommunication building.*
- [IEC 60071-1] IEC 60071-1:2019, *Insulation co-ordination – Part 1: Definitions, principles and rules.*
- [IEC 60071-2] IEC 60071-2:2018, *Insulation Co-ordination – Part 2: Application guidelines.*
- [IEC 60085] IEC 60085:2007, *Electrical insulation - Thermal evaluation and designation.*
- [IEC 60099-4] IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems.*
- [IEC 60099-6] IEC 60099-6:2019, *Surge arresters – Part 6: Surge arresters containing both series and parallel gapped structures – System voltage of 52 kV and less.*
- [IEC 60112] IEC 60112:2020, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials.*
- [IEC 60146-1-1] IEC 60146-1-1:2009, *Semiconductor converters - General requirements and line commutated converters – Part 1-1: Specification of basic requirements.*
- [IEC 60216] IEC 60216-1:2013, *Electrical insulating materials – Thermal endurance properties – Part 1: Ageing procedures and evaluation of test results.*
- [IEC 60364-1] IEC 60364-1:2005, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions.*

- [IEC 60529] IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*.
- [IEC 60664-1] IEC 60664-1:2020, *Insulation coordination for equipment within low-voltage supply systems – Part 1: Principles, requirements and tests*.
- [IEC 60695-11-10] IEC 60695-11-10:2013, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*.
- [IEC 61140] IEC 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*.
- [IEC 61180] IEC 61180:2016, *High-voltage test techniques for low-voltage equipment – Definitions, test and procedure requirements, test equipment*.
- [IEC 61558-1] IEC 61558-1:2017, *Safety of transformers, reactors, power supply units and combinations thereof - Part 1: General requirements and tests*.
- [IEC 61558-2-16] IEC 61558-2-16:2021, *Safety of transformers, reactors, power supply units and combinations thereof – Part 2-16: Particular requirements and tests for switch mode power supply units and transformers for switch mode power supply units for general applications*.
- [IEC 62271-200] IEC 62271-200:2011, *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*.
- [IEC 62477-1] IEC 62477-1:2016, *Safety requirements for power electronic converter systems and equipment – Part 1: General*.
- [IEC 62477-2] IEC 62477-2:2018, *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*.
- [ISO 9772] ISO 9772:2012, *Cellular plastics – Determination of horizontal burning characteristics of small specimens subjected to a small flame*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

In this Recommendation, definitions already introduced by [IEC 60071-1], [IEC 62477-1] and [IEC 62477-2] are used to maintain conformity.

3.1.1 power electronic converter (PEC) [IEC 62477-1]: Device or part thereof for the purpose of electronic power conversion, including signalling, measurement, control circuitries and other parts, if essential for the power conversion function.

3.1.2 power electronic converter system (PECS) [IEC 62477-1]: One or more power electronic converters intended to work together with other equipment.

3.2 Terms defined in this Recommendation

This Recommendation defines the following term:

3.2.1 medium voltage power electronic converter systems (MV-PECS): Power electronic converter system (PECS) that has AC medium voltage input with rated system voltages from 1 000 V AC up to 36 kV AC and low voltage output with rated voltages up to 1 000 V AC and/or 1 500 V DC.

NOTE – In this Recommendation, the output voltage limits up to ± 400 V DC.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC	Alternating Current
CTI	Comparative Tracking Index
DC	Direct Current
ICT	Information and Communication Technology
LV	Low Voltage
MET	Main Earthing Terminal
MOA	Metal-Oxide Surge Arrester
MV	Medium Voltage
MV-PECS	Medium Voltage Power Electronic Converter Systems
OVC	Overvoltage Category
PE	Protective Earthing
PEC	Power Electronic Converter
PECS	Power Electronic Converter System
PWB	Printed Wiring Board
SELV	Safety Extra Low Voltage

5 Conventions

None.

6 Reference configuration

6.1 Typical configuration of MV-PECS

The typical configuration of medium voltage power electronic converter systems (MV-PECS) includes a medium voltage input cabinet, AC/DC conversion cabinets, DC/AC conversion cabinets (optional, for low voltage AC output only), and battery cabinets. The quantities of AC/DC conversion cabinets, DC/AC conversion cabinets and battery cabinets can be configured for the customer's requirements. The typical configuration of MV-PECS is shown as Figure 1.

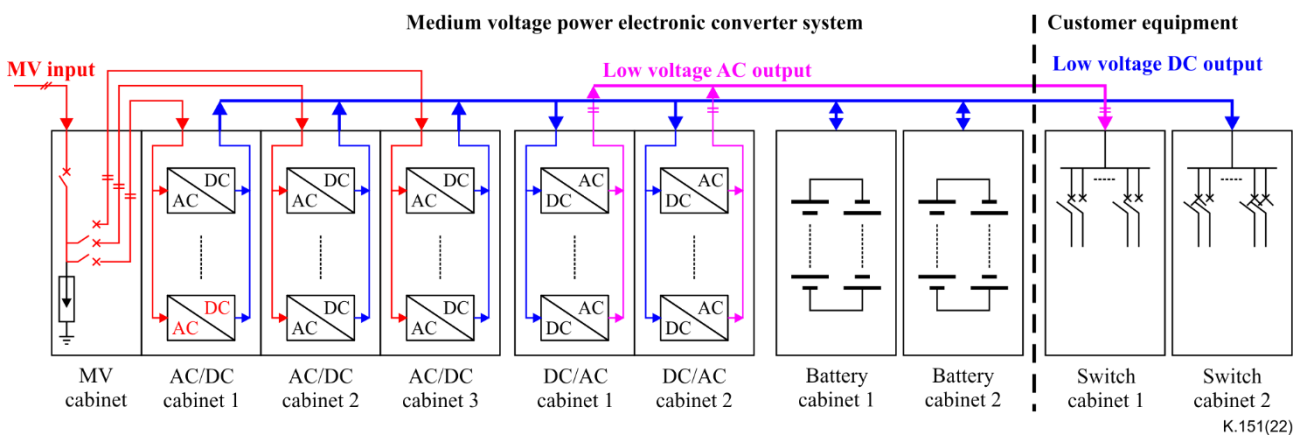


Figure 1 – Typical configuration of MV-PECS

The MV-PECS is powered by either overhead medium voltage (MV) power lines, as for most cases, or underground buried cables. Typically, the MV power lines or cables to MV-PECS consist of a three phase conductor without neutral conductor.

