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INTERNATIONAL STANDARD

Lightning and surge voltage protection for photovoltaic (PV) power supply systems

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Lightning and surge voltage protection for photovoltaic (PV) power supply systems

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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LIGHTNING AND SURGE VOLTAGE PROTECTION FOR PHOTOVOLTAIC (PV) POWER SUPPLY SYSTEMS

FOREWORD

IEC TR 63227 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
82/1501/DTR	82/1554A/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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

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- withdrawn,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

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LIGHTNING AND SURGE VOLTAGE PROTECTION FOR PHOTOVOLTAIC (PV) POWER SUPPLY SYSTEMS

1 Scope

This document deals with the protection of PV power supply systems against detrimental effects of lightning strikes and surge voltages of atmospheric origin. In the event that a lightning and/or surge voltage protection is required to be erected, this document describes requirements and measures for maintaining the safety, functionality, and availability of the PV power supply systems.

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 60364-4-44:2007/AMD1:2015, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-7-712:2017, *Low voltage electrical installations – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems*

IEC 61643-11:2011, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and test methods*

IEC 61643-21, *Low voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods*

IEC 61643-31, *Low-voltage surge protective devices – Part 31: Requirements and test methods for SPDs for photovoltaic* installations

IEC 62305-1, *Protection against lightning – Part 1: General principles*

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62305-3:2010, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC 62561-1, *Lightning Protection System Components (LPSC) – Part 1: Requirements for connection components*

IEC 62561-2, *Lightning Protection System Components (LPSC) – Part 2: Requirements for conductors and earth electrodes*

IEC 62561-3, *Lightning Protection System Components (LPSC) – Part 3: Requirements for isolating spark gaps (ISG)*

IEC 62561-4, *Lightning protection system components (LPSC) – Part 4: Requirements for conductor fasteners*

3 Terms and definitions

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

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

3.1
photovoltaic
PV
relating to the conversion of light directly into electrical energy

[SOURCE: IEC 62109-1:2011, 3.55]

3.2
PV module
smallest complete and environmentally protected assembly of interconnected PV cells

[SOURCE: IEC 60364-7-712:2017, 712.3.2]

3.3
PV inverter
device which converts DC voltage and DC current into AC voltage and AC current

3.4
PV string
circuit in which PV modules are connected in series to a PV sub-generator in order to achieve the specified output voltage

3.5
PV sub-generator
mechanically and electrically assembled combination of PV modules and other necessary components in order to form a DC power supply unit

3.6
PV generator
combination of PV sub-generators

3.7
surge protective device
SPD
device that contains at least one non-linear component and is intended to limit surge voltages and divert surge currents

Note 1 to entry: An SPD is a complete assembly having appropriate connecting means.

[SOURCE: IEC 61643-11:2011, 3.1.1]

3.8
voltage switching type SPD
SPD that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge

Note 1 to entry: Common examples of components used in voltage switching type SPDs are spark gaps, gas tubes, and thyristors. These are sometimes called “crowbar type” components.

[SOURCE: IEC 61643-11:2011, 3.1.4]

3.9
voltage limiting type SPD
SPD that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage

Note 1 to entry: Common examples of components used in voltage limiting type SPDs are varistors and avalanche breakdown diodes. These are sometimes called “damping type” components.

[SOURCE: IEC 61643-11:2011, 3.1.5]

3.10
combination type SPD
SPD that incorporates both voltage switching components and voltage limiting components

Note 1 to entry: The SPD can exhibit voltage switching (e.g. spark gap), voltage limiting (e.g. varistor) or both. These components can be connected in series as well as in parallel.

[SOURCE: IEC 61643-11:2011, 3.1.6, modified – Second sentence of definition moved to the note to entry. Second sentence of note to entry has been added.]

4 Design principles

4.1 Causes of damage and damages

The lightning current of a lightning discharge can be injected into PV power supply systems in different ways:

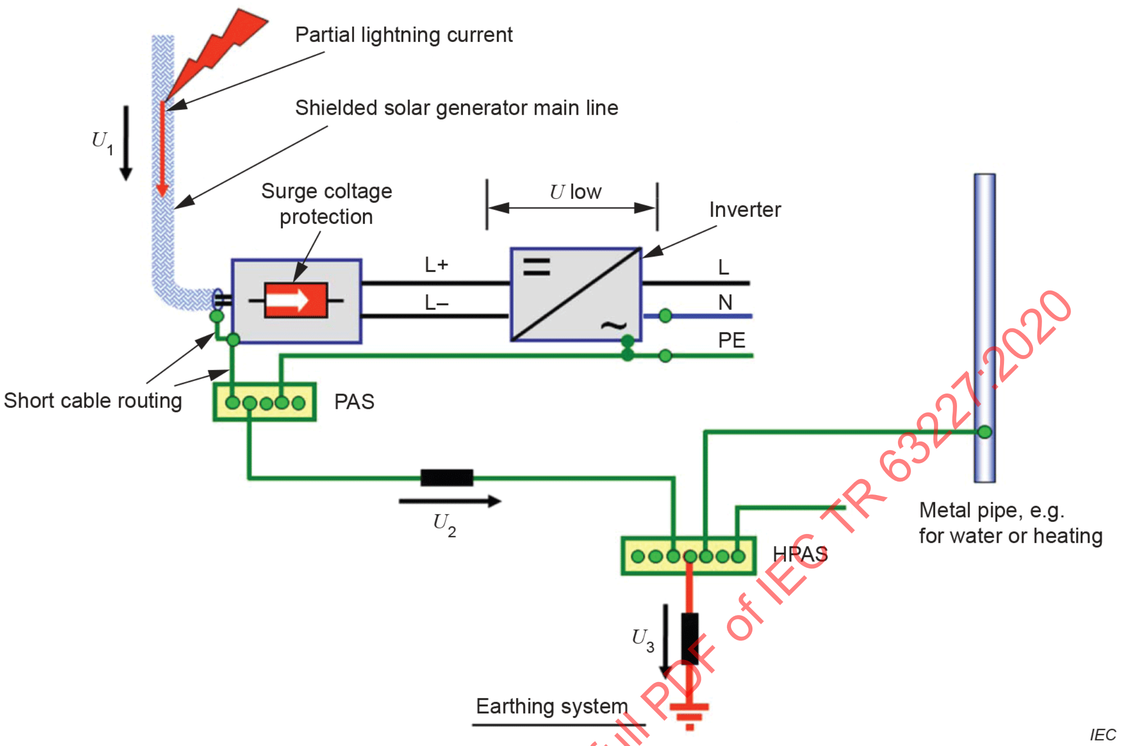
– by galvanic coupling;
– by magnetic field coupling;
– by electric field coupling.

The respective type of coupling is influenced by lightning protective measures (e.g. earthing, equipotential bonding, shielding of the structure, shielding of the electric lines as well as layout and type of these lines).

4.2 Galvanic coupling

A prerequisite for galvanic coupling is for the lightning current or at least part of it to be injected directly. The (partial) lightning current generates a direct-axis component of voltage at the impedances of the lines it passes through. When a structure is struck by lightning, the current flowing to earth normally generates a voltage magnitude of some hundred kilovolts at the effective conventional earth impedance.

Figure 1 shows examples of galvanic couplings at an equipotential bonding line carrying a (partial) lightning current and at the conventional earth impedance. This type of coupling is also present where a (partial) lightning current passes through a line’s cable screen. In that case, the (partial) lightning current causes a direct-axis component of voltage at the coupling impedance of the cable screen, which appears between the cable screen and the inner conductor. This direct-axis component of voltage U_1 can jeopardize the electric or electronic systems connected at the two line ends.



Key

U_1	Direct-axis component of voltage at the cable screen the current flows through
U_2	Direct-axis component of voltage at the voltage equalizing cable $U_2 = L\ \mathrm{d}i/\mathrm{d}t$
U_3	Voltage at the conventional earth impedance RE ($U_3 = i\ R_E$)
PAS	Equipotential bonding bar
HPAS	Main earthing bar

Figure 1 – Examples of direct-axis components of voltage for galvanic coupling

4.3 Magnetic field coupling

The process at which the magnetic field $H(t)$ of a lightning discharge passes through conductor loops is referred to as magnetic field coupling or magnetic induction (see Figure 2). If the conductor loops are open (idle motion), voltages u_{ind} will result in proportion to $\mathrm{d}H/\mathrm{d}t$; however, where the conductor loops are short-circuited currents, i_{ind} will result in proportion to $H(t)$.

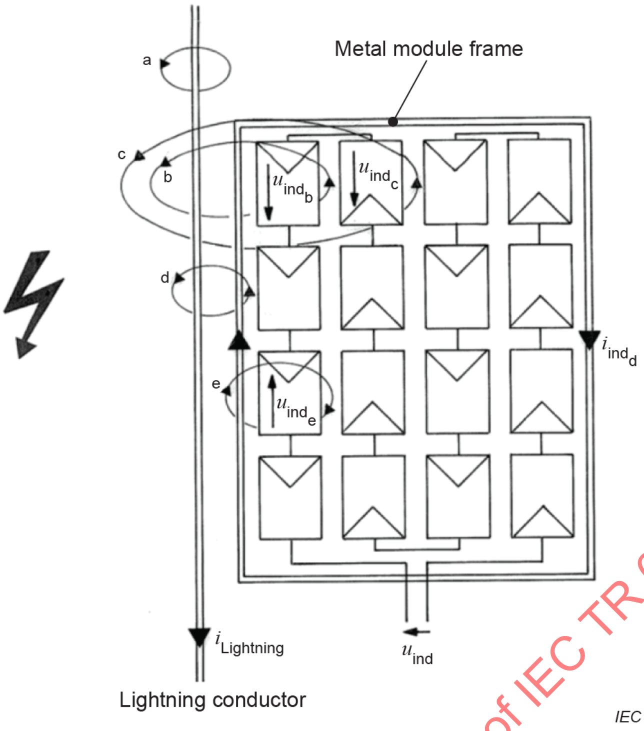


Figure 2 – Voltages induced in loops by the steepness of the lightning current

Magnetic injections can be reduced considerably by increasing the distance of air-termination systems and down-conductors to the PV modules. A minimum value of 0,5 m is recommended for the distance of air-termination systems and down-conductors to the PV modules. The separation distance s can differ from this value (see Annex C).

