# White paper

## Lightning and Surge Protection for Rooftop Photovoltaic (PV) Systems

### Contents

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## Lightning and Surge Protection for Rooftop Photovoltaic (PV) Systems

About one million PV systems are currently installed in Germany. Based on the fact that self-generated electricity is generally cheaper and provides a high degree of independence of electricity from the grid, PV systems will become an integral part of electrical installations in the future. However, PV systems are exposed to all types of weather conditions and must withstand these conditions over decades.

The cabling of PV systems frequently runs through the building and extends over long distances until it reaches the grid connection point.

Lightning discharges cause field-based and conducted electrical interference. This effect increases in relation with increasing cable lengths or conductor loops. Surges do not only damage the PV modules, inverters and their monitoring electronics, but also devices in the domestic installation. More importantly, production facilities of industrial buildings may also easily be damaged and production may come to a halt.

If surges are injected into systems that are far from the power grid, also referred to as stand-alone PV systems, the operation of the PV systems may be disrupted (e.g. medical equipment, water supply).

### Necessity of a lightning protection system on buildings

The energy released by a lightning discharge is one of the most frequent causes of fire. Therefore, personnel and fire protection is paramount if a direct lightning strike hits the building.

At the design stage of a PV system, it is evident whether a building is equipped with a lightning protection system. Some countries' building regulations require that public buildings (e.g. places of public assembly, schools and hospitals) be equipped with a lightning protection system. In case of industrial or private buildings it depends on their location, construction type and utilisation whether a lightning protection system must be installed. To this end, it must be determined whether a lightning strike is to be expected or could have severe consequences. Structures in need of protection must be provided with a permanently effective lightning protection system.

According to recent studies, the installation of PV modules on buildings does not increase the risk of a lightning strike, so the request for lightning protection measures cannot be derived directly from the mere existence of a PV system. However, substantial lightning interference may be injected into the building through these systems. Therefore, it is necessary to determine the risk of damage posed by a lightning strike as per IEC 62305-2 and to take the results from this into account for design. For this purpose, DEHN offers the "DEHNsupport Toolbox" software which allows to analyse the risk of damage. This risk analysis provides a result which is understood by all parties involved and which meets optimum technical and economic requirements.

Section 4.5 (Risk Management) of supplement 5 of the German DIN EN 62305-3 standard describes that a lightning protection system designed for class of LPS III (LPL III (lightning protection level)) meets the usual requirements for PV systems. In addition, adequate lightning protection measures are listed in the VdS directive 2010 "Risk-oriented lightning and surge protection for objects" by the German Insurance Association. This directive also requires that LPL III and thus a lightning protection system according to class of LPS III be used for rooftop PV systems (> 10 $kW_p$).

**As a general rule, photovoltaic systems on buildings must not interfere with the existing lightning protection measures.**

### Necessity of surge protection for PV systems

In case of a lightning discharge, surges are induced in electrical conductors. Surge protective devices (SPDs) have proven very effective in protecting electrical systems from these destructive voltage peaks and are frequently required in the insurance terms and conditions for PV systems. Section 4.5 of the CLC/TS 50539-12 standard (Selection and application principles - SPDs connected to photovoltaic installations) calls for the installation of surge protective devices unless a risk analysis demonstrates that SPDs are not required. This standard and supplement 5 of the German DIN EN 62305-3 standard provide a detailed description of the types of SPDs and their place of installation.

### Cable routing of PV systems

Cables must be installed in such a way that large conductor loops are avoided. This must be observed when connecting the d.c. circuits to a string and several strings with one another. Moreover, data or sensor lines must not be routed across several strings and form large conductor loops with the string lines. This must also be observed when connecting the inverter to the mains connection. For this reason, the power lines (d.c. and a.c.) and data lines (e.g. radiation sensor, yield monitoring) must be installed together with the equipotential bonding.

### Earthing of PV systems

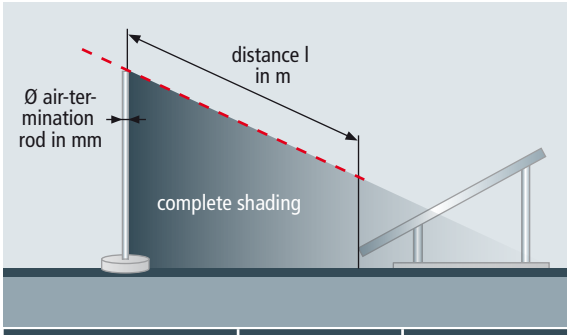
PV modules are typically fixed on metal mounting systems. The live PV components on the d.c. side have double or reinforced insulation (comparable to the previous protective insulation) as required in the IEC 60364-4-41 standard. The combination of numerous technologies on the module and inverter side (e.g. with or without galvanic isolation) results in different earthing requirements. Moreover, the insulation monitoring system integrated in the inverters is only permanently effective if the mounting system is connected to earth. Information on the practical implementation is provided in Supplement 5 of the German DIN EN 62305 standard. Section 7 of supplement 5 requires copper conductors with a cross-section of at least

Figure 1 UNI earthing clamp: A stainless steel intermediate element prevents contact corrosion, thus establishing reliable long-term connections between different conductor materials.