From the point view of the arrangement of current-carrying conductors under normal operating conditions, two types of DC low voltage (LV) output for MV-PECS are considered in this Recommendation as shown in Figure 2:

- 1) two-wire DC system without mid-point conductor,
- 2) three-wire DC system with mid-point conductor.

The typical voltages of DC output include 240 V DC, 400 V DC, etc.

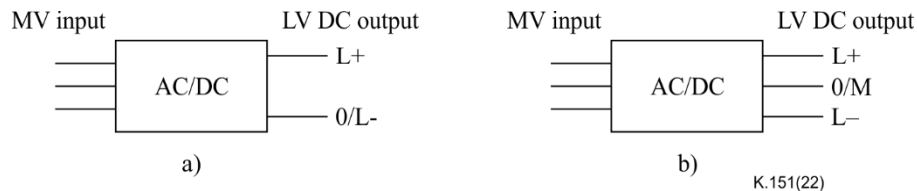


Figure 2 – Two types of DC low voltage output for MV-PECS

6.2 The consideration for electrical safety

6.2.1 Influencing factors

This clause gives minimum requirements for insulation, based on the principles of the IEC 60664 and IEC 60071 series standards.

Manufacturing tolerances shall be taken into account for the requirements in clause 6.2.

Insulation shall be selected after consideration of the following influences:

- pollution degree;
- overvoltage category;
- supply system earthing;
- impulse withstand voltage, temporary overvoltage and working voltage;
- location of insulation;
- type of insulation.

6.2.2 Pollution degree

Insulation, especially when provided by clearances and creepage distances, is affected by pollution which occurs during the expected lifetime of the MV-PECS. The micro-environmental conditions for insulation shall be applied according to Table 1.

Table 1 – Definitions of pollution degrees

Pollution degree	Description
1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
2	Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is to be expected.
3	Conductive pollution or dry non-conductive pollution occurs which becomes conductive due to condensation which is to be expected.
4	The pollution generates persistent conductivity caused for example by conductive dust or rain or snow.

The pollution degree shall be determined according to the environmental condition for which the product is specified.

The insulation may be determined according to pollution degree 2 if one of the following applies:

- 1) instructions are provided with the MV-PECS indicating that it shall be installed in a pollution degree 2 environment; or
- 2) the specific installation application of the MV-PECS is known to be a pollution degree 2 environment; or
- 3) the MV-PECS enclosure or coatings applied within the MV-PECS provide adequate protection against what is expected in pollution degree 3 and 4 (conductive pollution and condensation).

6.2.3 Overvoltage category (OVC)

The concept of overvoltage categories (based on [IEC 62477-2]) is used for equipment energized from the supply mains and addresses the level of overvoltage protection expected. The OVC for non-mains supply is determined by taking into account whether control of overvoltage is provided or not, and whether the MV-PECS is connected to outdoor lines or not, and if so, the length of the lines.

Four categories are considered.

- Equipment of overvoltage category IV (OVC IV) is for use at the origin of the installation.
NOTE 1 – Examples of such equipment are electricity meters and primary overcurrent protection equipment and other equipment connected directly to outdoor open lines.
- Equipment of overvoltage category III (OVC III) is equipment in fixed installations and for cases where the reliability and the availability of the equipment are subject to special requirements.
NOTE 2 – Examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation.
- Equipment of overvoltage category II (OVC II) is energy-consuming equipment to be supplied from the fixed installation.
NOTE 3 – Examples of such equipment are appliances, portable tools and other household and similar loads.

If such equipment is subjected to special requirements with regard to reliability and availability, overvoltage category III applies.

- Equipment of overvoltage category I (OVC I) is equipment for connection to circuits in which measures are taken to limit transient overvoltages to an appropriately low level.
NOTE 4 – Examples of such equipment are those containing electronic circuits protected to this level.

6.2.4 Determination of impulse withstand voltage and temporary overvoltage

Table 2 uses the system voltage and overvoltage category of the circuit under consideration to determine the impulse withstand voltage. The system voltage is also used to determine the temporary overvoltage.

A MV-PECS having more than one input or output shall be evaluated according to the input or output which gives the most severe requirements.

Table 2 – Impulse withstand voltage and temporary overvoltage versus system voltage

Column 1		2	3	4	5	6
System voltage ^a V Up to and including		Impulse withstand voltage V				Temporary overvoltage V
		Overvoltage category				
AC	DC	I	II	III	IV	r.m.s. / peak
/	225	800	1 500	2 500	4 000	1 350/1 910
/	450	1 500	2 500	4 000	6 000	1 500/2 120
/	900	2 500	4 000	6 000	8 000	1 800/2 550
1 000	/	4 000	6 000	8 000	12 000	3 000/4 250 ^b
7 200	/	17 500 ^c	29 000 ^c	40 000 ^d	60 000 ^d	20 000/28 300
12 000	/	29 000 ^c	42 500 ^c	60 000 ^d	75 000 ^d	28 000/39 600
17 500	/	40 000 ^c	55 000 ^c	75 000 ^d	95 000 ^d	38 000/53 750
24 000	/	52 000 ^c	75 000 ^c	95 000 ^d	125 000 ^d	50 000/70 700
36 000	/	75 000 ^c	95 000 ^c	125 000 ^d	145 000 ^d	70 000/99 000
Interpolation is permitted.						
^a Interpolation of system voltage is not permitted when determining the impulse withstand voltage for mains supply.						
^b This value differs from Table 9 of [IEC 62477-1] and is taken from [IEC 60146-1-1].						
^c These values have been derived or extrapolated from Tables 4 and 5 of [IEC 62477-1].						
^d These values have been derived or extrapolated from Table 2 of [IEC 60071-1].						