4.4 Electric field coupling

A prerequisite for electric field coupling is an “electrically effective aerial” (e.g. the module frame). The electric field strength resulting from the leader approaching reaches up to 500 kV/m at a distance of a couple hundred metres to the prospective striking point. As soon as the main discharge starts, the electric field breaks down. During that process, field changes dE/dt can appear at a magnitude of 500 (kV/m)/µs.

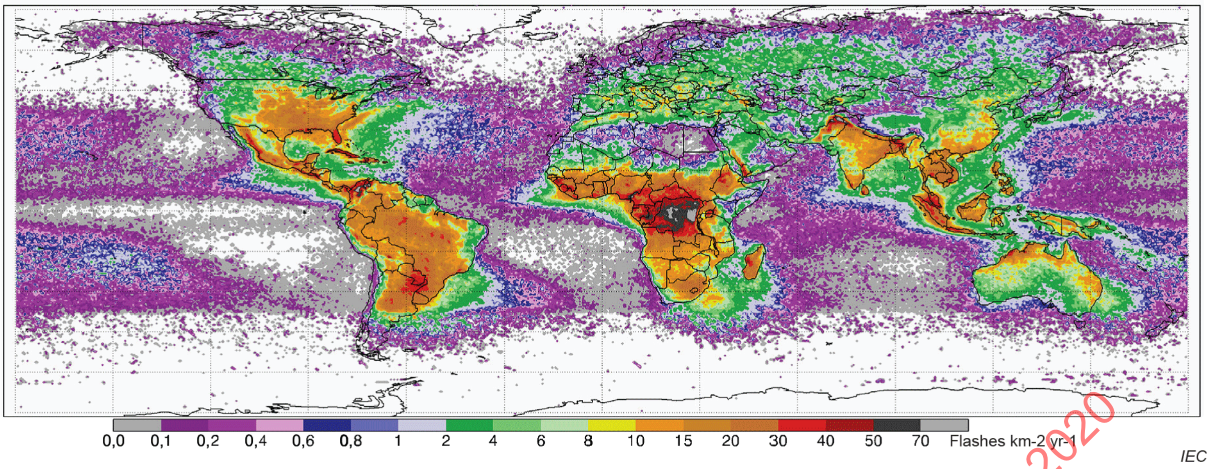
The effect of electric field coupling to equipment installed within and outside a structure is generally very small compared to that of magnetic field coupling.

4.5 Risk management

A lightning protection system (LPS) designed to comply with class III meets the regular requirements for PV power supply systems.

In special cases, e.g. for objects of cultural value or requirements for an increased availability of the system, it should be checked in accordance with IEC 62305-2 whether additional measures or a different LPS class is required.

The lightning protection measures for the PV power supply system are adapted to the LPS class of the structure. The LPS class of the building is determined by factors as its use, values and others as well as the area-specific lightning activity (Figure 3). The area-specific lightning activity should be also taken into account to decide on lightning protection measures for ground-mounted systems.



(Source: https://ghrc.nsstc.nasa.gov/pub/lis/climatology/LIS-OTD/HRFC/browse/HRFC_COM_FR_V2.3.2015.png)

Figure 3 – High resolution full climatology (HRFC)

5 Lightning protection system (LPS)

5.1 General

The erection of conventional PV power supply systems on or at buildings does not change the lightning strike risk. It is recommended to design and harmonize the PV power supply and lightning protection systems before erection.

The PV generator delivers current and voltage even at low amounts of solar irradiance. This has to be taken into account for mounting and troubleshooting purposes.

Suitable measures of external lightning protection are supposed to catch direct lightning and feed them into an earthing system such that no galvanically coupled currents can have an effect on metal building installations and the PV power supply system.

In addition to that, measures of internal lightning protection are used to prevent impacts that lightning strikes and potential differences may have onto and inside the building.

The purpose of these measures is to prevent damage to the building (mechanical damages up and including fire and its effects) as well as damage to the PV power supply system (supply networks, controls and electrical protective equipment). Where the legislator requires lightning protective measures as part of the preventive fire protection, these shall not be affected by PV power supply systems.

For lightning protection, the IEC 62305 series applies.

For the erection of PV power supply systems, the IEC 60364 series and, in particular, IEC 60364-7-712 apply.

In order for a lightning protection system to be erected, co-ordination across all trades involved is required.

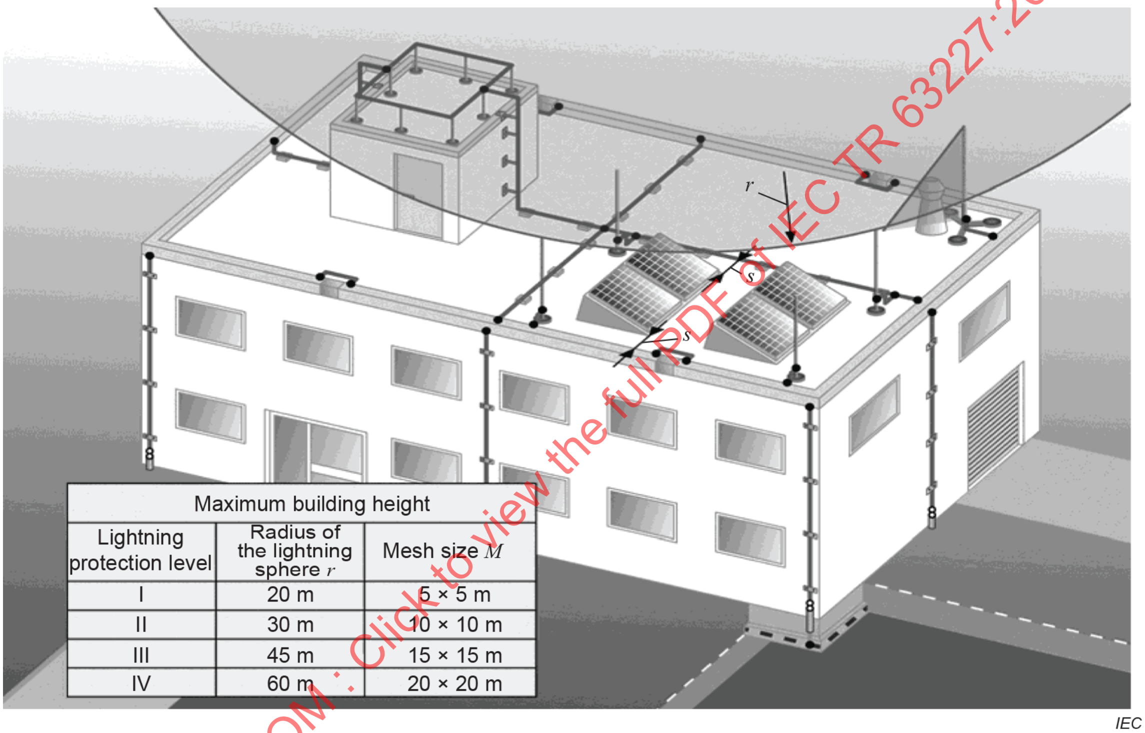
Design, erection, and inspection are carried out by lightning protection specialists. The requirements for lightning protection specialists are specified in IEC 62305-3. A lightning protection specialist is someone who is able to design, erect or inspect lightning protection systems based on their professional training, knowledge, and experience as well as knowledge of the relevant standards.

5.2 External lightning protection

Within the meaning of the lightning protection standard IEC 62305-3, PV power supply systems as roof fixtures shall, where possible, be protected against direct lightning strikes by means of separate air-termination systems. Arrangement and positioning of the air-termination systems can be determined by three different methods (see Figure 4):

– rolling sphere method;
– mesh method;
– protection angle method.

The rolling sphere method represents a universal design method which is particularly recommended for geometrically complicated application cases.



Maximum building height		
Lightning protection level	Radius of the lightning sphere r	Mesh size M
I	20 m	5 × 5 m
II	30 m	10 × 10 m
III	45 m	15 × 15 m
IV	60 m	20 × 20 m

Figure 4 – Example for the design of the air-termination system for a PV power supply system using the rolling sphere method

The air-termination systems are set up observing the separation distance (see Figure 5). This is the distance to be maintained in order to prevent dangerous sparking against parts of the PV power supply system (see Annex E). Between the PV modules and any metal parts such as lightning protection systems, gutters, dormer windows or antenna systems, the separation distances s determined in accordance with IEC 62305-3 shall preferably be maintained.