6 mm² or equivalent for functional earthing. If the mounting system is directly connected to the external lightning protection system due to the fact that the separation distance s cannot be kept, these conductors become part of the lightning equipotential bonding. Consequently, these elements must be capable of carrying lightning current. The minimum requirement for a lightning protection system designed for class of LPS III is a copper conductor with a cross-section of 16 mm² or equivalent. UNI earthing clamps (Figure 1) can be fixed on all common mounting systems. They connect for example copper conductors with a cross-section of 6 or 16 mm² and bare round wires (with a diameter from 8 to 10 mm) to the mounting frame in such a way that they can carry lightning currents. The integrated stainless steel (V4A) contact plate ensures that the mounting systems (Al) are protected against corrosion.

## Separation distance s as per IEC 62305-3

A certain separation distance s must be kept between a lightning protection system and a PV system. It defines the distance required to avoid uncontrolled flashover to adjacent metal parts as a result of a lightning strike into the external lightning protection system. Such an uncontrolled flashover may lead to a building fire in the worst case. Then, damage to the PV system becomes irrelevant. To this end, DEHN offers a Lightning Protection Guide that gives more detailed information on the calculation of the separation distance s and the DEHN Distance Tool software that allows to easily determine the separation distance.




| Ø air-termination rod | x factor | = distance l |
|---|---|---|
| 10 mm | 108 | 1.08 m |
| 16 mm | 108 | 1.76 m |

Figure 2 Distance between the module and the air-termination rod required to prevent complete shading

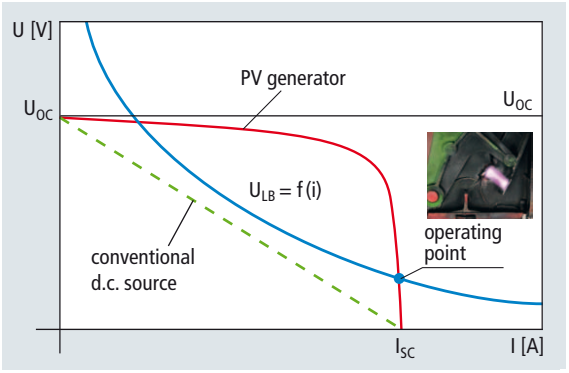



Figure 3 Source characteristic of a conventional d.c. source versus the source characteristic of a PV generator. When switching PV generators, the source characteristic of the PV generator crosses the arc voltage range.

## Complete shading of solar cells

The distance between the solar generator and the external lightning protection system is absolutely essential to prevent excessive shading. Diffuse shadows cast by, for example overhead lines, do not significantly affect the PV system and the yield. However, in case of complete shading, a dark clearly outlined shadow is cast on the surface behind an object, changing the current flowing through the PV modules. For this reason, shading of solar cells and the associated bypass diodes must be prevented. This can be achieved by keeping a sufficient distance. For example, if an air-termination rod of 10 mm shades a module, complete shading is steadily reduced as the distance from the module increases. After 1.08 m only a diffuse shadow is cast on the module (Figure 2). Annex A of supplement 5 of the German DIN EN 62305-3 standard provides more detailed information on the calculation of complete shading.

# White paper

## Lightning and Surge Protection for Rooftop Photovoltaic (PV) Systems

### Special surge protective devices for the d.c. side of photovoltaic systems

The U/I characteristics of photovoltaic current sources is very different from that of conventional d.c. sources: They have a non-linear characteristic (Figure 3) and cause long-term persistence of ignited arcs. This special feature does not only require larger PV switches and PV fuses, but also a disconnector adapted to the particular surge protective device that is capable of coping with PV currents as required in supplement 5 of the German DIN EN 62305-3 standard (section 5.6.1) as well as in the CLC/TS 50539-12 standard.

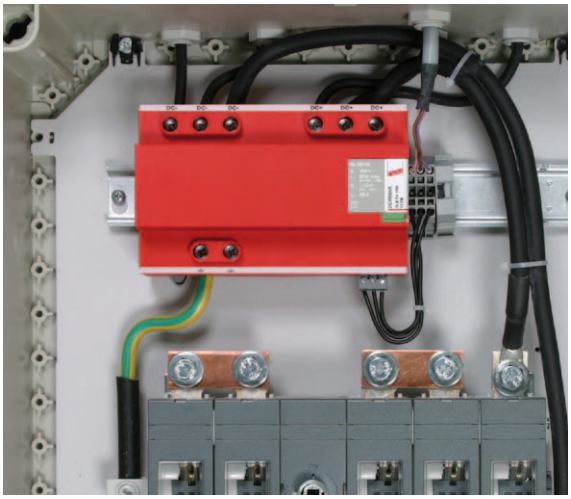


Figure 4 Type 1 DEHNlimit PV 1000 V2 combined arrester for protecting photovoltaic systems against surges and even direct partial lightning currents

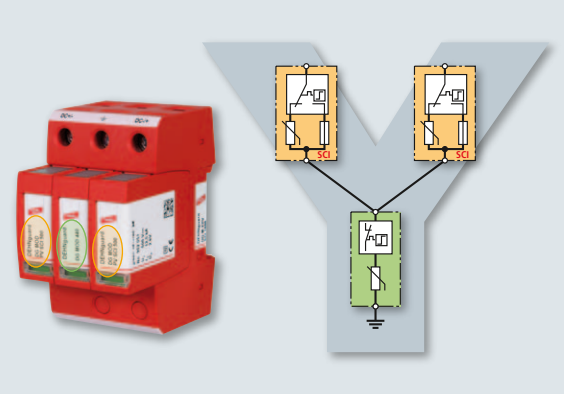


Figure 5 Modular type 2 DEHNguard M YPV SCI … (FM) surge arrester with fault-resistant Y circuit and three-step d.c. switching device