6.2.5 Determination of the system voltage

For MV-PECS supplied by an AC medium voltage power supply, the neutral point is generally not grounded directly, so the system voltage is the r.m.s. value of the supply voltage between phases.

NOTE – If the neutral point is grounded directly, the system voltage of MV-PECS is under consideration.

6.2.6 Components bridging insulation

Components bridging insulation shall comply with the requirements of the level of insulation (e.g., basic, reinforced, double) they are bridging.

6.2.7 Insulation to the surroundings

Insulation for basic, supplementary, and reinforced insulation between a circuit and its surroundings shall be designed according to:

- the impulse withstand voltage; or
- the temporary overvoltage; or
- the working voltage of the circuit.

For creepage distances, the r.m.s. value of the working voltage is used. For clearance distances and solid insulation, the impulse withstand voltage, the temporary overvoltage or the recurring peak value of the working voltage is used.

Insulation between two circuits shall be designed according to the circuit having the more severe requirement.

For the design of simple and protective separation between circuits the insulation shall be designed according to:

- the circuit having the more severe requirement; or

- the working voltage between the circuits;
whichever gives the most severe requirement.

6.3 The ports susceptible to lightning surge

There are four types of ports that are susceptible to lightning surge, as shown in Figure 3.

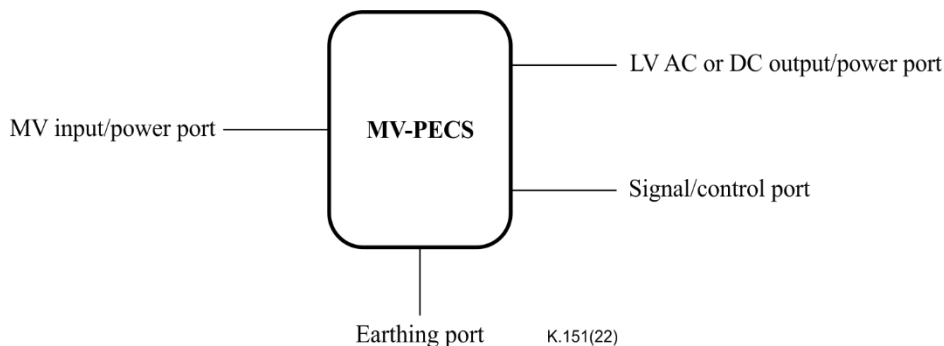


Figure 3 – Ports susceptible to lightning surge

Typically, overhead power lines are used to power the MV-PECS. The MV input power port of MV-PECS is highly exposed to lightning surge both from direct lightning stroke to overhead power or nearby lightning stroke. Occasionally, underground buried cables are used to power the MV-PECS. The MV input power port of MV-PECS is exposed to lightning surge as well. Therefore, measures should be adopted to limit the amplitude and reduce the steepness of lightning surge into MV-PECS. See clause 9.1 for details.

7 Earthing and bonding

7.1 General consideration

The consideration of earthing and bonding for the following parts refers to [ITU-T K.27]:

- bonding configuration for ICT data centre or telecommunication centre;
- the bonding and earthing implement of ICT equipment and/or installation;
- the exposed conductive parts and extraneous conductive parts inside the buildings;
- the incoming and outgoing power and/or signal conductors;
- the incoming and outgoing metal pipes or like elements.

7.2 Earthing configuration for low voltage DC output of MV-PECS

Low voltage DC power distribution in ICT or telecommunication buildings should be designed to limit coupling to telecommunication circuits arising from:

- mutual impedance of shared conductors;
- mutual inductive coupling (especially during short circuit conditions);
- common source impedances.

It is specified in [b-ETSI EN 301 605] that the DC power distribution of the secondary supply serving the ICT system shall conform to the requirements of the IT or TN-S system. As discussed in clause 6.1, there are at least two situations for low voltage DC output of MV-PECS:

- 1) two-wire DC system without mid-point conductor,
- 2) three-wire DC system with mid-point conductor.

Therefore, there are several types of earthing configuration for low voltage DC output of MV-PECS.

7.2.1 IT d.c. system

Figure 4 shows an example of an IT system earthing arrangement for DC power system according to [b-ETSI EN 301 605] and [IEC 60364-1]. Type a) and type b) are used for two-wire DC system without mid-point conductor and three-wire DC system with mid-point conductor respectively. Both line conductors (L+ and L-) are isolated from or may be connected to the main earthing terminal (MET) via a high-ohmic resistor(s).

For two-wire DC system without mid-point conductor, a preferred symmetrical earthing arrangement is recommended. The high-ohmic mid-point terminal is the common point between two symmetrical high-ohmic resistors (typically $> 50 \text{ k}\Omega$) whose opposite ends are electrically connected to the different line conductors (L+ and L-) of the same circuit.