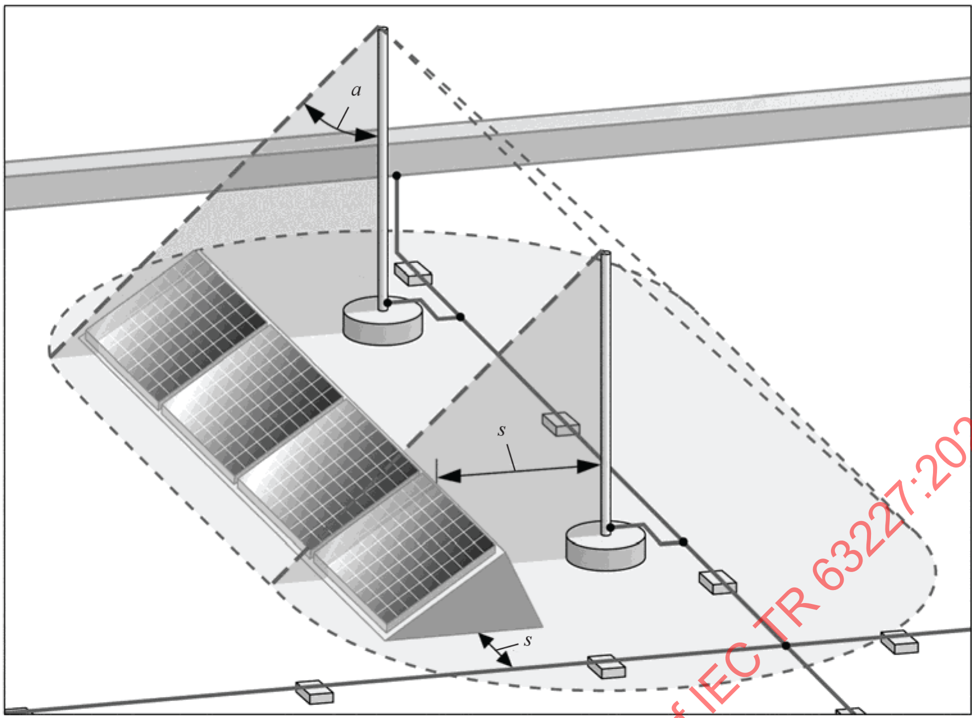


Figure 5 – Maintaining the separation distance

Where the separation distance cannot be provided, e.g. in the case of a metal roof, it is recommended to provide for suitable connections between the lightning protection system and the components of the PV power supply system. The resulting partial lightning currents into the building and into the PV power supply system can only be decoupled in the earthing system.

For connections and connection components through which (partial) lightning currents will pass, the specifications given in IEC 62561-1, IEC 62561-2, IEC 62561-3 and IEC 62561-4 apply.

For the first installation of a PV power supply system on a structure, adjustments of the existing LPS and electrical system can be required.

For the erection of an external lightning protection, the possibility of the PV modules being shadowed by air-termination systems shall be taken into account (see Figure 6 and Annex A).

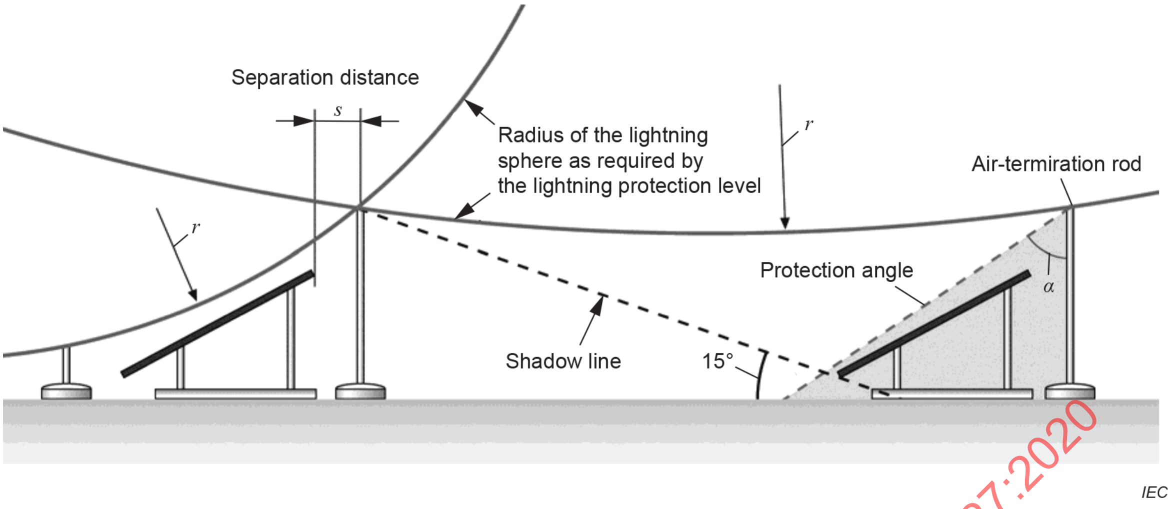


Figure 6 – Example for the design of the air-termination system for a PV power supply system

5.3 Internal lightning protection

The purpose of the internal lightning protection is to prevent dangerous sparking inside the structure to be protected.

Dangerous sparking can occur between the external lightning protection system and other components, e.g.:

– the metal installation;
– the PV power supply system;
– the electrical and electronic systems within the structure to be protected;
– the external conductive parts, cables, and lines inserted into the structure.

Dangerous sparking can be prevented by:

– providing the required separation distance of metal parts and electrical equipment to the lightning protection system; or
– consistent lightning equipotential bonding of the metal parts and electrical equipment with the lightning protection system.

The resulting partial lightning currents into the building and into the PV power supply system shall be taken into account.

Whether surge voltage protective measures are to be provided on the AC side of the PV power supply system is determined as specified in IEC 60364-4-44:2007/AMD1:2015, Clause 443.

If it is determined that surge voltage protective measures are required on the AC side and, in particular, if the protection of the inverter is to be ensured, then surge voltage protective measures are required also on the DC side.

If signal and communication circuits are available in the PV power supply system, then these signal and communication circuits shall also be protected by surge protective devices (SPDs).

For surge protective devices (SPDs) installed on the AC side of the PV power supply system, IEC 61643-11 applies.

For surge protective devices (SPDs) installed in the signal and communication circuits, IEC 61643-21 applies.

For surge protective devices (SPDs) installed on the DC side of the PV power supply system, IEC 61643-31 applies.

5.4 Lightning equipotential bonding

Lightning equipotential bonding is achieved by connecting the lightning protection system to:

- the metal frame of the structure;
- the installations made of metal;
- the external conductive parts and lines connected to the structure;
- the electrical and electronic systems within the structure to be protected.

If lightning equipotential bonding is provided when installing the internal system, then part of the lightning current can pass into such systems and this effect shall be taken into account.

Connection measures can be:

- equipotential bonding lines, where electrical continuity is not achieved by the natural connections;
- surge protective devices, where direct connection to equipotential bonding conductors is not possible.

If the distance between the SPD and the inverter to be protected is greater than 10 m, then additional surge protective devices are installed in the vicinity of the inverter to be protected.

EXAMPLE The DC line is included in the lightning equipotential bonding upon entry into the structure and the following distance between the installation location of the surge protective device and the inverter is greater than 10 m.

5.5 Lightning protection zone concept

For highly sensitive facilities in structures, e.g. computer centres or telecommunications systems, application of the lightning protection zone concept as specified in IEC 62305-4 can be required. In these cases, the respective lightning and surge voltage protection measures shall also be implemented for the PV power supply system.

5.6 Selection of surge protective devices (SPDs)

5.6.1 General

Depending on whether or not an external lightning protection system is installed and whether or not the required separation distance is maintained between this external lightning protection system and the elements of the PV power supply system, the required SPDs are selected in accordance with Figure 7 and Table 1.

Where an external lightning protection system is neither installed nor planned to be installed, the effects of surge voltages and the resulting economic losses can be reduced by means of surge protective devices (SPDs) (see Figure 6) or shielding measures (see IEC 62305-4).

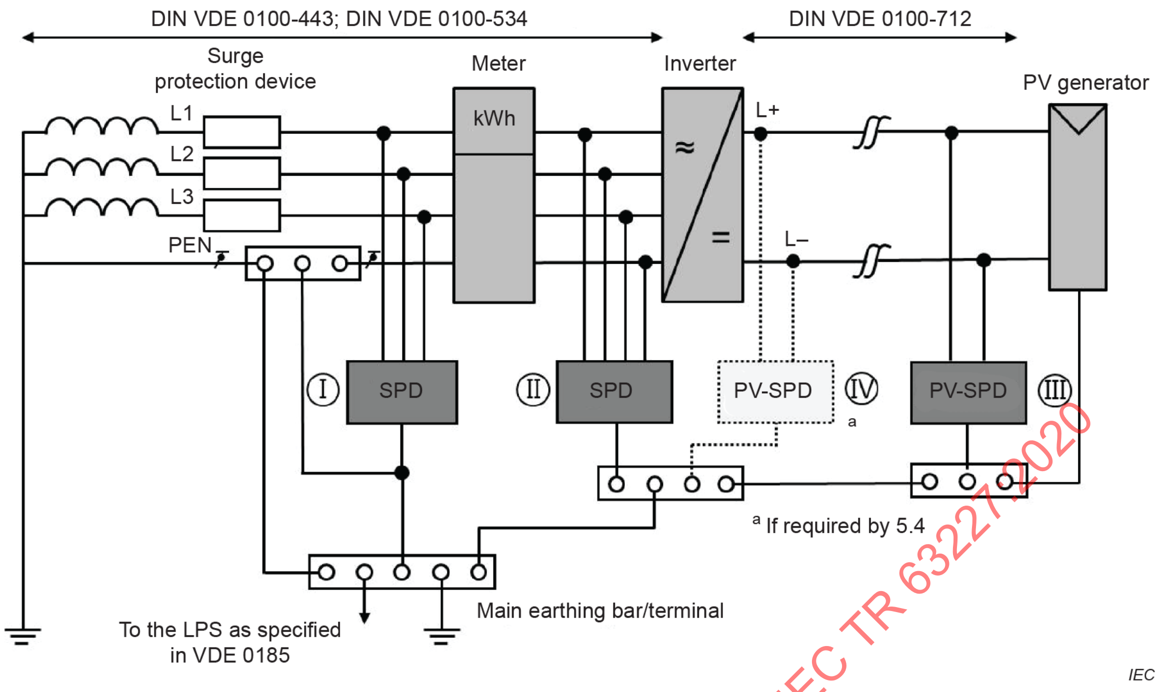


Figure 7 – Use of SPDs in PV power supply systems

The SPDs are selected from Table 1 depending on the test class and minimum cross-section of the equipotential bonding.