### Type 1 d.c. arrester for use in PV systems: Multipole type 1 combined d.c. arrester, DEHNlimit PV 1000 V2

The DEHNlimit PV 1000 V2 combined arrester (Figure 4) with its powerful d.c. extinguishing spark gap meets the above requirements. Its multiple terminals allow series connection as required in the IEC 60364-5-53 standard to ensure effective lightning equipotential bonding in compliance with IEC 62305-3. Remote signalling contacts are optionally available. The encapsulated spark gap technology efficiently protects the terminal equipment on the d.c. side (PV generator, inverter) even in case of direct lightning currents. Moreover, the so-called "wave breaker function" reduces the lightning current load on the devices to be protected to a minimum. This voltage-switching combined arrester combines a lightning current arrester and a surge arrester in a single device, thus providing highly efficient protection of terminal equipment. It can be used for PV systems up to 1000 V d.c. $U_{PV\ max}$. Supplement 5 of the German DIN EN 62305-3 standard recommends a lightning impulse current carrying capability $I_{imp}$ of at least 10 kA of wave form 10/350 µs (LPL III) for every live conductor. Due to the high lightning current discharge capacity of DEHNlimit PV 1000 V2 of 25 kA (10/350 µs) per pole, the arrester can be used for all lightning protection levels (LPL I, LPL II, LPL III/IV). This makes the type 1 combined arrester ideal for use in photovoltaic power supply systems.

### Type 2 d.c. arrester for use in PV systems: Modular type 2 d.c. surge arrester, DEHNguard M YPV SCI … (FM)

Reliable operation of SPDs in d.c. PV circuits is also indispensable when using type 2 surge protective devices. To this end, the DEHNguard M YPV SCI … (FM) surge arrester features an approved fault-resistant Y protective circuit and a three-step d.c. switching device (Figure 5). This d.c. switching device consists of a combined disconnection and short-circuiting device with Thermo Dynamic Control and a fuse. In case of overload, the device (Figure 6) safely disconnects the arrester from the gen-

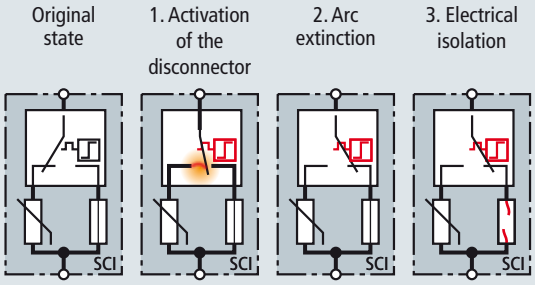



Figure 6 Switching phases of the three-step d.c. switching device integrated in DEHNguard M YPV SCI … (FM)

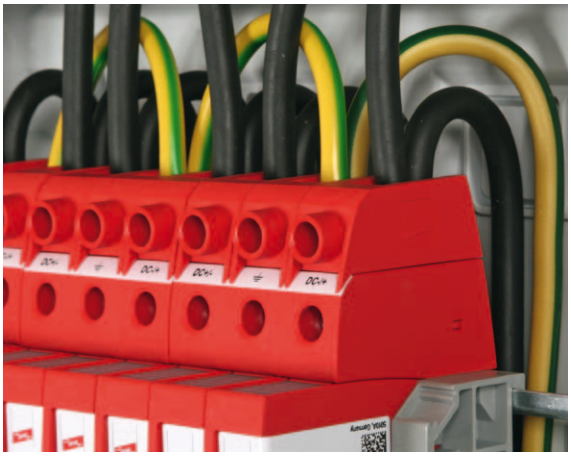


Figure 7 Simple series connection by means of a STAK 25 terminal

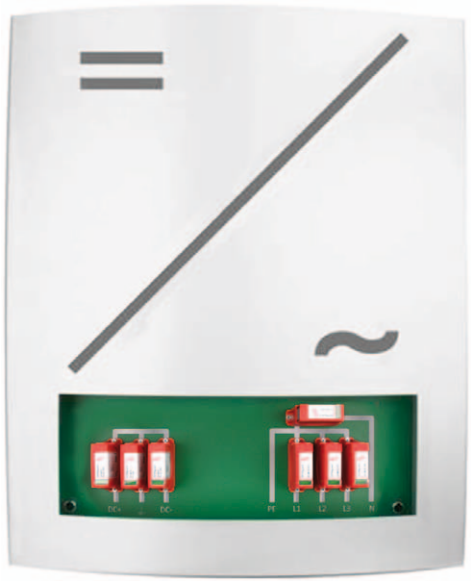


Figure 8 Type 2 DEHNguard SPD integrated in the inverter for the a.c. and d.c. side

erator voltage and reliably extinguishes d.c. arcs. Thus, DEHNguard M YPV SCI … (FM) allows to protect PV generators up to 1000 A without additional backup fuse. Furthermore, the integrated fuse allows safe replacement of the relevant protection modules without arc formation. The STAK 25 terminal (Figure 7) can be snapped onto the SPD, allowing series connection for a variety of applications.