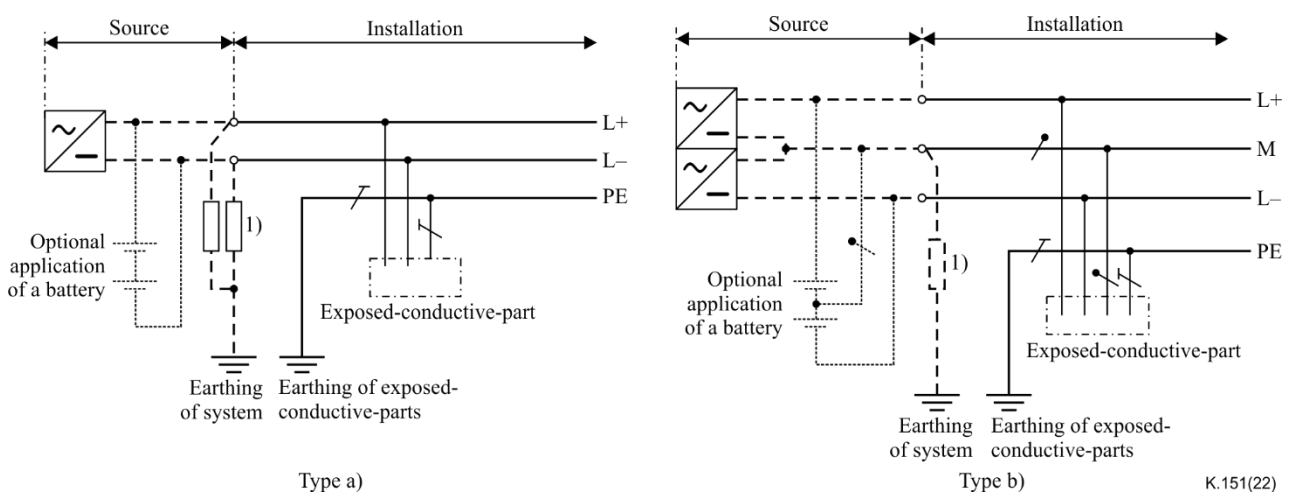


Figure 4 – IT system earthing

7.2.2 TNS d.c. system

Figure 5 shows an example of TNS system earthing arrangement for DC power system according to [b-ETSI EN 301 605] and [IEC 60364-1]. Type a) and type b) are used for two-wire DC system without mid-point conductor and three-wire DC system with mid-point conductor respectively.

For two-wire DC system, it is recommended the negative line terminals (L-) of MV-PECS be connected to the MET if TNS system is adopted. The earthed line conductor (L-) shall be separated from the PE-conductor throughout the installation.

For three-wire DC system, it is recommended the mid-point conductor terminals (M) of MV-PECS be connected to the MET if TNS system is adopted. The earthed mid-point conductor (M) shall be separated from the PE-conductor throughout the installation.

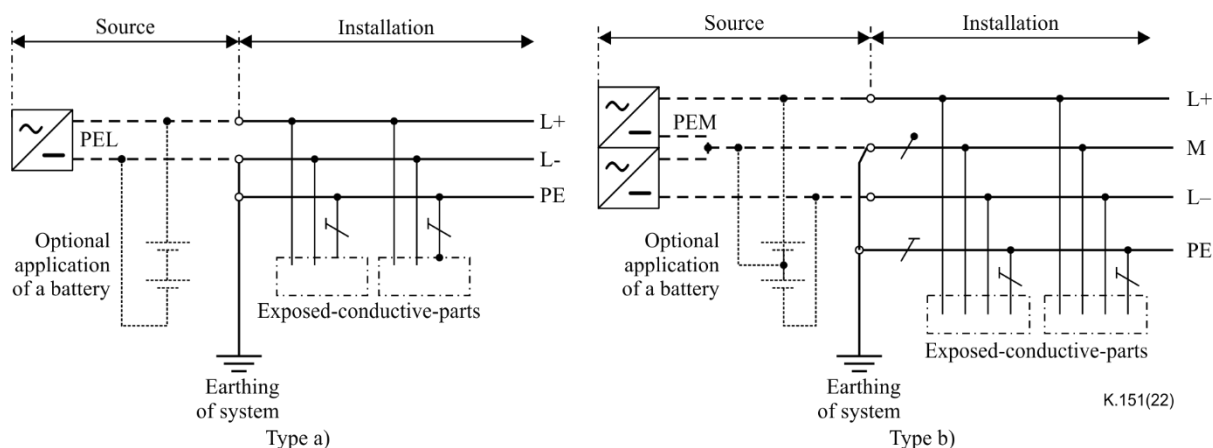


Figure 5 – TNS system earthing

Refer to [IEC 60364-1] for more information about arrangements of current-carrying conductors and types of system earthing.

8 Electrical safety

8.1 Protection against electric shock

8.1.1 General

Protection against electric shock depends on the system voltage and insulation requirements, and is to be provided by at least one of the following measures:

- basic protection and fault protection;
- enhanced protection

Protection under normal conditions is provided by basic protection, and protection under single fault conditions is provided by fault protection. Enhanced protection provides protection under both conditions.

8.1.2 Requirements for protection against electric shock

Table 3 shows possible solutions for compliance with clause 8.1 for the application of simple or protective separation, dependent on the system voltage under consideration and of adjacent circuits.

The requirements of this standard for protection against electric shock may be fulfilled by other means than those shown in Table 3, in which case failure analysis and testing shall show that the requirements of clause 8.1 are met.

Table 3 – Protection requirements for circuit under consideration

Circuit under consideration	Protection against accessibility	Protection to accessible conductive parts connected to PE	Protection to accessible conductive parts that are not connected to PE	Protection to adjacent circuit		
				SELV	LV	MV
SELV	No	1	1	1	Enhanced protection	Enhanced protection
LV	Enhanced protection	Basic protection	Enhanced protection		1 or 2	Enhanced protection
MV	Enhanced protection	Basic protection	Enhanced protection			2

Key:
1 Protection is not necessary for safety, but can be required for functional reasons.
2 Basic protection for circuit of higher voltage.
1 or 2 Depending on separation with other circuits.

8.1.3 Provision for basic protection

8.1.3.1 General

Basic protection is employed to prevent persons from touching hazardous live parts. It shall be provided by one or more of the measures given in:

- protection by means of basic insulation of live parts in clause 8.1.3.2;
- protection by means of enclosures or barriers in clause 8.1.3.3;
- protection by means of limitation of touch current and charge in clause 8.1.3.4;
- protection by means of limited voltages in clause 8.1.3.5.

NOTE – Further measures to fulfil the requirement for basic protection are given in [IEC 61140]. Product committees using this document as a reference document might consider those measures.

8.1.3.2 Protection by means of basic insulation of live parts

Live parts shall be completely surrounded with insulation if their working voltage is greater than safety extra low voltage (SELV) or if they do not have protective separation from adjacent circuits of hazardous voltage.

Basic insulation may be provided by solid insulation or air clearance.

The insulation shall be rated according to the impulse voltage, temporary overvoltage or working voltage (see clause 6.2.7), whichever gives the most severe requirement. It shall not be possible to remove the insulation without the use of a tool or key.

An accessible conductive part is considered to be conductive if its surface is bare or is covered by an insulating layer that does not comply with the requirements of at least basic insulation.

Any accessible conductive part is considered to be a hazardous live part if not separated from the live parts by at least as specified in Table 3.