Table 1 – Selection of the SPD test class (type) and minimum cross-section of the equipotential bonding

Situation		Equipotential bonding	SPD at installation location "I"	SPD at the installation location "II"	SPD at the installation location "III" and at the installation location "IV"
A	Installation of SPDs in a structure without an external lightning protection system (LPS) (see Figure 7)	6 mm^2*	Class II tested SPDs as specified in IEC 61643-11	Class II tested SPDs as specified in IEC 61643-11	Class II tested SPDs as specified in IEC 61643-31
B	Installation of SPDs in a structure with an external lightning protection system (LPS), separation distance s is maintained (see Figure 8)	6 mm^2	Class I tested SPDs as specified in IEC 61643-11	Class II tested SPDs as specified in IEC 61643-11	Class II tested SPDs as specified in IEC 61643-31
C	Installation of SPDs in a structure with an external lightning protection system (LPS), separation distance s is not maintained (see Figure 9)	16 mm^2	Class I tested SPDs as specified in IEC 61643-11	Class I tested SPDs as specified in IEC 61643-11	Class I tested SPDs as specified in IEC 61643-31

* if necessary.

If an external lightning protection system is already installed on the building or required for legal reasons or, respectively, desired for insurance reasons, then the PV power supply system is protected by surge protective devices (SPDs) (see Figure 8).

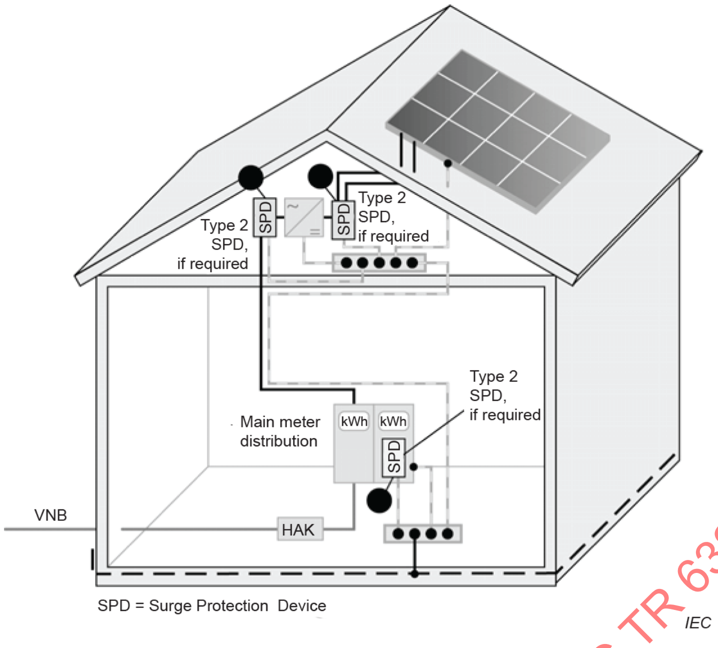


Figure 8 – Situation A) The surge voltage protection concept for a PV power supply system on a building without external lightning protection

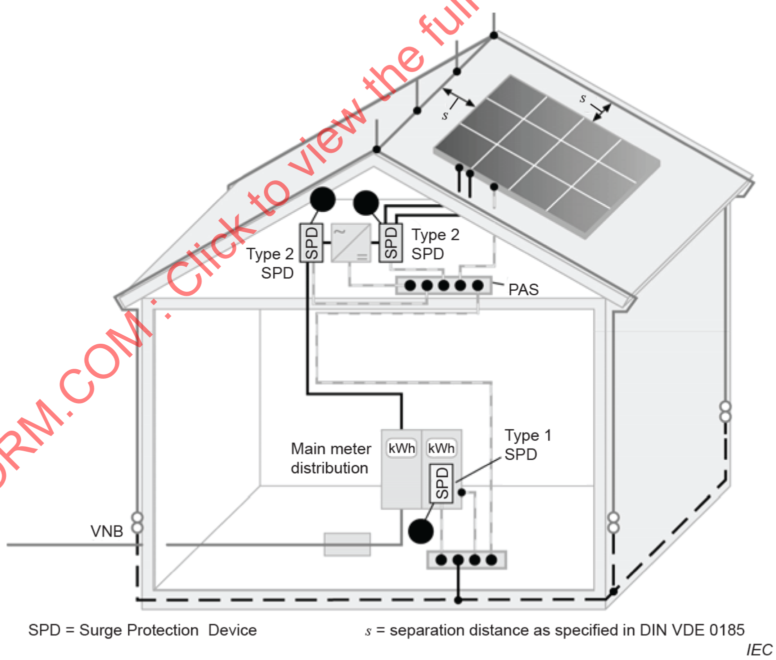


Figure 9 – Situation B) Surge voltage protection concept for a PV power supply system on a building with external lightning protection, the separation distance *s* is maintained

If the separation distance is maintained (see Figure 9), then DC lines can be mounted on the outside of the structure, fully shielded down to ground level. In that case, inductively injected voltages are reduced. The cable screen has to be connected to the earthing system at the module rack and at the base. The use of Class II tested SPDs may then be omitted.

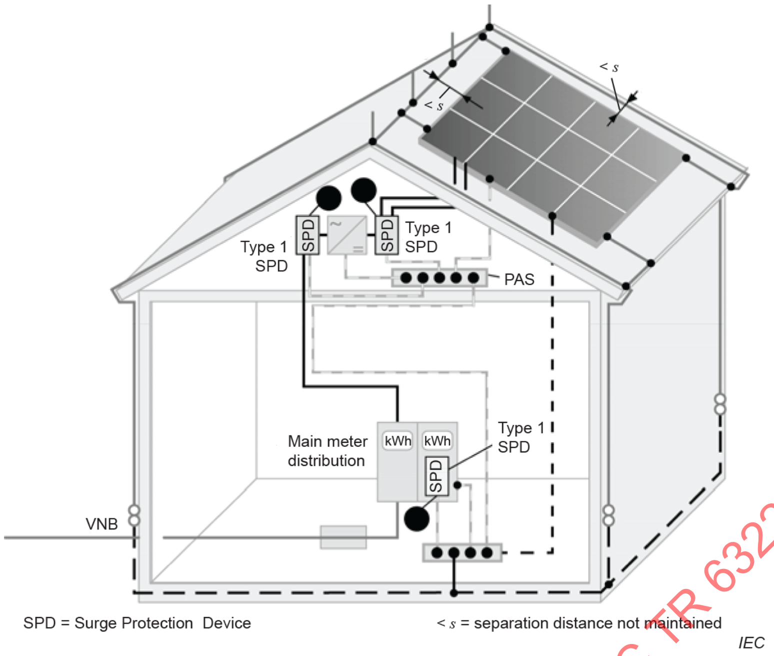


Figure 10 – Situation C) Surge voltage protection concept for a PV power supply system on a building with external lightning protection, the separation distance s is not maintained

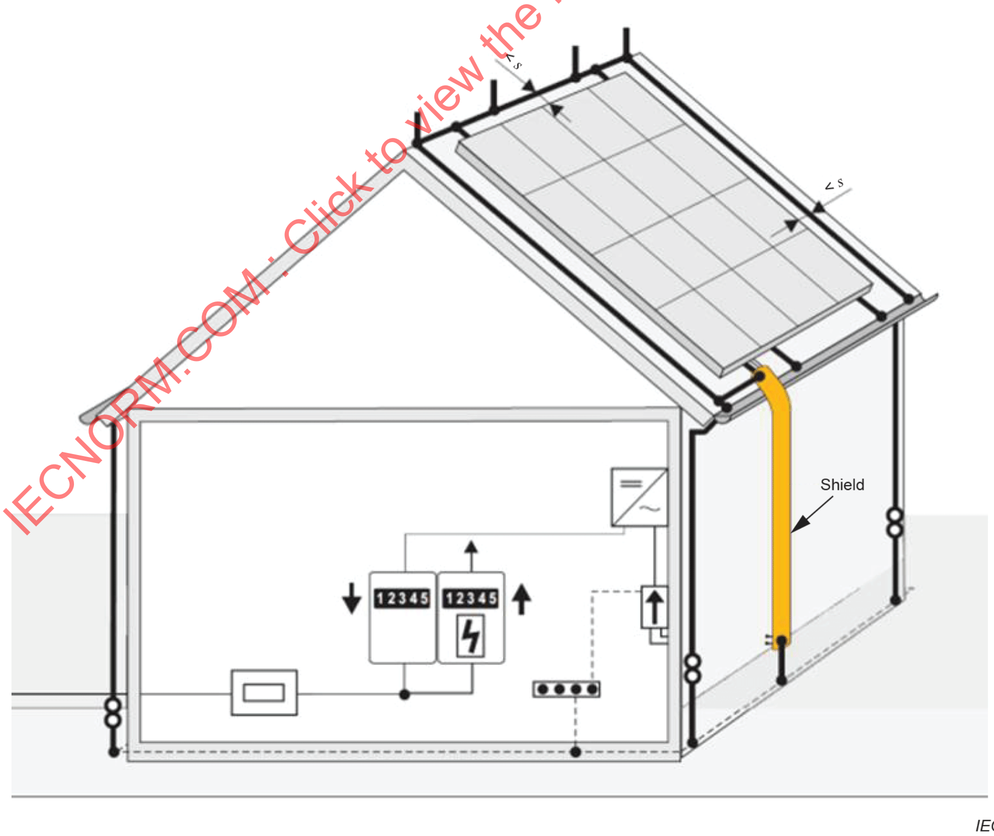


Figure 11 – Situation C) Surge voltage protection concept for a PV power supply system on a building with external lightning protection, the separation distance s is not maintained, use of a shield able to carry the lightning current

If the separation distance cannot be maintained (see Figure 10), then DC lines can be mounted with a shield on the outside of the structure down to ground level (see Figure 11). In that case, the cable screen has to be connected to the air-termination system at the highest point and to the earthing system at the base directly before entry into the building. The cable screen has to be constructed to withstand the impulse currents associated with lightning discharges and it is to be included in the lightning equipotential bonding as described in IEC 62305-3 and IEC 62305-4.

The use of a Type 2 surge protective device on ground level can be sufficient if, at the roof level PV generator, only a small partial lightning current is injected. This depends on the length of the shielded line, the quality of the shield used, on the execution of the lightning equipotential bonding on the roof level (mesh size) and the number of down-conductors of the external lightning protection. This shall be checked for the individual case (with regard to this, see IEC 62305-4).