The numerous technologies combined in the DEHNguard M YPV SCI … (FM) arrester prevent damage to surge protective device due to insulation faults in the PV circuit, the risk of fire of an overloaded arrester and puts the arrester in a safe electrical state without disrupting the operation of the PV system. Thanks to the protective circuit, the voltage-limiting characteristic of varistors can be used to its full extent even in PV d.c. circuits and numerous small voltage peaks are minimised. Thus, the SCI technology of the DEHNguard M YPV SCI … (FM) arrester increases the service life of the entire d.c.-side PV system.

### Selection of SPDs according to the voltage protection level $U_p$

The operating voltage on the d.c. side of PV systems differs from system to system. At present, values up to 1500 V d.c. are possible. Consequently, the dielectric strength of terminal equipment also differs. Requirements for e.g. inverters are specified in Table 12 of the IEC 62109-1 standard. To ensure that the PV system is reliably protected, the voltage protection level $U_p$ of the SPD must be lower than the dielectric strength of the PV system to be protected. The CLC/TS 50539-12 standard requires that $U_p$ is at least 20 % lower than the dielectric strength of the PV system. Type 1 or type 2 SPDs must be energy coordinated with the input of terminal equipment. If SPDs are already integrated in terminal equipment, coordination between the type 2 SPD and the input circuit of terminal equipment is to be ensured by the manufacturer (Figure 8).

## Application examples

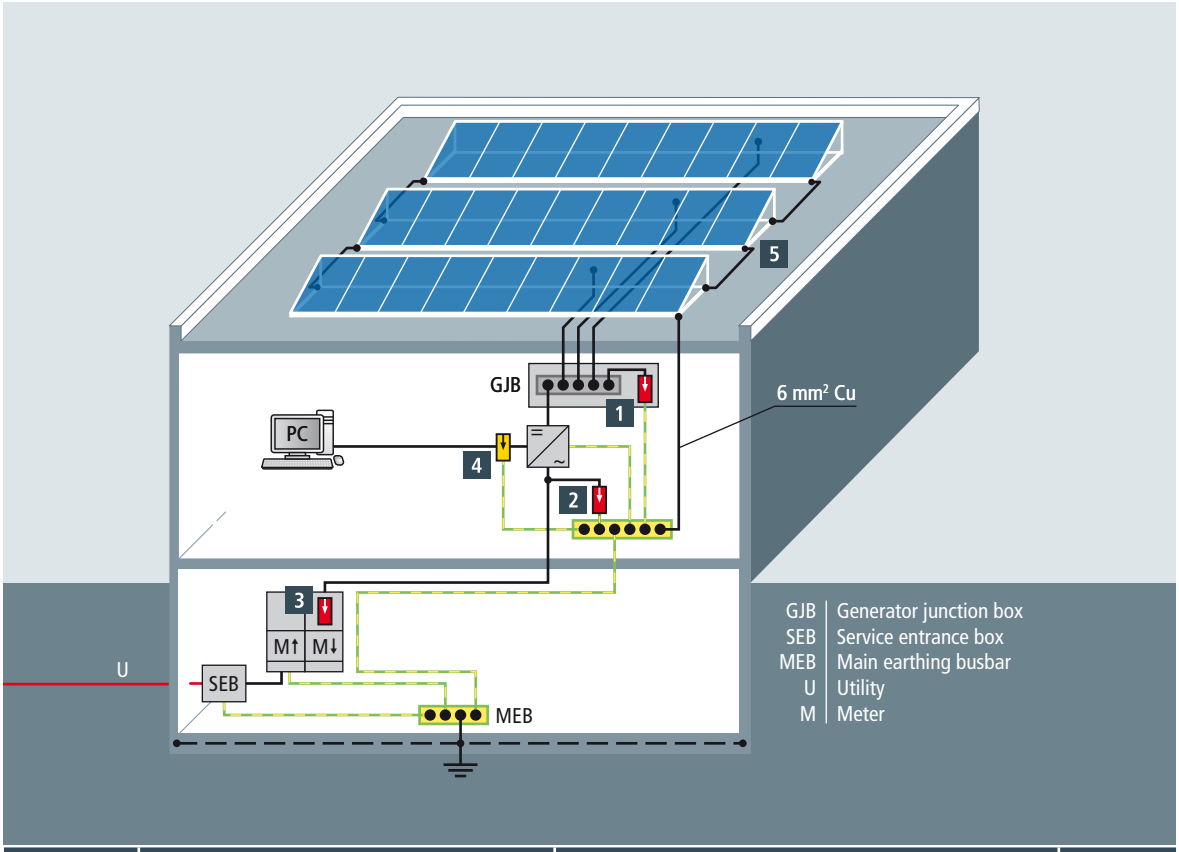
### Building without external lightning protection system

Figure 9 shows the surge protection concept for a PV system on a building without external lightning protection system. Dangerous surges are inductively coupled into the PV system as a result of a nearby lightning strike or travel from the power supply system through the service entrance to the consumer's installation. Type 2 SPDs are to be installed at the following locations:

- d.c.-side of the generator, modules and inverters
- a.c. output of the inverter
- Low-voltage main distribution board
- Wired communication interfaces