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

8.1.3.3 Protection by means of enclosures or barriers

Live parts with voltage higher than SELV shall be:

- arranged in enclosures or located behind enclosures or barriers, which meet at least the requirements of the protective Type IPXXB according to [IEC 60529];
- located at the top surfaces of enclosures or barriers which are accessible when the equipment is energized shall meet at least the requirements of the protective type IP3X with regard to vertical access only.

For moveable equipment with no defined top and bottom this requirement of protective Type IP3X applies to all sides.

If the MV-PECS is installed in a restricted access area, IPXXB instead of IP3X applies.

Product committees using this document as a reference document might consider less requirements for equipment having openings in the top of an enclosure with a height exceeding 1.8 m.

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 live parts.

Where the enclosure is required to be opened and the MV-PECS energized during installation or maintenance:

- a) accessible live parts of voltage higher than SELV shall be protected by at least IPXXA;
- b) live parts of voltage higher than SELV that are likely to be touched when making adjustments shall be protected by at least IPXXB;
- c) it shall be ensured that persons are aware that live parts with voltage higher than SELV are accessible.

Open type sub-assemblies and equipment do not require protective measures for basic protection. The information provided with the MV-PECS shall indicate that protection shall be provided in the end application.

8.1.3.4 Protection by means of limitation of touch current and charge

The limitation of touch current and discharge energy shall not exceed:

- a value of 3.5 mA a.c. or 10 mA d.c. for the limitation of touch current; and
- a value of 50 μ C for the limitation of discharge energy.

NOTE – Product committees using this document as a reference document may consider the touch current level of 0.5 mA a.c. / 2 mA d.c. as threshold of perception as recommended by [IEC 61140].

8.1.3.5 Protection by means of limited voltages

The voltage between simultaneously accessible parts shall not be greater than SELV.

8.1.4 Provision for fault protection

8.1.4.1 General

Fault protection is required to prevent shock currents which can result from contact with accessible conductive parts during and after an insulation failure.

Fault protection shall be provided by one or more of the following measures:

- Protective equipotential bonding in combinations with the PE conductor in clause 7;
- Automatic disconnection of supply in clause 8.1.4.2;
- Supplementary insulation in clause 8.1.4.3;

- Simple separation between circuits in clause 8.1.4.4;
- Electrically protective screening in clause 8.1.4.5.

Fault protection shall be independent and additional to those for basic protection.

NOTE – Further measures to fulfil the requirement for fault protection are given in [IEC 61140]. Product committees using this document as a reference document might consider those measures.

8.1.4.2 Automatic disconnection of supply

For automatic disconnection of supply:

- a protective equipotential bonding system shall be provided; and
- a protective device operated by the fault current shall disconnect one or more of the line conductors supplying the equipment, system or installation, in case of a failure of basic insulation.

The protective device shall interrupt the fault current within a time as specified in [IEC 62477-1].

8.1.4.3 Supplementary insulation

Supplementary insulation is an independent insulation applied in addition to basic insulation for fault protection and shall be dimensioned to withstand the same stresses as specified for basic insulation.

8.1.4.4 Simple separation between circuits

Simple separation between a circuit and other circuits or earth shall be achieved by basic insulation throughout, rated for the highest voltage present.

If any component is connected between the separated circuits, that component shall withstand the electric stresses specified for the insulation which it bridges.

If any component is connected between a circuit and a circuit connected to earth, its impedance shall limit the current flow through the component to the steady-state touch current values indicated in clause 8.1.3.4.

8.1.4.5 Electrically protective screening

Electrically protective screening interposed between hazardous live parts of a MV-PECS, shall consist of a conductive screen connected to the protective equipotential bonding of the MV-PECS whereby the screen is separated from live parts by at least simple separation.

The protective screen and the connection to the protective equipotential bonding system of the MV-PECS and that interconnection shall comply with the requirements of clause 7.

8.1.5 Enhanced protection

8.1.5.1 General

Enhanced protection shall provide both basic and fault protection and can be achieved by means of:

- reinforced insulation in clause 8.1.5.2;
- protective separation between circuits in clause 8.1.5.3;
- protection by means of in clause 8.1.5.4.

NOTE – Further measures to fulfil the requirement for enhanced protection are given in [IEC 61140]. Product committees using this document as a reference document might consider those measures.

8.1.5.2 Reinforced insulation

Reinforced insulation shall be so designed as to be able to withstand electric, thermal, mechanical, and environmental stresses with the same reliability of protection as provided by double insulation (basic insulation and supplementary insulation, see clauses 8.1.3.2 and 8.1.4.3).

8.1.5.3 Protective separation between circuits

Protective separation between a circuit and other circuits shall be achieved by one of the following means:

- double insulation (basic insulation and supplementary insulation in clauses 8.1.3.2 and 8.1.4.3);
- reinforced insulation in clause 8.1.5.2;
- electrically protective screening in clause 8.1.4.5;
- a combination of these provisions.

If conductors of the separated circuit are contained together with conductors of other circuits in a multi-conductor cable or in another grouping of conductors, they shall be insulated, individually or collectively, for the highest voltage present, so that double insulation is achieved.

If any component is connected between the separated circuits, that component shall comply with the requirements for protective impedance devices (see clause 8.1.5.4)

8.1.5.4 Protection by means of protective impedance

Protective impedance shall be arranged so that under both normal and single fault conditions the current and discharge energy available shall be limited according to clause 8.1.3.4.

The protective impedances shall be designed and tested to withstand the impulse voltages and temporary overvoltage for the circuits to which they are connected.

Compliance with the requirement for the discharge energy shall be checked by performing calculations and/or measurements to determine the voltage and capacitance.

NOTE – A protective impedance designed according to this clause is not considered to be a galvanic connection.

8.1.6 Clearance distances

For clearance distances and solid insulation, the impulse withstand voltage, the temporary overvoltage or the recurring peak value of the working voltage is used.

For MV-PECS, clearances for functional, basic, and supplementary insulation shall be dimensioned according to Table 4.

Interpolation is permitted when clearance is determined from temporary overvoltage or working voltage. Clearances for reinforced insulation shall be dimensioned to withstand 1.6 times the impulse withstand voltage, temporary over-voltage or working voltage.