SPDs to be used on the DC side of PV power supply systems are designed to be suitable for the type and magnitude of the occurring voltages. The maximum operating voltage in PV power supply systems can reach values of up to 1 500 V DC.

The rated voltage U_c of Class I and Class II tested SPDs on the DC side depends on the type of protective circuit and the magnitude of the maximum operating voltage of the PV modules. For functionally earthed PV power supply systems, see 5.8.

The maximum permitted protection level U_p of surge protective devices should be equal or less than the rated impulse withstand voltage of the connected equipment. For the DC side, which, due to functional reasons, does not have a rated impulse withstand voltage, the energetic coordination between surge protective devices and the device input shall be taken into account (see 5.7).

NOTE The surge protection components inside PV inverters serves is generally used only for the internal equipment protection and does not normally meet the requirements for Class I and Class II tested SPDs.

An overview for the selection of SPDs in a PV power supply system is shown in Figure 12.

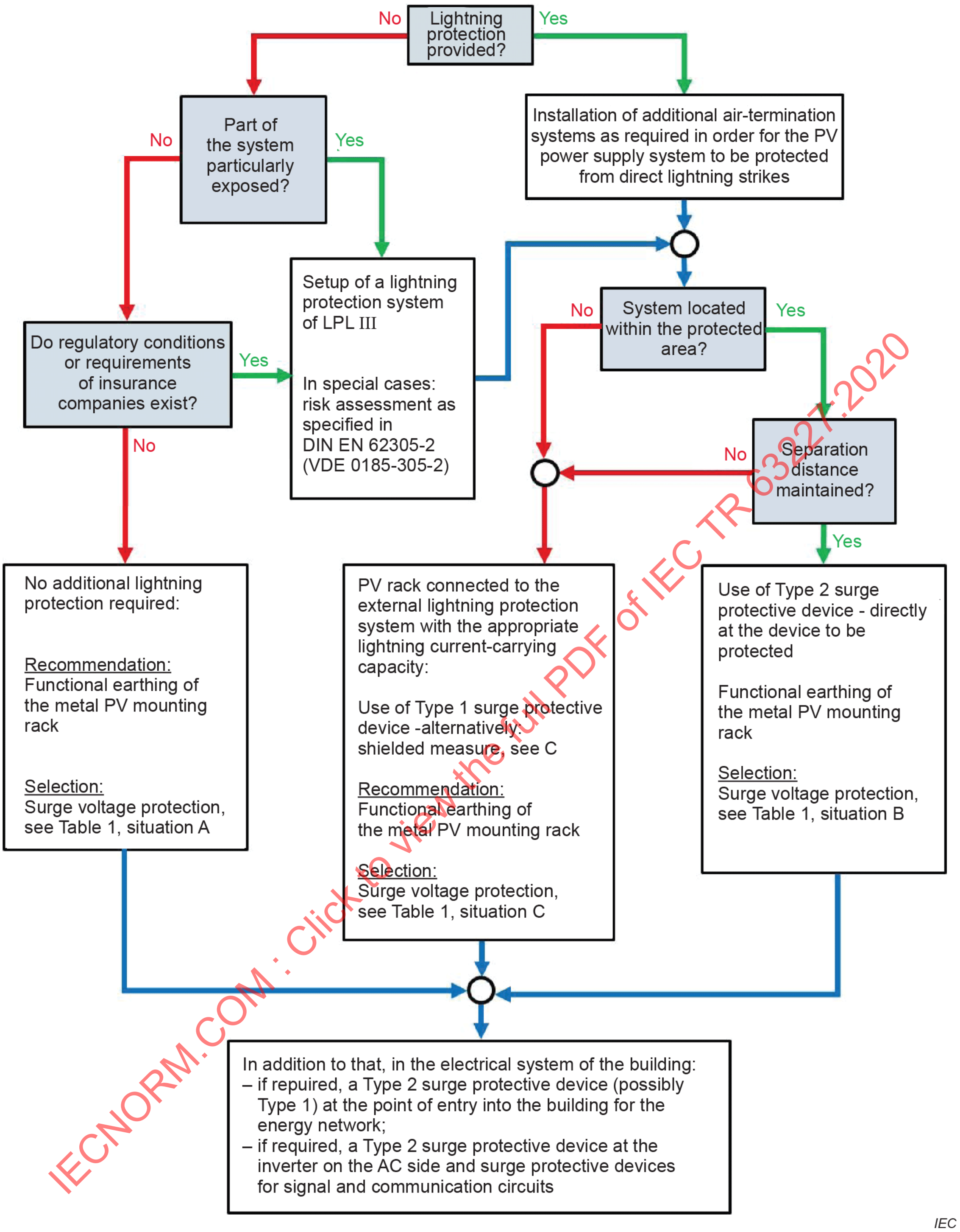


Figure 12 – Flow chart for the selection of protective measures

With regard to whether or not surge voltage protective measures are required IEC 60364-4-44:2007/AMD1:2015, Clause 443 and IEC 60364-7-712 are also to be considered.

5.6.2 Class I tested SPD, lightning current-carrying capacity I_{imp}

The use of Class I tested SPD on the DC- side of PV power supply systems is recommended for cases where:

– external lightning protection is installed; and

– the required separation distance to the elements of the PV power supply system is not maintained.

In 4.5, it is described that a lightning protection system of lightning protection level III meets the regular requirements for PV power supply systems. In special cases, e.g. where other lightning protection levels are required, the necessity of additional measures is checked in accordance with IEC 62305-2.

The lightning current-carrying capacity I_{imp} of Class I tested SPDs shall be adequate to the loads occurring at the installation location as specified in IEC 62305-1 and is selected from Table 2 or Table 3 depending on the type of SPD. Alternatively, the lightning current-carrying capacity may be calculated as described in IEC 62305-4.

Table 2 – Selection of the minimum discharge capacity of voltage limiting SPDs of Class I tested (voltage limiting type) or combined SPDs of Type 1 (series connection of voltage limiting type and voltage switching type)

Lightning protection level LPL and maximum lightning current (10/350)		Number of down-conductors of the external lightning protection system			
		< 4 (see Figure 13)		≥ 4	
		Values for voltage limiting Class I tested SPDs or combined class I tested SPDs (series connection) based on a selection $I_{8/20}$ (8/20 µs) and $I_{10/350}$ (10/350 µs)			
		$I_{SPD\ 1} = I_{SPD\ 2}$ $I_{8/20}$ / $I_{10/350}$	$I_{SPD\ 3} = I_{SPD\ 1} + I_{SPD\ 2} = I_{total}$ $I_{8/20}$ / $I_{10/350}$	$I_{SPD\ 1} = I_{SPD\ 2}$ $I_{8/20}$ / $I_{10/350}$	$I_{SPD\ 3} = I_{SPD\ 1} + I_{SPD\ 2} = I_{total}$ $I_{8/20}$ / $I_{10/350}$
I or unknown	200 kA	17 / 10	34 / 20	10 / 5	20 / 10
II	150 kA	12,5 / 7,5	25 / 15	7,5 / 3,75	15 / 7,5
III or IV	100 kA	8,5 / 5	17 / 10	5 / 2,5	10 / 5

NOTE 1 The designations SPD 1, SPD 2, and SPD 3 refer to the representation in Figure 12.

NOTE 2 For this application two choices are available, i.e. the use of **either**

– a voltage limiting or combined SPD of Type 1 with $I_{imp} \geq I_{10/350}$ **and with** $I_{in} \geq I_{8/20}$; or

– a voltage limiting or combined SPD of Type 1 with $I_{imp} \geq I_{8/20}$.

EXAMPLE For the protection of the DC side of a PV installation on a building with LPS, with lightning protection level LPL III, with less than 4 down-conductors and insufficient separation distance s, the following SPD selection of a voltage limiting Class I tested SPD would be possible. Either:

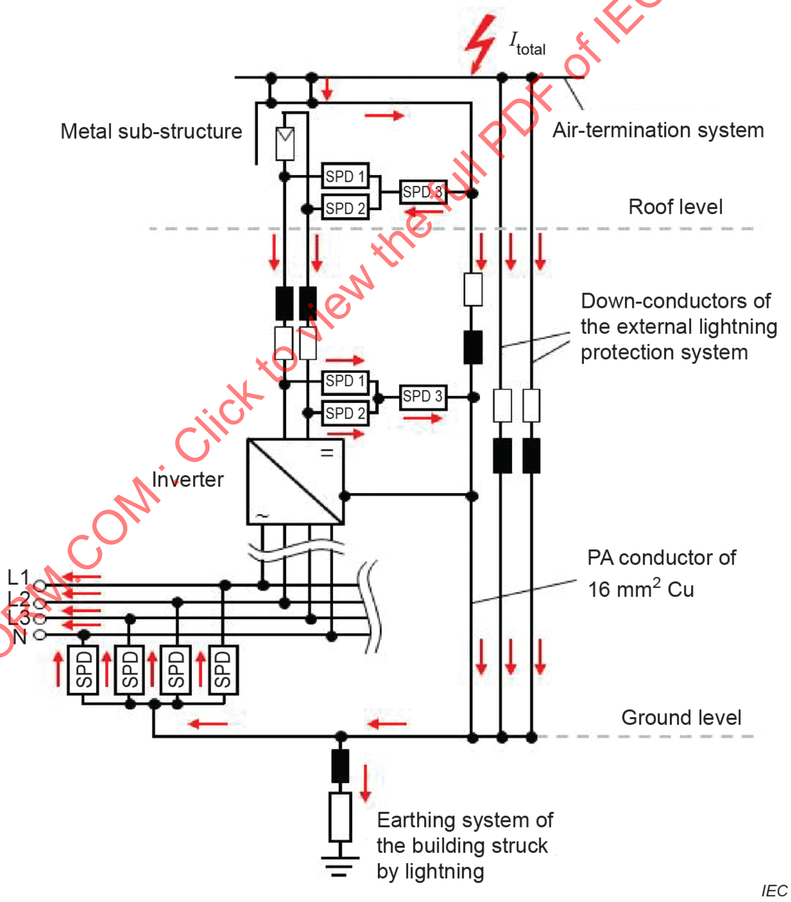
– a Class I tested SPD with I_{imp} = 5 kA per protection path and additionally tested for test class II with I_n = 8,5 kA per protection path; or

– a Class I tested SPD with I_{imp} = 8,5 kA per protection path.