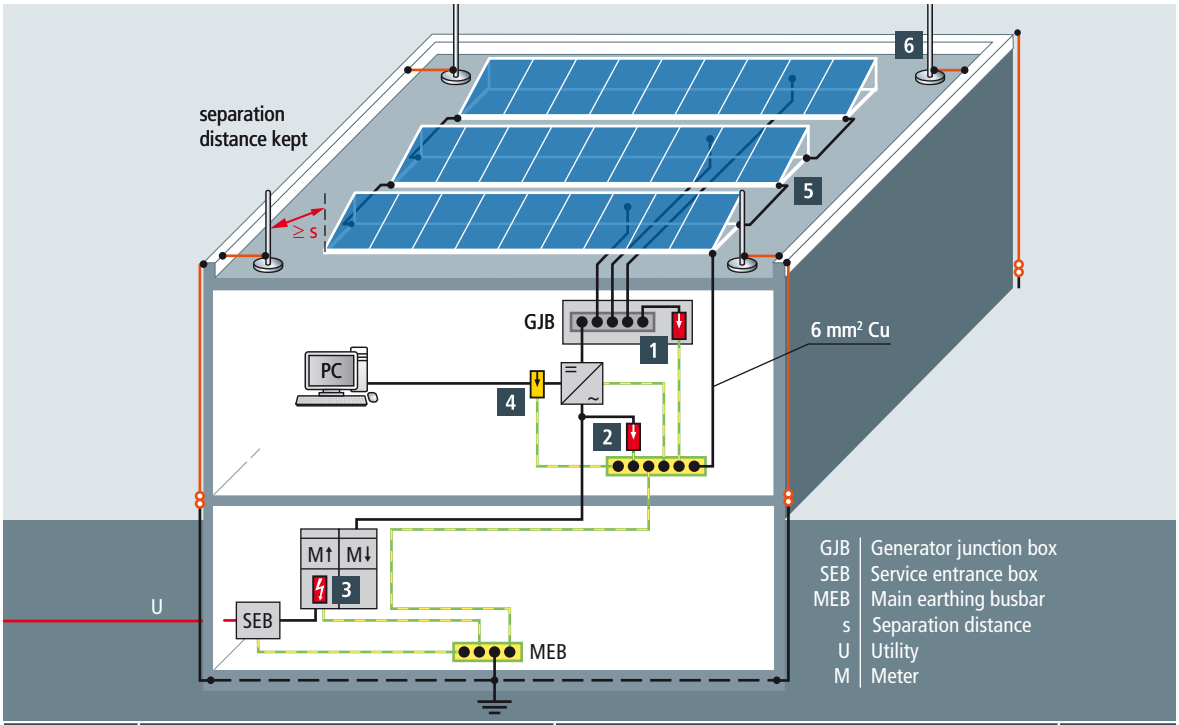
Every d.c. input (MPP) of the inverter must be protected by a type 2 surge protective device, for example DEHNguard M YPV SCI … (FM), that reliably protects the d.c. side of PV systems. The CLC/TS 50539–12 standard requires that an additional type 2 d.c. arrester be installed on the module side if




| No. in Fig. | Protection for | SPD *FM = Floating remote signalling contact | Part No. |
|---|---|---|---|
| **d.c. input of the inverter** | | | |
| 1 | Per (MPP) string | DEHNguard DG M YPV SCI 1000 FM* | 952 515 |
| **a.c. output of the inverter** | | | |
| 2 | TN-C systems | DEHNguard DG M TNC 275 FM* | 952 305 |
| | TN-S systems | DEHNguard DG M TNS 275 FM* | 952 405 |
| | TT systems | DEHNguard DG M TT 275 FM* | 952 315 |
| **Low-voltage input** | | | |
| 3 | TN-C systems | DEHNguard DG M TNC CI 275 FM* | 952 309 |
| | TN-S systems | DEHNguard DG M TNS CI 275 FM* | 952 406 |
| | TT systems | DEHNguard DG M TT CI 275 FM* | 952 327 |
| **Data interface** | | | |
| 4 | Two pairs, even with different operating voltages up to 180 V | BLITZDUCTOR BXTU ML4 BD 0-180 + BXT BAS base part | 920 349 + 920 300 |
| **Functional earthing** | | | |
| 5 | Functional potential | UNI earthing clamp | 540 250 |

Figure 9 Surge protection concept for a PV system on a building without external protection system




| No. in Fig. | Protection for | SPD *FM = Floating remote signalling contact | Part No. |
|---|---|---|---|
| **d.c. input of the inverter** | | | |
| 1 | Per (MPP) string | DEHNguard DG M YPV SCI 1000 FM* | 952 515 |
| **a.c. output of the inverter** | | | |
| 2 | TN-C systems | DEHNguard DG M TNC 275 FM* | 952 305 |
| | TN-S systems | DEHNguard DG M TNS 275 FM* | 952 405 |
| | TT systems | DEHNguard DG M TT 275 FM* | 952 315 |
| **Low-voltage input** | | | |
| 3 | TN-C systems | DEHNventil DV ZP TNC 255<br>DEHNventil DV M TNC 255 FM* | 900 390<br>951 305 |
| | TN-S systems | DEHNventil DV M TNS 255 FM* | 951 405 |
| | TT systems | DEHNventil DV ZP TT 255 (also for TN-S systems)<br>DEHNventil DV M TT 255 FM* | 900 391<br>951 315 |
| **Data interface** | | | |
| 4 | Two pairs, even with different operating voltages up to 180 V | BLITZDUCTOR BXTU ML4 BD 0-180<br>+ BXT BAS base part | 920 349<br>+ 920 300 |
| **Functional earthing / External lightning protection** | | | |
| 5 | Functional potential | UNI earthing clamp | 540 250 |
| 6 | PV modules | Air-termination rod with concrete base (8.5 kg) | 101 000<br>+ 102 075 |