Clearance distances for use in altitudes above 2 000 m shall be calculated using a correction factor according to Table A.2 of [IEC 60664-1].

Table 4 – Clearance distances for functional, basic, or supplementary insulation

Impulse withstand voltage ^d V	Temporary overvoltage ^{d e} (peak) ^f V only relevant for determining insulation between surroundings and circuits	Working voltage ^{d e} (recurring peak) ^a V	Minimum clearance distances in air up to 2 000 m above sea level g mm			
			Pollution degree			
			1	2	3	4
330	330	260	0.01	0.2 ^{b c}	0.8 ^c	1.6 ^c
500	500	400	0.04			
800	710	560	0.10			
1 500	1 270	1 010	0.5	0.5	1.5	
2 500	2 220	1 770	1.5	1.5		
4 000	3 430	2 740	3.0			
6 000	4 890	3 910	5.5			
8 000	6 060	4 840	8.0			
12 000	9 430	7 540	14			
20 000	12 000	7 600	25			
40 000	26 000	16 000	60			
60 000	37 000	23 000	90			
75 000	48 000	30 000	120			
95 000	61 000	38 000	160			
125 000	80 000	50 000	220			
145 000	99 000	60 000	270			
170 000	116 000	70 000	320			
250 000	170 000	103 000	480			

^a This voltage is approximately 0,8 times the voltage required to break down the associated clearance.
^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 distances 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 60664-1].
^d Interpolation is permitted for non-mains supply.
^e Clearances for temporary overvoltage and working voltage are derived from Table F.7a of [IEC 60664-1].
^f Only relevant for determining insulation between surroundings and circuits see [IEC 60071-1].
^g If the altitude exceeds 2 000 m, the altitude correction coefficient specified in [IEC 60664-1] shall be considered.

8.1.7 Creepage distances

For creepage distances, the r.m.s. value of the working voltage is used.

8.1.7.1 Insulating material groups

Insulating materials are classified into four groups corresponding to their comparative tracking index (CTI) when tested according to clause 6.2 of [IEC 60112]:

- Insulating material group I: $CTI \geq 600$;
- Insulating material group II: $600 > CTI \geq 400$;
- Insulating material group IIIa: $400 > CTI \geq 175$;
- Insulating material group IIIb: $175 > CTI \geq 100$.

Creepage distance requirements for printed wiring boards (PWBs) exposed to pollution degree 3 environmental conditions shall be determined based on Table 5 pollution degree 3 under "Other insulators".

For inorganic insulating materials, for example glass or ceramic, which do not track, the creepage distance may equal the associated clearance distance, as determined from Table 4.

8.1.7.2 Determination

Creepage distances for functional, basic, and supplementary insulation shall be dimensioned according to Table 5. Interpolation is permitted. Creepage distances for reinforced insulation shall be twice the distances required for basic insulation.

Table 5 – Creepage distances (in millimetres)

Column 1	2	3	4	5	6	7	8	9	10	11	12
Working voltage (r.m.s.) V	PWB ^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	
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	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					

^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, and for higher voltages, creepage distances should be dimensioned according to Table F.4 of [IEC 60664-1].

^d Values for creepage distances are not determined for this range. For values, see Table 1 of [IEC 60071-2].

8.1.8 Withstand voltage requirement

The test is used to verify that the clearances and solid insulation of components and assembled MV-PECS have adequate dielectric strength to resist temporary overvoltage conditions.

The values of the test voltage for circuits connected directly to mains supply are determined from column 2 or 3 of Table 6.

The values of the test voltage for circuits connected directly to non-mains supply without temporary overvoltage are determined from column 2 or 3 of Table 7.

The test voltage from column 2 is used for testing circuits with basic insulation.

Between circuits with protective separation (double or reinforced insulation), the test voltage of column 3 shall be applied for type tests. For routine tests between circuits with protective separation the values from column 2 shall be applied to prevent damage to the solid insulation by partial discharge.

The values of column 3 shall apply to MV-PECS with enhanced protection according to clause 8.1.5.

The test is performed between circuits and accessible surfaces of MV-PECS, which are nonconductive or which are conductive but not connected to the PE conductor.

The voltage test shall be performed with a sinusoidal voltage at 50 Hz or 60 Hz. If the circuit contains capacitors the test may be performed with a d.c. voltage of a value equal to the peak value of the specified a.c. voltage.

Table 6 – AC or DC test voltage for circuits connected directly to mains supply

Column 1 <i>System voltage</i>		2 ^b <i>Voltage for type testing circuits with simple separation, and for all routine testing</i>		3 ^b <i>Voltage for type testing circuits with protective separation, and between circuits and accessible surfaces (nonconductive or conductive but not connected to protective earth)</i>	
a.c. r.m.s. V	d.c. V	a.c. r.m.s. ^a V	d.c. V	a.c. r.m.s. V	d.c. V
≤ 50	≤ 50	1 250	1 770	2 500	3 540
100	100	1 300	1 840	2 600	3 680
150	150	1 350	1 910	2 700	3 820
300	300	1 500	2 120	3 000	4 240
600	600	1 800	2 550	3 600	5 090
1 000	1 000	2 200	3 110	4 400	6 220
1 001	1 501	3 000	4 250	4 800	6 800
3 600	5 400	10 000	14 150	16 000	22 650
7 200	10 800	20 000	28 300	32 000	45 300
12 000	18 000	28 000	39 600	44 800	63 350
17 500	26 250	38 000	53 700	60 800	85 900
24 000	36 000	50 000	70 700	80 000	113 100
36 000	54 000	70 000	99 000	112 000	158 400

Interpolation is permitted.

^a Values from Table 2 of [IEC 60071-1].

^b A voltage source with a short-circuit current of at least 0.1 A according to [IEC 61180] is used for this test.