Table 3 – Selection of the minimum discharge capacity of voltage switching class I tested SPDs (voltage switching) or combined class I tested SPDs (parallel connection of voltage limiting and voltage switching)

Lightning protection level LPL and maximum lightning current (10/350)		Number of down-conductors of the external lightning protection system			
		< 4		≥ 4	
		Values for voltage switching type class I tested SPDs or combined class I tested SPDs (parallel connection)			
		$I_{SPD\ 1} = I_{SPD\ 2}$ I_{imp}	$I_{SPD\ 3} = I_{SPD\ 1} + I_{SPD\ 2} = I_{total}$ I_{imp}	$I_{SPD\ 1} = I_{SPD\ 2}$ I_{imp}	$I_{SPD\ 3} = I_{SPD\ 1} + I_{SPD\ 2} = I_{total}$ I_{imp}
I or unknown	200 kA	25	50	12,5	25
II	150 kA	18,5	37,5	9	18
III or IV	100 kA	12,5	25	6,25	12,5

NOTE 3 The designations SPD 1, SPD 2, and SPD 3 refer to the representation in Figure 13.



NOTE Provide for local equipotential bonding in the region of the inverter.

Figure 13 – Example of a structure with two down-conductors of the external lightning protection system

5.6.3 Class II tested SPD, nominal impulse discharge surge current I_n

The nominal impulse discharge surge current I_n of the Type 2 surge protective device should be at least 5 kA of the wave form 8/20 for each live conductor. Otherwise, the nominal impulse discharge surge current shall correspond to the loads occurring at the installation location.

The surge protective device is positioned directly at the device to be protected.

5.7 Coordination of surge protective devices

For the coordination of surge protective device with the equipment to be protected, adjustments are required (see IEC 61643-12).

5.8 Selection of surge protective devices for a functionally earthed line conductor

If a live conductor is earthed with low impedance on the DC side, then this measure causes the full generator voltage of the non-earthed line conductor to be equal to the earth potential. This has to be considered when selecting the surge protective devices with regard to the protection level and the rated voltage U_c.

Where a live conductor on the DC side is permanently (e.g. without the use of fuses or other switching organs) earthed with low impedance and where this earthing meets the requirements of the lightning equipotential bonding, the use of a surge protective device for this conductor may be omitted.

6 Routing and shielding of cables/lines

The magnetic field produced by lightning strikes hitting directly or in close proximity can only be reduced by spatial shielding. On the other hand, voltages and currents induced in the electrical or electronic system can also be reduced by spatial shielding, by line routing and shielding or by a combination of both these measures (see Figure 14). Under certain conditions, the expenses required for surge voltage protective measures can thus be reduced. With regard to shielding, line shielding, and line routing, IEC 62305-4 gives detailed information on design, installation rules and the calculation of magnetic fields and induced voltages or currents.

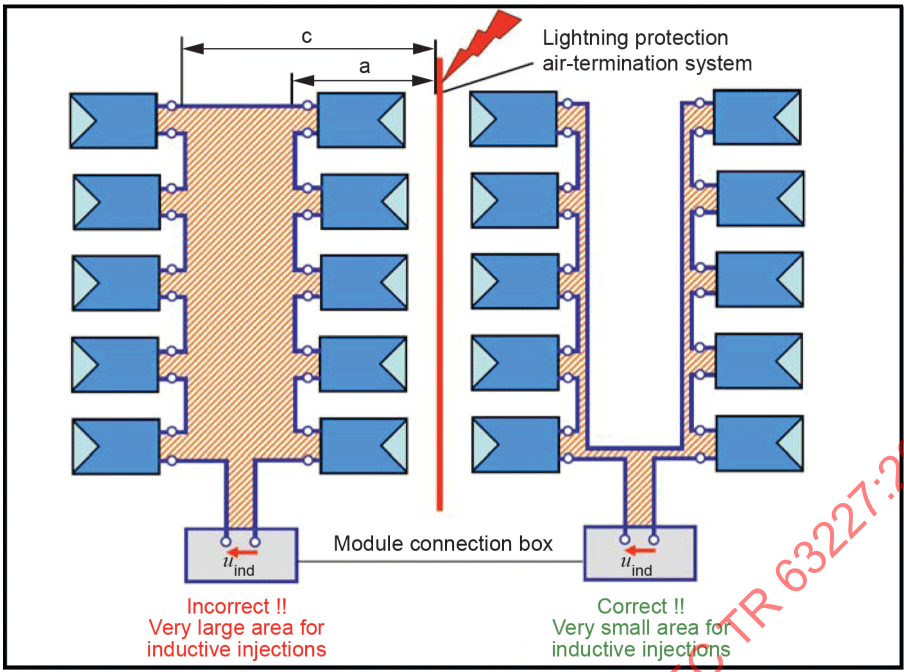
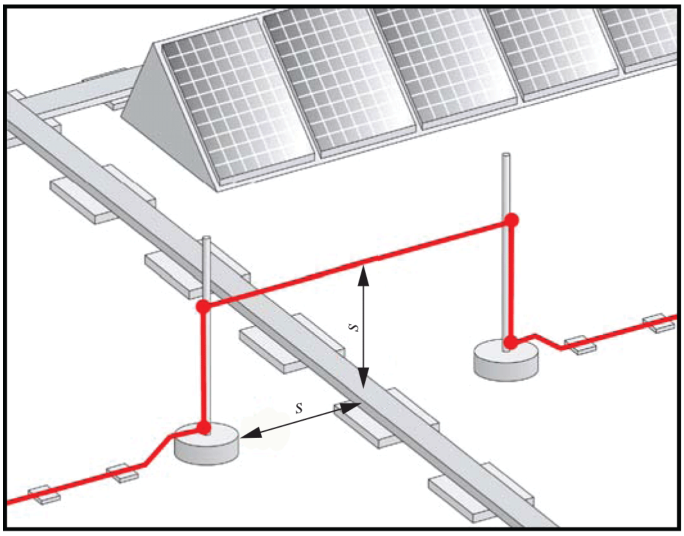


Figure 14 – Reduction of the effects of induction by shielding and line routing

Where go-and-return lines are provided in separate PV cables/lines, it is recommended to always route them in parallel and as close together as possible.

In practice, large spatial shields cannot be used for PV power supply systems because the PV modules are positioned outside the shielding. This largely refers to the shielding of the lines and suitable line routing (closely parallel routing of the individual conductors).

The shielding may either consist of a closed metal cable channel or cable duct in which the lines are laid, or the single-wired lines may themselves have a cable screen (see Figure 15). If the air-termination system is not provided with an insulation, then (partial) lightning currents can flow on this shielding; if so, then this shielding should be appropriately dimensioned (with a minimum of 16 mm^2 Cu or an equivalent current-carrying capacity).



In order for the separation distance *s* to be maintained, the crossing lightning conductor is mounted on stilts.

Figure 15 – Example for the shielding of the generator main lines by closed metal cable channels

7 Functional earthing/lightning equipotential bonding

Where the PV generator is not installed in an exposed position and an external lightning protection system is neither installed nor planned to be installed, it is recommended to ensure that the metal sub-structure is functionally earthed. The conductor cross section should be no less than 6 mm^2 Cu or of an equivalent current-carrying capacity. Also, all module rack rails should be connected to each other using this line cross-section.

If the system is located inside the area protected by air-termination systems and if the separation distance is maintained, then functional earthing is provided for the metal sub-structure. The line cross-section should be no less than 6 mm^2 Cu or of an equivalent current-carrying capacity. Also, all module rack rails should be connected to each other using this line cross section (see Figure 16).

If the system is located inside the area protected by air-termination systems and the separation distance is not maintained, then any metal sub-structures shall be connected to the external lightning protection system and to the main earthing rail of the building as shown in Figure 17. The metal sub-structures are connected as required for the respective lightning protection level. The cross-section should be no less than 16 mm^2 Cu or 25 mm^2 Al. In addition to that, the fastening means (e.g. support profiles) shall be connected to each other. The requirements for natural components specified in IEC 62305-3 apply.

The functional earthing/lightning equipotential bonding conductor is installed in parallel and with the closest possible contact to the DC and AC cables/lines.

Metal frames of PV modules are not mandatorily required to be included in the equipotential bonding. For some specific PV modules, an earth connection of the PV module frames is needed for functional reasons. The module manufacturer's installation provisions are to be taken into account. Details for protection of Tracking PV power supply systems are given in Annex B.