Figure 10 Surge protection concept for a PV system on a building with external protection

Figure 11 Determination of the protected zone using the protective angle method

the distance between the inverter input and the PV generator exceeds 10 m.
The a.c. outputs of the inverters are sufficiently protected if the distance between PV inverters and the place of installation of the type 2 arrester at the mains connection point (low-voltage infeed) is less than 5 m. For greater cable lengths, it is advisable to install an additional type 2 surge protective device, for example DEHNguard M …275, upstream of the a.c. input of the inverter. However, if the cable lengths exceed 10 m, the installation of an additional type 2 surge protective device is mandatory in accordance with the CLC/TS 50539–12 standard. Moreover, a type 2 DEHNguard M … CI 275 (FM) surge protective device must be installed downstream of the meter of the low-voltage infeed. CI (Circuit Interruption) stands for a coordinated fuse integrated in the protective path of the arrester, allowing the arrester to be used in the a.c. circuit without additional backup fuse. DEHNguard M … CI 275 (FM) is available for every low-voltage system configuration (TN-C, TN-S, TT).

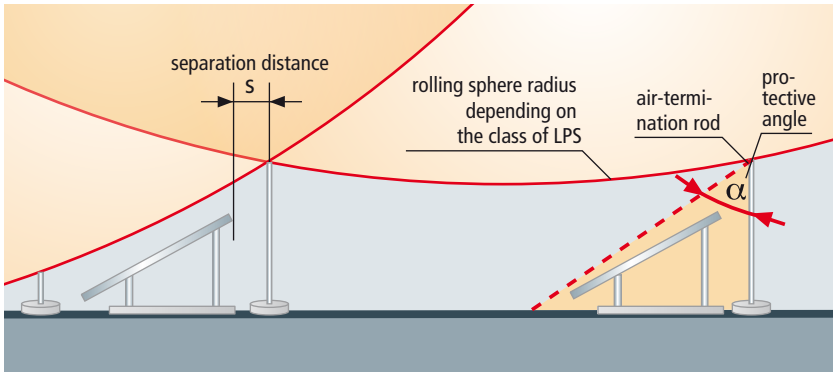
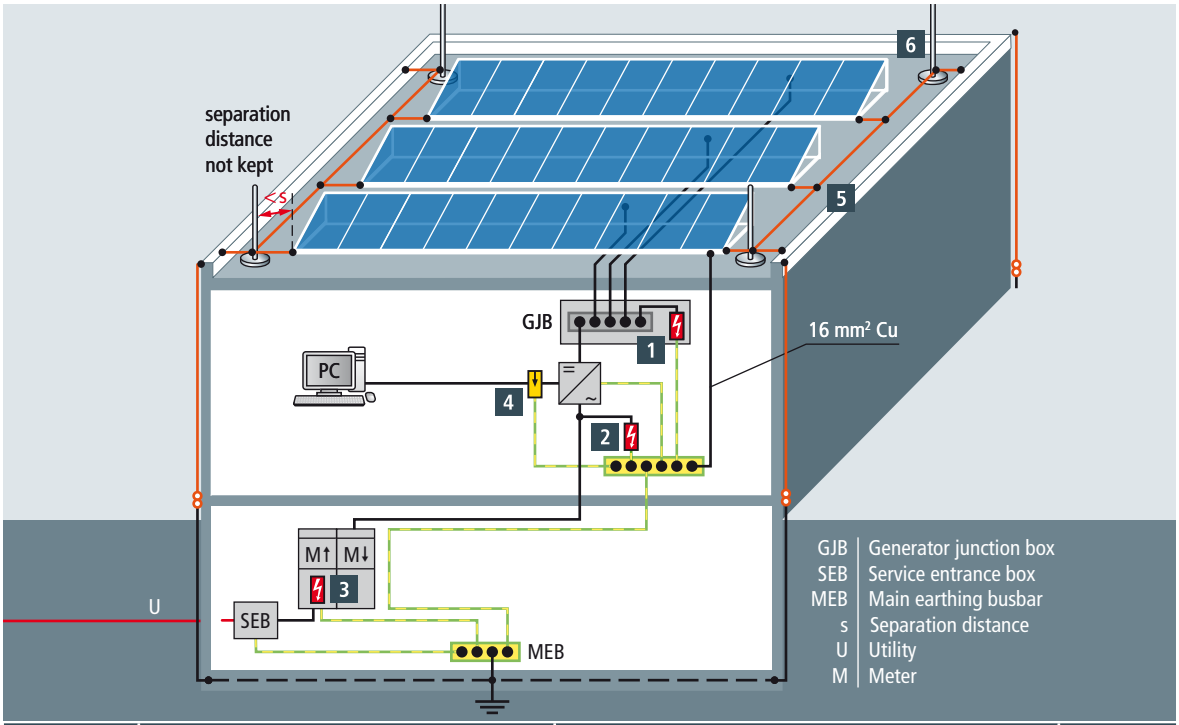



Figure 12 Rolling sphere method versus protective angle method for determining the protected zone

If inverters are connected to data and sensor lines to monitor the yield, suitable surge protective devices are required. BLITZDUCTOR XTU, which features connections for two pairs, for example for incoming and outgoing data lines, can be used for data systems based on RS 485.