Table 7 – AC or DC test voltage for circuits connected to non-mains supply without temporary overvoltage

Column 1 <i>Working voltage (recurring peak)</i>	2 ^a <i>Voltage for type testing circuits with simple separation, and for all routine testing</i>		3 ^a <i>Voltage for type testing circuits with protective separation, and between circuits and accessible surfaces (nonconductive or conductive but not connected to protective earth)</i>	
	a.c. r.m.s. V	d.c. V	a.c. r.m.s. V	d.c. V
≤ 71	80	110	160	220
141	160	225	320	450
212	240	340	480	680
330	380	530	760	1 100
440	500	700	1 000	1 400
600	680	960	1 400	1 900
1 000	1 100	1 600	2 200	3 200
1 600	1 800	2 600	2 900	4 200

Interpolation is permitted.
 NOTE – Test voltages in this table are based upon 80% of the withstand voltage for the corresponding clearance of Table 10 as provided by Table A.1 of [IEC 60664-1].
 a A voltage source with a short circuit current of at least 0.1 A according to [IEC 61180] is used for this test.

8.1.9 Impulse voltage requirement

The impulse voltage test is performed with a voltage having a 1.2/50 μs waveform, see [IEC 61180], and is intended to simulate overvoltage of atmospheric origin. It also covers overvoltage due to switching of equipment.

Tests on components and devices for protective separation are performed as a type test and a sample test before they are assembled into the MV-PECS, using the impulse withstand voltages listed in column 3 or column 5 of Table 8 and Table 9.

To ensure that surge protective devices are able to reduce the overvoltage, the values of column 2 or column 4 in Table 8 and Table 9, are applied to the MV-PECS as a type test. The measured peak voltage shall not exceed the next lower voltage value of the same column of that table.

The impulse voltage test is successfully passed if no puncture of insulation, flashover, or sparkover occurs. In the case of components and devices which use solid insulation for protective separation, a subsequent partial discharge test (see clause 8.1.10) shall also be passed.

Table 8 – Impulse test voltage for MV circuit

Column 1		2		3	
System voltage		Impulse withstand voltage for insulation between circuits and their surroundings according to over-voltage category III		Impulse withstand voltage for insulation between circuits and their surroundings according to overvoltage category IV	
AC	DC	Basic or supplementary	Reinforced	Basic or supplementary	Reinforced
V	V	V	V	V	V
1 001	1 501	8 000	12 800	12 000	19 200
3 600	5 400	20 000	32 000	40 000	64 000
7 200	10 800	40 000	64 000	60 000	96 000
12 000	18 000	60 000	96 000	75 000	120 000
17 500	26 250	75 000	120 000	95 000	152 000
24 000	36 000	95 000	152 000	125 000	200 000
36 000	54 000	125 000	200 000	145 000	232 000

Interpolation is permitted.
NOTE – Test voltages for overvoltage categories I and II can be derived in a similar way from Table 2.

Table 9 – Impulse test voltage LV circuit

Column 1	2	3	4	5
System voltage	Impulse withstand voltage for <i>insulation</i> between circuits connected to <i>non-mains supply</i> and their surroundings according to overvoltage category II		Impulse withstand voltage for <i>insulation</i> between circuits connected to <i>mains supply</i> and their surroundings according to overvoltage category III	
V	Basic or supplementary V	Reinforced V	Basic or supplementary V	Reinforced V
≤ 50	500	800	800	1 500
100	800	1 500	1 500	2 500
150	1 500	2 500	2 500	4 000
300	2 500	4 000	4 000	6 000
600	4 000	6 000	6 000	8 000
1 000	6 000	8 000	8 000	12 000
–	Interpolation is permitted		Interpolation is not permitted	

NOTE 1 – Test voltages for overvoltage categories I and III can be derived in a similar way from Table 2.
NOTE 2 – Test voltages for overvoltage categories II and IV can be derived in a similar way from Table 2.

8.1.10 Partial discharge requirement

The partial discharge test shall confirm that the solid insulation used in components and sub-assemblies for protective separation of electrical circuits remains partial-discharge-free within the specified voltage range.

This test may be omitted for insulating materials which are not degraded by partial discharge, for example ceramics.

The partial discharge inception and extinction voltage are influenced by climatic factors (e.g., temperature and moisture), equipment self-heating, and manufacturing tolerance. These

influencing variables can be significant under certain conditions and shall therefore be taken into account during type testing.

The test circuit and test method are referred to [IEC 60664-1].

Starting from a voltage below the rated partial discharge test voltage, the voltage shall be linearly increased to 1.875 times U_{PD} and held for a maximum time of 5 s.

The voltage shall then be linearly decreased to 1.5 times U_{PD} ($\pm 5\%$) and held for a maximum time of 15 s, during which the partial discharge is measured.

The test shall be considered to have been successfully passed if the partial discharge is less than 10 pC during the measurement period.

NOTE 1 – The rated partial discharge test voltage U_{PD} is the recurring peak voltage measured across the insulation.

NOTE 2 – Live parts belonging to the same circuit shall be connected together.

NOTE 3 – It is recommended that the partial discharge test is performed after the impulse voltage test in order that any damage caused by the impulse voltage test is apparent.

NOTE 4 – It is advisable that the partial discharge test is performed before inserting the components or devices into the equipment because partial discharge testing is not normally possible when the equipment is assembled.

8.2 Requirements for protection against fire and thermal hazards

8.2.1 Components within a circuit representing a fire hazard

Inside fire enclosures, materials for components and other parts and all materials in contact with such parts shall comply with flammability class V-2 as classified in [IEC 60695-11-10] or flammability class HF-2 as classified in [ISO 9772] or better.

The risk of ignition due to high temperature shall be minimized by the appropriate selection and use of components and by suitable construction.

Electrical components shall be used in such a way that their maximum working temperature under normal or single fault conditions is less than that necessary to cause ignition of the surrounding materials with which they are likely to come into contact. Under normal conditions the limits in Table 10 shall not be exceeded for components or their surrounding material.

Where it is not practical to protect components against overheating under fault conditions, all materials in contact with such components shall be of flammability class V-1, according to [IEC 60695-11-10], or better.