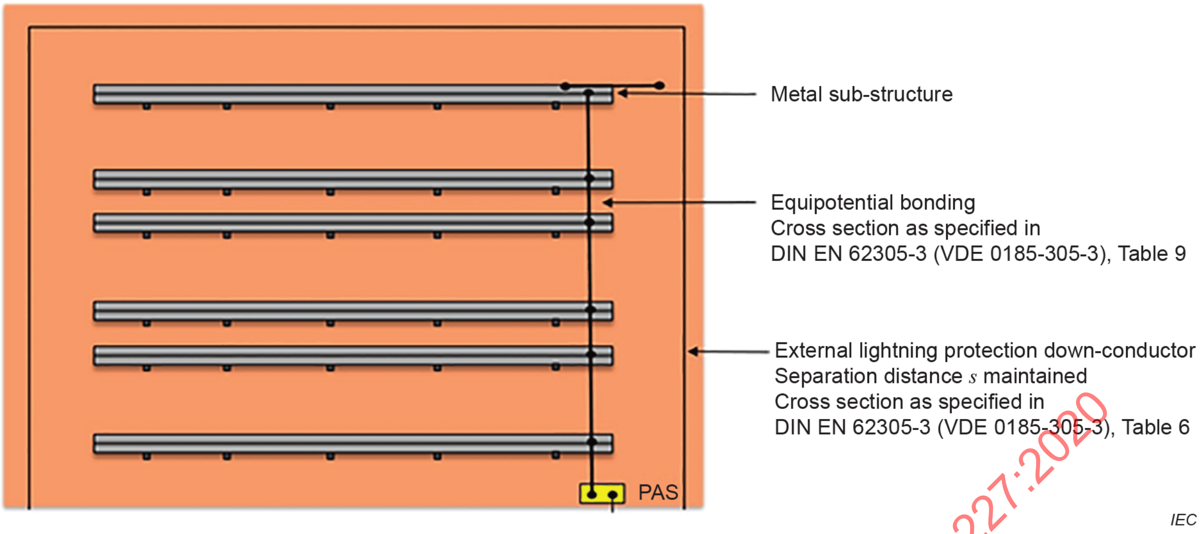


Figure 16 – Functional earthing of the module racks in case no external lightning protection is available or the separation distance is not maintained

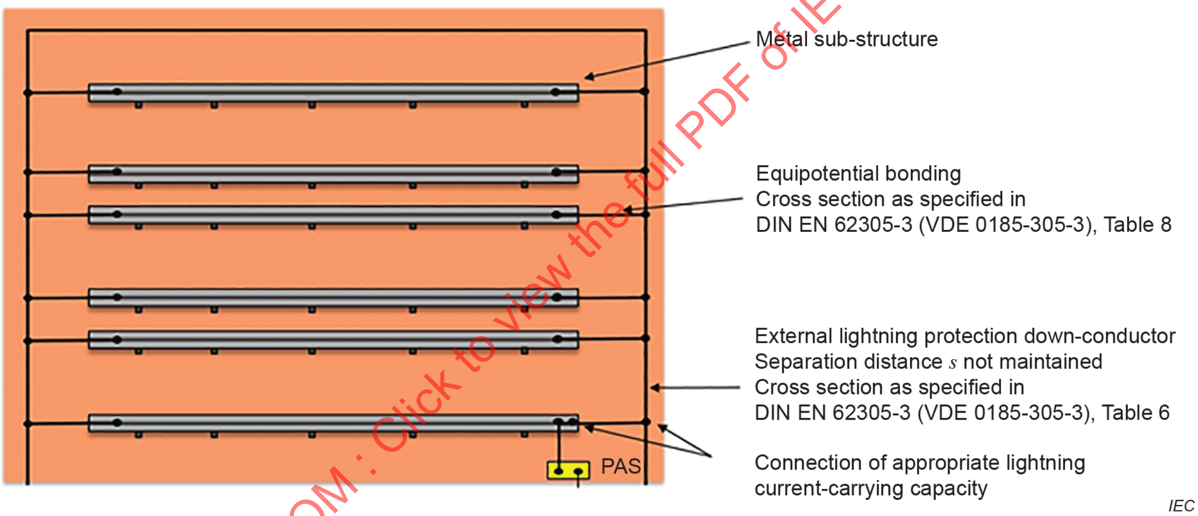


Figure 17 – Lightning equipotential bonding at the module racks in case the separation distance is not maintained

8 Inspection and documentation

Inspection and documentation of the lightning protection system are carried out as specified in IEC 62305-3:2010, Clause 7 and E.7.

The inspection of the surge protective device comprises:

– proper selection in accordance with 5.6;

– checking for compliance with the installation specifications of the manufacturer;

– checking the state of the status display/remote signalling.

Annex A
(informative)

Shadowing

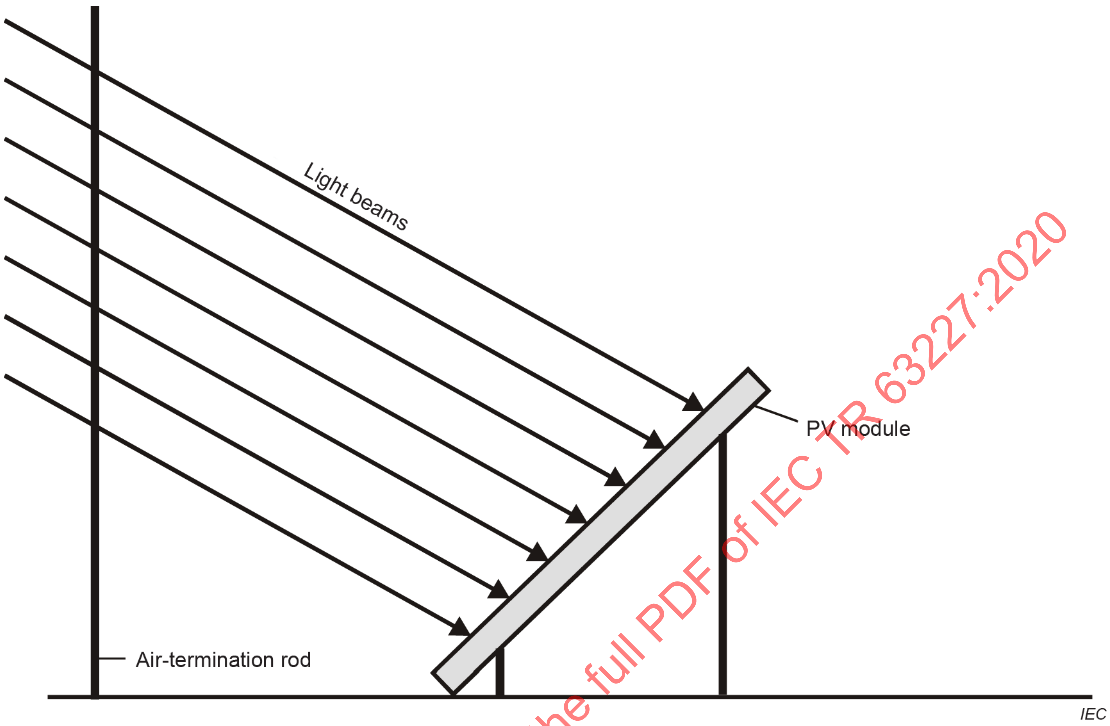


Figure A.1 – Shadowing of a PV module by a lightning rod

The effect of a reduction in irradiance (e.g. by a lightning rod of a lightning protection system) on a PV module is determined by several parameters. The electrical reverse characteristic of partially shaded solar cells, the possible presence of by-pass diodes in the modules and the operating point set for the PV module or module string, respectively, has great effect on the performance and the power output of the partially shaded PV module. Therefore, the shadowing of photovoltaic surfaces should be kept to a minimum.

The appearance of an umbra on the solar cell or the PV module, respectively, should be avoided in any case (see Figure A.1). "Umbra" here is the term for the area that receives no solar irradiance whatsoever and which, therefore, remains completely "dark". The surrounding area known as penumbra or diffuse shade is subject to a lower solar radiation, because, here, the sun is only partly eclipsed by the lightning rod or lightning line. As a function of the dimensions of the lightning rod or lightning line, a minimum distance can be calculated from the relationship for "similar triangles" that is just sufficient so that an umbra can no longer appear (see Figure A.2):

$$\frac{a_f}{d_f} = \frac{a_s + a_f}{d_s} \qquad \text{(A.1)}$$

where

d_s is the diameter of the sun at the equator (with d_s = 1,39 × 10^9 m);

d_f is the diameter of the lightning rod or lightning line;

a_s is the distance between sun and earth (a_s = 150 × 10^9 m);

a_f is the (minimum) distance between lightning rod or lightning line, respectively, and the PV module (negligibly small, in proportion to the distance between sun and earth).

This yields a very simple relationship:

$$a_f\,[\mathrm{m}] = 108\, d_f\,[\mathrm{m}] \tag{A.2}$$

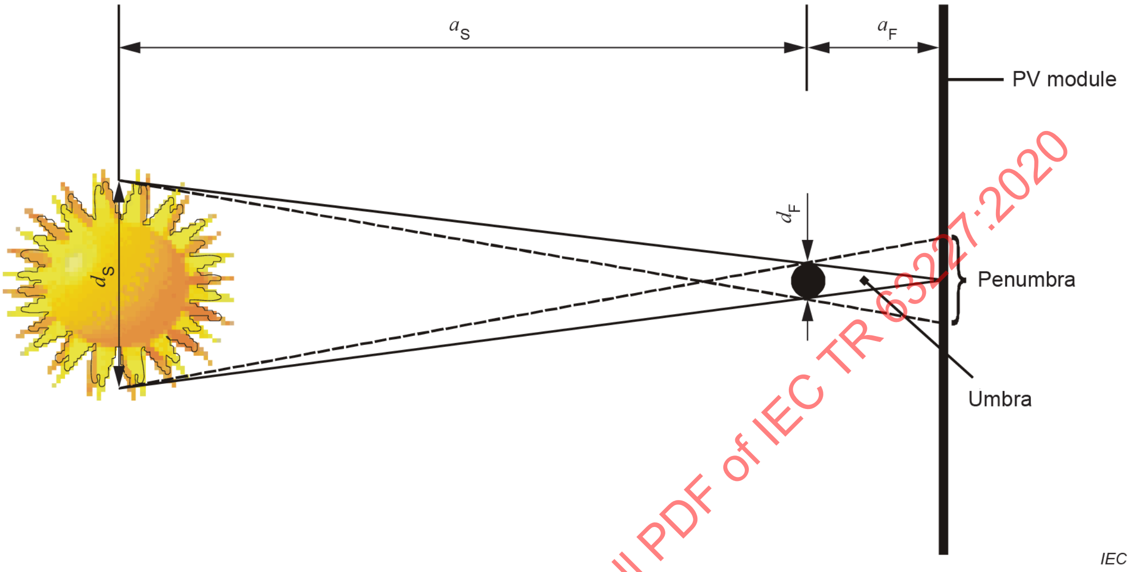


Figure A.2 – Minimum distance between the lightning rod or lightning line and the PV module required to prevent an umbra

Where the distance of the lightning rod is equal to or greater than the minimum distance obtained from Equation (A.2), an umbra is avoided (see Table A.1).