### Building with external lightning protection system, separation distance s is kept

Figure 10 shows the surge protection concept for a PV system with external lightning protection system and a sufficient separation distance s between the PV system and the external lightning protection system.
The primary protection goal is to avoid damage to persons and property (building fire) as a result of a lightning strike. In this context, it is important that the PV system does not interfere with the lightning protection system. Moreover, the PV system itself must be protected from direct lightning strikes. This means that the PV system must be installed in the protected zone of the external lightning protection system. Air-termination systems (e.g. air-termination rods) form this protected zone and prevent direct lightning strikes in the PV modules and cabling. The protective angle method (Figure 11) or rolling sphere method (Figure 12) as described in section 5.2.2 of the IEC 62305-3 standard may be used to determine this protected zone. A variety of practical examples is provided in the Lightning Protection Guide from DEHN. A certain separation distance s must be kept between all conductive parts of the PV system and the lightning protection system. In this context, complete shading must be prevented by, for example, keeping a sufficient distance between the air-termination rods and the PV module.
Lightning equipotential bonding is an integral part of a lightning protection system. It must be implemented for all conductive systems and lines entering the building from the outside which may carry lightning currents. This is achieved by directly connecting all metal systems and indirectly connecting all energised systems via type 1 lightning current arresters to the earth-termination system. Lightning equipotential bonding should be implemented as close as possible to the entrance point into the building to prevent partial lightning currents from entering the building. The mains connection point must be protected by a multipole type 1 SPD with spark gap technology, for example a DEHNventil ZP combined arrester. This arrester complies with the VDS directives and can be directly installed on the busbar system upstream of the meter.




| No. in Fig. | Protection for | SPD *FM = Floating remote signalling contact | Part No. |
|---|---|---|---|
| **d.c. input of the inverter** | | | |
| 1 | Per (MPP) string | DEHNlimit DLM PV 1000 V2 FM* | 900 345 |
| **a.c. output of the inverter** | | | |
| 2 | TN-C systems | DEHNshield DSH TNC 255 | 941 300 |
| | TN-S systems | DEHNshield DSH TNS 255 | 941 400 |
| | TT systems | DEHNshield DSH TT 255 | 941 310 |
| **NS-Eingang** | | | |
| 3 | TN-C systems | DEHNventil DV ZP TNC 255<br>DEHNventil DV M TNC 255 FM* | 900 390<br>951 305 |
| | TN-S systems | DEHNventil DV M TNS 255 FM* | 951 405 |
| | TT systems | DEHNventil DV ZP TT 255 (also for TN-S systems)<br>DEHNventil DV M TT 255 FM* | 900 391<br>951 315 |
| **Data interface** | | | |
| 4 | Two pairs, even with different operating voltages up to 180 V | BLITZDUCTOR BXTU ML4 BD 0-180<br>+ BXT BAS base part | 920 349<br>+ 920 300 |
| **Functional earthing / External lightning protection** | | | |
| 5 | Functional potential | UNI earthing clamp | 540 250 |
| 6 | PV modules | Air-termination rod with concrete base (8.5 kg) | 101 000<br>+ 102 075 |

Figure 13 Surge protection concept for a PV system on a building with external protection system, separation distance is not kept

If no busbar system is installed, it is advisable to use a type 1 DEHNventil M … 255 combined arrester. This combined arrester combines a lightning current arrester and a surge arrester in a single device. If the cable lengths between the arrester and the inverter are smaller than 5 m, there is sufficient protection without additional surge protective device. For greater cable lengths, it is advisable to install additional type 2 DEHNguard M surge protective devices upstream of the a.c. input of the inverter. However, if the cable length exceeds 10 m, the installation of additional surge protective devices is mandatory in accordance with CLC/TS 50539–12.
Every d.c. input (MPP) of the inverter must be protected by a type 2 PV arrester, for example DEHNguard M YPV SCI … (FM). This also applies to transformerless devices. If the inverters are connected to data lines, for example to monitor the yield, surge protective devices for data transmission must be installed. For this purpose, BLITZDUCTOR XTU with actiVsense technology can be used for lines with analogue signal and data bus systems such as RS485. It automatically detects the operating voltage of the wanted signal and adjusts the voltage protection level to this operating voltage.

### High-voltage-insulated HVI Conductors

Another possibility of keeping the separation distance s is to use high-voltage-insulated conductors such as HVI or HVI light Conductors which allow to keep a separation distance s of 0.75 m (HVI) or 0.45 m (HVI light) in air. HVI Conductors may directly contact the PV system. However, no metal parts may be situated in the sealing end range and the separation distance s must be maintained. More detailed information on the application and installation of HVI Conductors are provided in the relevant installation instructions.