Table 10 – Maximum measured total temperatures for internal materials and components

Materials and components	Thermocouple method °C	Rise of resistance method °C
1 Rubber- or thermoplastic-insulated conductors ^a	75	
2 Field wiring terminals and other parts that may contact the <i>insulation</i> of field wiring ^b	b	
3 Copper bus bars and connecting straps	c	
4 <i>Insulation systems</i> on magnetic components ^d	e	e
Class A (105)	90	100
Class E (120)	105	115
Class B (130)	110	120
Class F (155)	130	140
Class H (180)	155	165
Class N (200)	165	175
Class R (220)	180	190
Class S (240)	195	205
5 Phenolic composition ^a	165	
6 On bare resistor material	415	
7 Capacitor	f	
8 Power electronic devices	g	
9 PWBs	h	
10 Components bridging at least <i>basic protection</i>	f	
11 Liquid cooling medium	i	

^a The limitation on phenolic composition and on rubber and thermoplastic *insulation* does not apply to compounds which have been investigated and found to meet the requirements for a higher temperature.
^b The maximum terminal temperature should not exceed the temperature rating of the terminal and the *insulation* temperature rating of the conductor or cable specified by the manufacturer (see clause 6.3.6.4 of [IEC 62477-1]).
^c The maximum permitted temperature is determined by the temperature limit of support materials or *insulation* of connecting wires or other components. A maximum temperature of 140 °C is recommended.
^d The maximum temperatures on *insulation* of magnetic components assume thermocouples are applied on the surface of coils, and are therefore not located on hot-spots. Rise of resistance method results in a measurement of the average temperature of the winding.
^e These limits are extracted from the group safety standards [IEC 61558-1] and [IEC 61558-2-16] (safety of power transformers, power supplies, reactors and similar products). For magnetic components, not covered by the scope of IEC 61558 series, committees for product standards may define other limits in accordance with [IEC 60085] and [IEC 60216].
^f For a component, the maximum temperature specified by the manufacturer should not be exceeded.
^g The maximum temperature on the case should be the maximum case temperature for the applied power dissipation specified by the manufacturer of power electronic devices.
^h The maximum operating temperature of the PWB shall not be exceeded.
ⁱ The maximum temperature of the cooling medium, specified by the manufacturer of the medium or determined from the known characteristics of the medium, should not be exceeded.

8.2.2 Internal arc classification requirements

The main purpose of the internal arc classification is that the manufacturer provides all necessary information in the product documentation and marking to ensure that the final installation can provide protection against an internal arc fault event. No arc fault testing is required to meet the minimum requirements of this document. It is intended that this information is provided in full to the end user. The manufacturer can only be responsible to transfer this information to the customer. The manufacturer can decide whether to perform the test in consultation with the customer.

The MV-PECS shall meet internal arc test requirements in clause 6.106 of [IEC 62271-200]. If the upstream of the MV-PECS is configured with fuses with controllable breaking characteristics, the MV-PECS can be equipped with fuses for internal arc tests and meet the criteria in clause 6.106 of [IEC 62271-200].

9 Lightning surge protection

9.1 Protection of MV power line

In order to limit the amplitude and reduce the steepness of lightning surge into medium voltage (MV) arresters and MV-PECS system, it is suggested to protect the incoming section of MV power line against the direct lightning stroke.

NOTE – For medium voltage system, the term of "incoming section of MV power line" refers to the last 1~2 km MV power line connected to substation, which needs to be specially protected against direct lightning stroke by means of overhead ground wire or by use of underground buried cable.

There are some measures to protect the incoming section of MV power line against the direct lightning stroke. Two simplified protection measures shown in Figure 6 are used as an example for reference only.

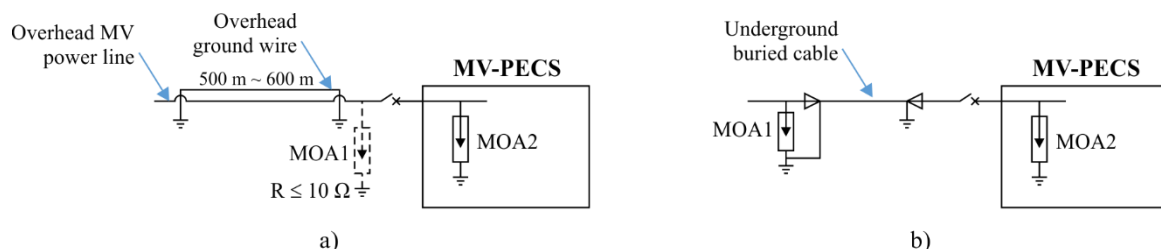


Figure 6 – Simplified protection measures for incoming section of MV power line

Where overhead MV power lines are used to power the MV-PECS, it is suggested to set overhead ground wire above MV power lines at least 500 m ~ 600 m from the end pole to ICT data centre or telecommunication centre. In addition, it is suggested to install a set of metal-oxide surge arresters (MOAs) between power lines to earth at the end pole to further limit the amplitude of lightning surge. The minimum nominal discharge current I_n of MOA is recommended as shown in Table 11.

Where underground buried cables are used to power the MV-PECS, it is suggested to install a set of MOA between power lines to earth at the joint point of overhead power lines and underground buried cables. The minimum nominal discharge current I_n of MOA is recommended as shown in Table 11.

The MOA shall comply with [IEC 60099-4] or [IEC 60099-6].

9.2 Protection of MV input port

It is suggested to install a set of MOA at the upstream of AC/DC conversion cabinets, generally in medium voltage input cabinet, to protect both differential mode power circuits and components and common mode insulation. The minimum nominal discharge current I_n of MOA is recommended as shown in Table 11.

The MOA shall comply with [IEC 60099-4] or [IEC 60099-6].

Table 11 – Minimum nominal discharge current In of MOA

Installation scenarios	Phase to earth	Phase to phase
Low exposed area	5 kA	2.5 kA
Medium exposed area	5 kA	2.5 kA
High exposed area	10 kA	5 kA

9.3 Protection of LV output port and signal/control ports

For the LV output port and signal/control ports, the resistibility requirements of [ITU-T K.20] shall be met.

Bibliography

- [b-ETSI EN 301 605] ETSI EN 301 605 V1.1.1 (2013), *Environmental Engineering (EE); Earthing and bonding of 400 V DC data and telecom (ICT) equipment.*

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