Table A.1 – Minimum distance of air-termination systems required to avoid an umbra

Diameter of the air-termination system m	Distance of the air-termination system to the PV module m
0,008	0,86
0,010	1,08
0,016	1,73

Annex B
(informative)

Tracking PV power supply system – External lightning protection/down-conductors

For concentrating and tracking PV power supply systems, it is possible to install, for example, small air-termination tips at the corners of the tracking base, which "capture" and pass the lightning into the metal support structure of the tracking base. The length of the air-termination tips leading to the tracking base should be determined using the rolling sphere method, see 5.2, such that the rolling sphere does not touch the tracking base for any of its positions (e.g. horizontal for storm position).

These air-termination tips should be bent and fastened to the support arms so that their distance to the edge of the PV module is no less than 10 cm. In order for transitions at moveable parts not to be overloaded by the lightning current, the shafts may be connected to the vertical mast (base) with at least 16 mm^2 of flexible copper line or a line of equivalent current-carrying capacity. The mast is connected to the earthing system (see Annex D).

Annex C
(informative)

Practical example: lightning protection for a PV power supply system installed on a saddle roof building

PV power supply systems are often installed on buildings with saddle roofs already equipped with a lightning protection system (see Figure C.1). In that case, it is required to dismantle the air-termination lines located underneath the PV power supply system. On the one hand, they can no longer serve their original purpose (capture lightning) and, on the other hand, they cause inacceptable proximities between the lightning protection and PV power supply systems. Figure C.1 shows the adjustment of the air-termination line system. In such a case, it should first be ensured that, even with these air-termination lines dismantled, a direct lightning strike into the PV power supply system is prevented, if necessary, by means of additional lightning rods. This can be checked using the suitable methods (in particular the rolling sphere method).

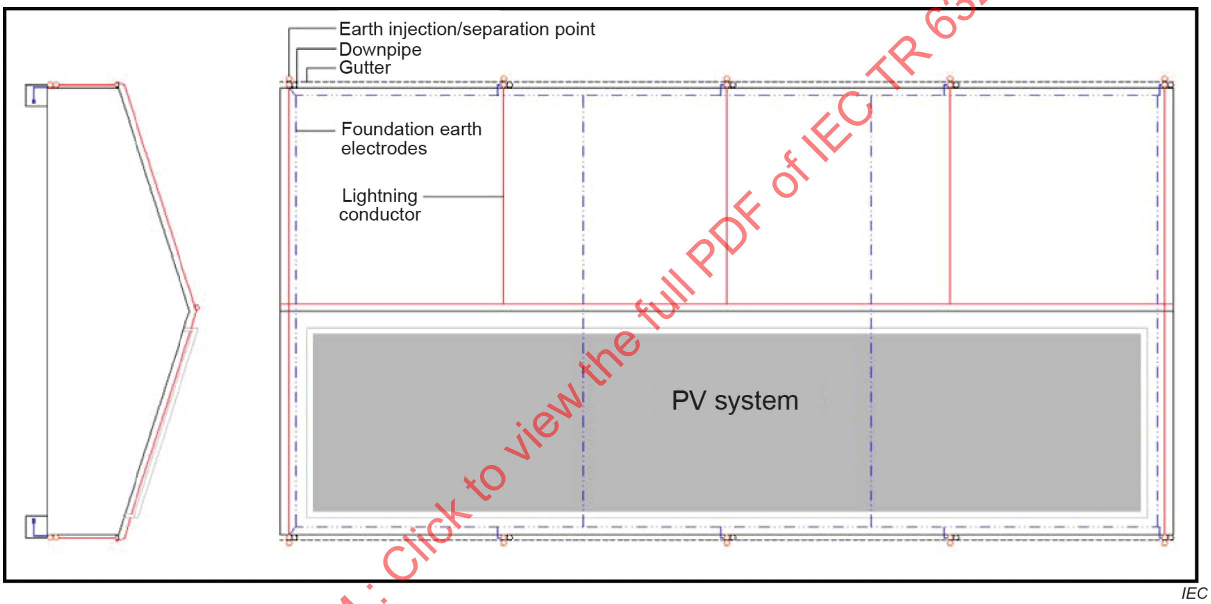


Figure C.1 – Saddle roof building – Meshed air-termination systems of lightning protection level III, the PV power supply system spans several meshes

The following shows how to calculate the separation distances. This will be exemplified using Figure C.1.

The building has a building area of 50 m × 25 m, an eaves height of 4 m and a ridge height of 8 m. Without a PV power supply system, the building had a conventional lightning protection system of lightning protection level III. The air-termination system had been adapted to building geometry with a mesh size of approximately 12,5 m × 13 m.

The separation distances are calculated as specified in IEC 62305-3:2010, 6.3.3 and Figure C.5:

$$s = \frac{k_\mathrm{i}}{k_\mathrm{m}} \left(k_\mathrm{C1} \times l_1 + k_\mathrm{C2} \times l_2 + \ldots + k_\mathrm{Cn} \times l_\mathrm{n} \right) \qquad \text{(C.1)}$$

where

k_i is dependent on the selected lightning protection level of the LPS (see IEC 62305-3:2010, Table 10);

k_c is dependent on the lightning current passing into the down-conductors (see IEC 62305-3:2010, Table 12);

l is the total or partial length of the air-termination system or the down-conductor from the point at which the separation distance is to be determined to the closest point of the equipotential bonding, in metres.

The k_c values can be determined as follows, provided the meshing of the air-termination system is as symmetrical as possible (with a mesh size of, for example, 15 m × 15 m for lightning protection level III):

1) The first step is to establish the shortest path for the lightning current to the earthing system.
2) The limit value $1/n$ is then established (n = number of down-conductors).

   The current partitioning specified in the following steps is continued until the value is less than the calculated limit value. In that case all further calculations are carried out using this limit value.
3) After its injection into the first node, the lightning current splits up in correspondence to the number of conductions. For example k_{c1} = 0,5 for two conductions, k_{c1} = 0,33 for three conductions, k_{c1} = 0,25 for four conductions, etc.
4) With every following node the current ($k_{c2...n}$) is reduced to half its value.

Figure C.2 shows an example for the separation distance calculation.

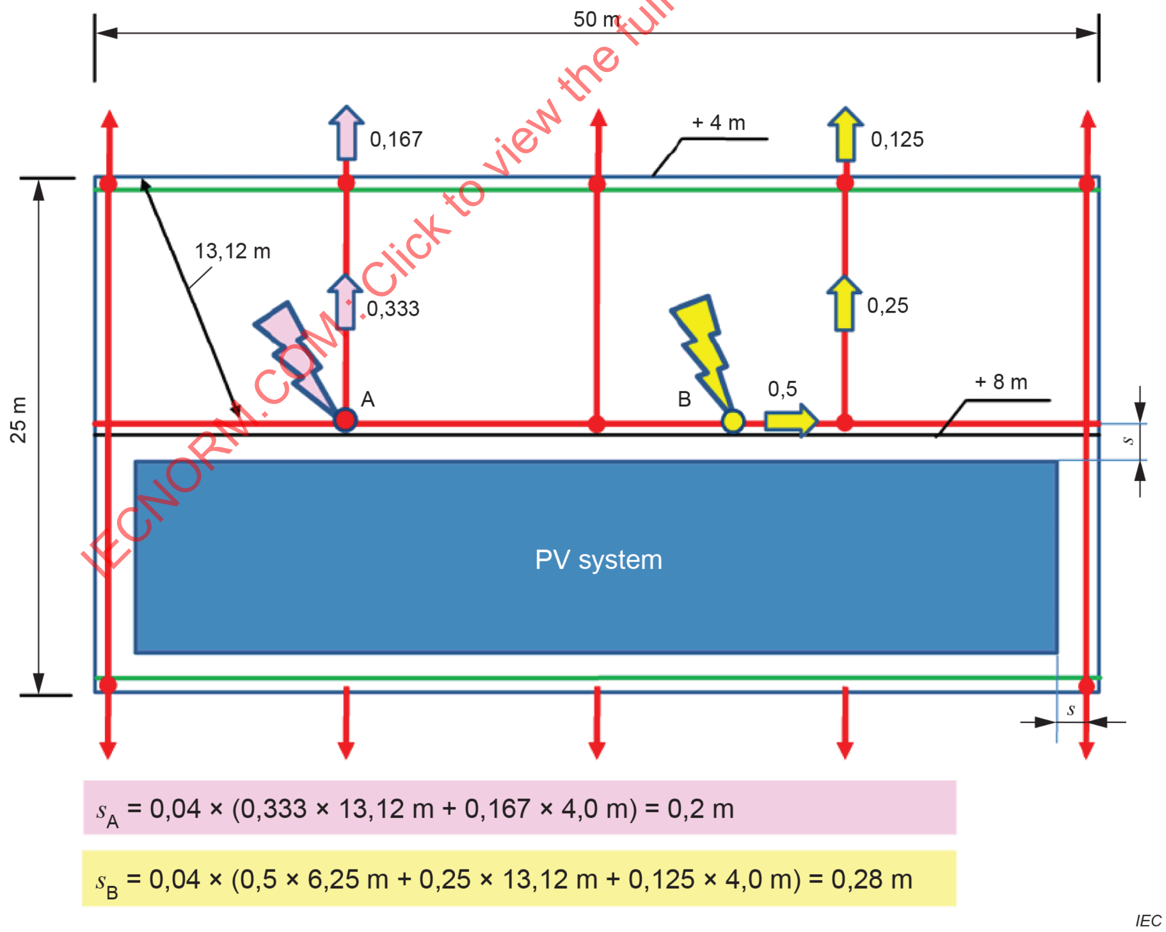


Figure C.2 – Example for the calculation of the separation distances for lightning protection level III