9.18 Lightning and surge protection for PV systems and solar power plants

9.18.1 Lightning and surge protection for photovoltaic (PV) systems

The guaranteed service life of 20 years for photovoltaic generators and their exposed installation sites as well as the sensitive electronics of the inverter really require effective lightning and surge protection.

Not only house owners install a PV system on their rooftop but also private operating companies make more and more investments in shared systems, which are erected on large-surface roofs, on traffic structures, or unused open areas.

Because of the big space requirements of the photovoltaic generator, PV systems are especially threatened by lightning discharges during thunderstorms. Causes for surges in PV systems are inductive or capacitive voltages deriving from lightning discharges as well as lightning surges and switching operations in the upstream power supply system. Lightning surges in the PV system can damage PV modules and inverters. This can have serious consequences for the operation of the system. Firstly, high repair costs, for example, those of the inverter, have a negative effect, and, secondly, the system failure can result in considerable profit cuts for the operator of the plant.

Necessity of lightning protection

For the installation of PV systems it must be generally distinguished between an installation on a building with or without lightning protection. For public buildings, e.g., assembly places, schools, hospitals, in Germany building regulations request lightning protection systems for safety reasons. For this purpose, buildings or structures are differentiated, for which, according to their location, construction type, or utilisation, a lightning strike could easily have severe consequences. Such buildings or structures in need of protection have to be provided with a permanently effective lightning protection system.

In case of privately used buildings lightning protection is often refrained from. This happens partly out of financial reasons, but also because of lacking sensibility with respect to this topic.

If a building without external lightning protection was selected as location for a PV system, the question arises, if, with the additional installation of the PV generator on the roof, lightning protection should be provided for the entire structure. According to the current scientific state of the art, the installation of PV modules on buildings does not increase the risk of a lightning strike, so that the request for lightning protection can not be derived directly from the mere existence of a PV system. However, there may be an increased danger for the electric facilities of the building in the event of a lightning strike. This is based on the fact that, due to the wiring of the PV lines inside the building in existing risers and cable runs, strong conducted and radiated interferences may result from lightning currents. Therefore, it is necessary, to estimate the risk by lightning strikes, and to take the results from this into account for the design. IEC 62305-2 (EN 62305-2) states procedures and data for the calculation of the risk resulting from lightning strikes into structures and for the choice of lightning protection systems. For this purpose DEHN + SÖHNE offers the software DEHNsupport. The risk analysis presented here ensures that it is possible to draw up a lightning protection concept which is understood by all parties involved, and which meets optimum technical and economic requirements, i.e. the necessary protection can be guaranteed with as little expenditure as possible.

The German Insurance Association has picked up the risk estimate in their guideline VdS 2010 "Risikoorientierter Blitz- und Überspannungsschutz für Objekte" (Risk oriented lightning and surge protection for objects) (taken from IEC 62305-2 (EN 62305-2)) and present lightning protection measures for buildings or structures as they are seen by the insurance industry. In Table 3, this guideline assigns classes of lightning protection systems and measures against surges to objects in a simplified manner. Furthermore, the guideline also refers to buildings with alternative power supply installations, as for example, buildings with a PV system (> 10 kW). According to this, for such objects lightning protection level (LPL) III has to be taken into account. Hence a LPS Class III is required as well as additional surge protective measures.

A system of protection against lightning (LPS) designed for class III meets the usual requirements for PV and solar thermal systems: "Photovoltaic and solar thermal systems on buildings must not interfere the existing lightning protection measures. Photovoltaic and solar thermal systems shall be protected by isolated air-termination systems according to 5.2 and 6.3 of IEC 62305-3 (EN 62305-3) against direct lightning strikes. If a direct connection can not be avoided, the effects of partial lightning currents entering the building have to be taken into consideration."

Protection of photovoltaic inverters against surges also in case of direct lightning strikes

If a PV system shall be installed on a building with external lightning protection system, one of the basic requirements is that the PV modules are within the protective area of an isolated air-termination system. Additionally, the separation distance between the PV supporting frame and the external lightning protection system has to be kept in order to prevent uncontrolled sparkover. Otherwise considerable partial lightning currents can be carried into the building or structure.

Often the operator wants the whole roof to be covered with PV modules in order to gain a possibly high economic profit. In these cases the separation distance often can not be realised and the PV supporting frame has to be integrated into the external lightning protection. Here, the effects of the currents coupled into the building or structure have to be taken into consideration and a lightning equipotential bonding has to be provided. Meaning that lightning equipotential bonding now also is necessary for the d.c. conductors carrying lightning current. According to IEC 62305-3 the d.c. conductors have to be protected by surge protective devices (SPDs) Type 1. Surge protective devices Type 1 on spark gap basis, for use on the d.c. voltage side, were not available up to now. The problem was that the spark gap once being tripped, could not be quenched again and hence the arc persisted.