### Building with external lightning protection system, separation distance s is not kept

If the roofing is made of metal or is formed by the PV system itself, the separation distance s cannot be kept. The metal components of the PV mounting system must be connected to the external lightning protection system in such a way that they can carry lightning currents (copper conductor with a cross-section of at least 16 mm$^2$ or equivalent). This means that lightning equipotential bonding must also be implemented for the PV lines entering the building from the outside (Figure 13). According to supplement 5 of the German DIN EN 62305-3 standard and the CLC/TS 50539–12 standard, d.c. lines (with a length > 10 m) must be protected by a type 1 SPD.
For this purpose, a series connected DEHNlimit PV 1000 V2 combined arrester is used. Lightning equipotential bonding must also be implemented in the low-voltage infeed. If the PV inverter(s) is (are) situated more than 10 m from the type 1 SPD installed at the mains connection point, an additional type 1 SPD must be installed on the a.c. side of the inverter(s) (e.g. DEHNshield … 255 combined arrester). Suitable surge protective devices must also be installed to protect the relevant data

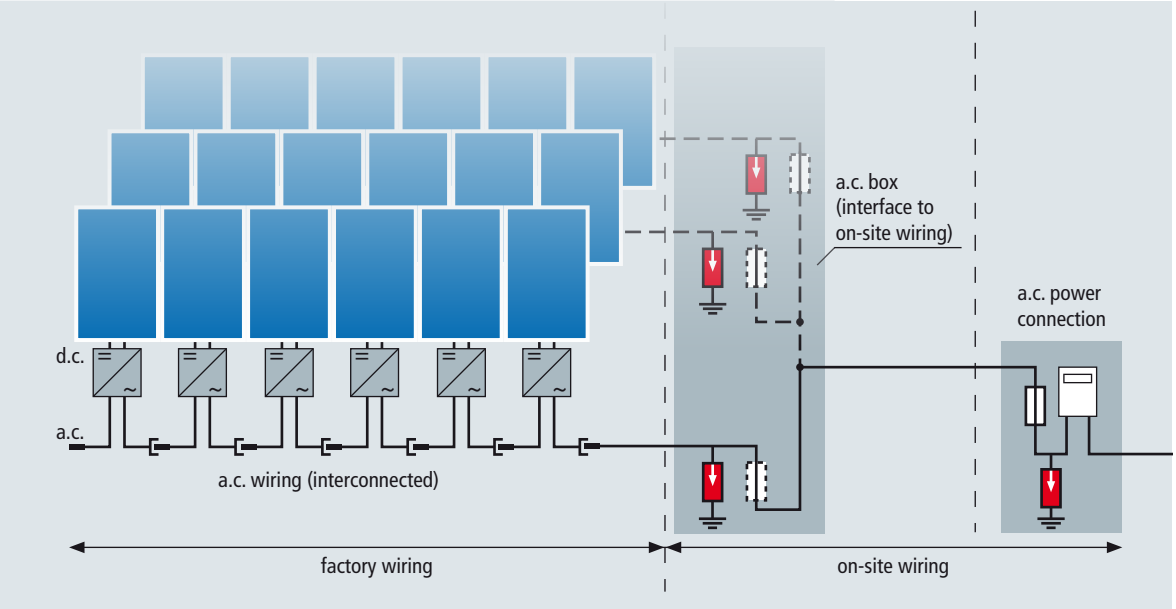



Figure 13 Surge protection for a module inverter in a connection enclosure for factory wiring

lines for yield monitoring. BLITZDUCTOR XTU surge protective devices protect data systems, for example based on RS 485.

### PV systems with module inverters

Module inverters (micro-inverters) require a different surge protection concept. To this end, the d.c. line of a module or a pair of modules is directly connected to the small-sized inverter. When installing the d.c. lines of modules, unnecessary conductor loops must be avoided. Direct inductive coupling into such small d.c. structures typically only has a low energetic destruction potential. The extensive cabling of a PV system with module inverters is located on the a.c. side (Figure 14). If the module inverter is directly fitted at the module, surge protective devices may only be installed on the a.c. side:

- Buildings without external lightning protection system = type 2 DEHNguard M … 275 arresters for alternating/three-phase current in close proximity to the module inverter and DEHNguard … 275 CI at the low-voltage infeed.
- Buildings with external lightning protection system, separation distance s is kept = type 2 arrester, for example DEHNguard M … 275 in close proximity to the module inverters and type 1 arresters which are capable of carrying lightning currents at the low-voltage infeed, for example DEHNventil ZP.
- Buildings with external lightning protection system, separation distance s is not kept = type 1 arrester, for example DEHNshield … 255, in close proximity to the module inverters and type 1 DEHNventil ZP arresters which are capable of carrying lightning currents at the low-voltage infeed.

Independent of particular manufacturers, module inverters feature data monitoring systems. If data is modulated to the a.c. lines via the module inverters, a surge protective device, for example DEHNbox DBX KT BD, must be installed on the separate receiving units (decoupling/data processing). The same applies to interface connections with downstream bus systems and their voltage supply (e.g. Ethernet, ISDN).

Solar power generation systems are an integral part of today's electrical systems. They should be equipped with lightning and surge protection, thus ensuring long-term faultless operation of these sources of electricity.

Bild 14 Rooftop PV system

**Surge Protection**
**Lightning Protection**
**Safety Equipment**
**DEHN protects.**

DEHN + SÖHNE
GmbH + Co.KG.

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