With the combined lightning current and surge arrester DEHNlimit PV 1000 (**Figure 9.18.1.1**) DEHN + SÖHNE succeeded in developing a direct current extinguishing spark gap arrester. Thus DEHNlimit PV 1000 is the ideal arrester for use in photovoltaic power plants. The encapsulated creeping spark gap technology provides a safe protection of the PV generator and the inverter also in case of direct lightning currents. This combined arrester is applicable for PV systems up to 1000 V $U_{OC\ STC}$. DEHNlimit PV 1000 has a high lightning current discharge capability of 50 kA 10/350 µs.

Single pole photovoltaic arrester Type 2 with integrated short-circuiting device

The inner structure of DEHNguard PV 500 SCP a surge arrester Type 2 (**Figure 9.18.1.2**) sets new patterns for safety. In this arrester the proved double effect of the monitoring and disconnecting device Thermo Dynamic Control has been combined with an additional short-circuiting device. This completely new kind of arrester monitoring ensures operation safety without risk of fire hazard, even if the devices are overloaded for example at insulation faults in the PV generator circuit. The following example explains the effectiveness of the short-circuiting device in DEHNguard PV 500 SCP:

1. **Figure 9.18.1.3**: An insulation fault arises during the operation of the PV system.
2. **Figure 9.18.1.4**: With the consequence of the surge arrester being overloaded by the exceeding maximum continuous voltage U_c.
3. **Figure 9.18.1.5**: The combined disconnection and short-circuiting device of DEHNguard PV 500 SCP will be activated. It is able to carry a short-circuit current up to 50 A automatically until the PV system is repaired. This ensures a safe operation without risk of fire hazard for the system even at an insulation fault in the PV generator circuit.

Fig. 9.18.1.1 Combined arrester Type 1, DEHNlimit PV, to protect photovoltaic inverters from surges also in case of direct lightning strikes

Fig. 9.18.1.2 Single pole photovoltaic arrester Type 2, DEHNguard PV 500 SCP, with integrated short-circuiting device

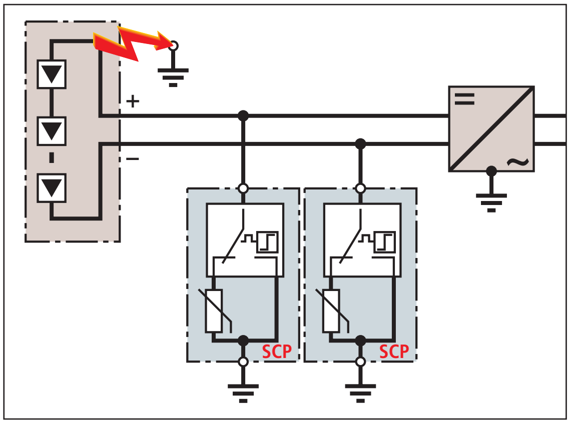

Fig. 9.18.1.3 Isolation fault at the PV generator

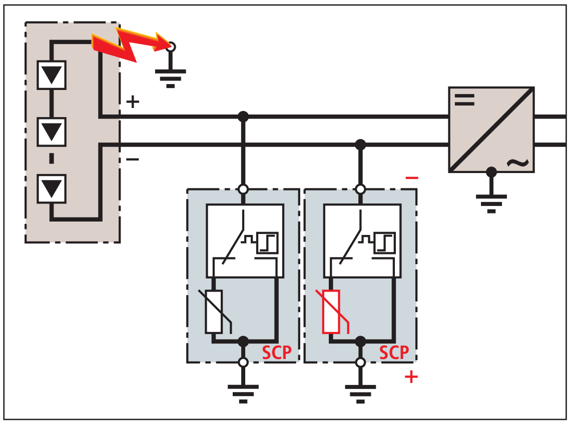

Fig. 9.18.1.4 Overloading of SPD due to an isolation fault

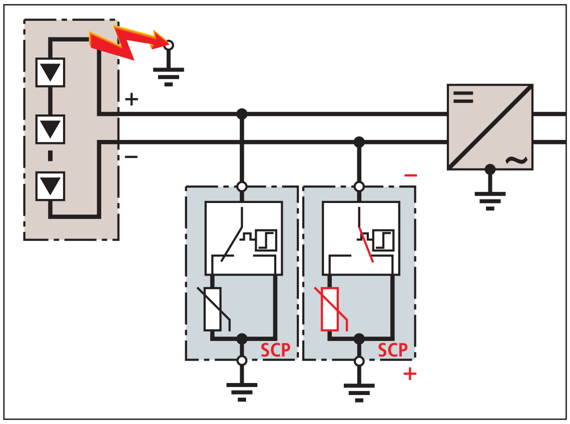

Fig. 9.18.1.5 Activation of the DEHNguard PV 500 SCP disconnecting and short-circuiting device ensures safe operating state also in case of an isolation fault in the PV generator circuit

Examples of application

Buildings without external lightning protection system

Figure 9.18.1.6 shows the surge protection concept for a PV system on a building without external lightning protection system. Possible installation sites of the surge protective devices can be:

⇒ d.c. input of the inverter

⇒ a.c. output of the inverter

⇒ low-voltage (l.v.) supply

DEHNguard, an SPD Type 2 is installed in the l.v. incoming feeder. This DEHNguard M Type of surge arrester, a complete prewired unit is available for each low-voltage system (TN-C, TN-S, TT) (**Table 9.18.1.1**). If the distance between the PV inverter and the installation site of the DEHNguard is not greater than 5 m (l.v. supply), the a.c. output of the inverter is sufficiently protected. At greater conductor lengths additional surge protective devices SPDs Type 2 are necessary upstream the a.c. input of the inverter (**Table 9.18.1.1**).
At the d.c. input of the inverter each of the incoming string conductors has to be protected to earth by a DEHNguard surge protective device Type PV 500 SCP installed between plus and minus. This installation provides safe surge protection for PV systems with a generator voltage up to 1000 V d.c..

The operating voltage of the chosen surge protective devices shall be approx. 10 % higher than the expected open-circuit voltage of the solar generator during maximum solarisation on a cold winter day.

Buildings with external lightning protection system and separation distance kept

The correct operating condition of the lightning protection system has to be proven by existing test reports or by maintenance tests. If faults are found during the examination of the external lightning protection system (i.e. intense corrosion, loose and free clamping elements), the constructor of the PV system has the duty to inform the owner of the building about these faults in writing.
The PV system on the roof surface should be designed under consideration of the existing external lightning protection system. For this purpose, the PV system has to be installed within the protection zone of the external lightning protec-

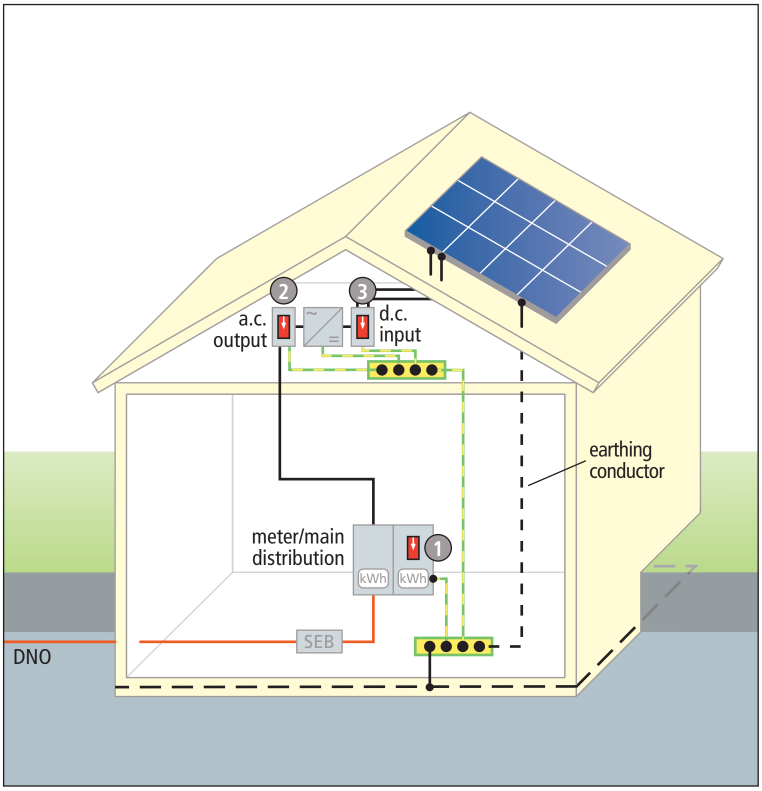

Fig. 9.18.1.6 Surge protection concept for a PV system on a building without external lightning protection

tion system to ensure its protection against a direct lightning strike. By using suitable air-termination systems, like air-termination rods, for example, direct lightning strikes into the PV modules can be prevented. The necessary air-termination rods possibly to be installed additionally, must be arranged to prevent a direct strike into the PV module within their protection zone and, secondly, any casting of a shadow on the modules.

It has to be considered that a separation distance s must be kept between the PV components and metal parts like lightning protection systems, rain gutters, skylights, solar cells or antenna systems in compliance with IEC 62305-3 (EN 62305-3). The separation distance has to be calculated according to IEC 62305-3 (EN 62305-3)3. The PV system shown in **Figure 9.18.1.7** is located in the protective area of the external lightning protection system. **Figure 9.18.1.7** illustrates the concept of

Figure 9.18.1.6	Protection for...	SPDs	Part No.
L.v. supply			
1	TN-C system	DEHNguard M, DG M TNC 275 DEHNguard M, DG M TNC 275 FM	952 300 952 305
	TN-S system	DEHNguard M, DG M TNS 275 DEHNguard M, DG M TNS 275 FM	952 400 952 405
	TT system	DEHNguard M, DG M TT 275 DEHNguard M, DG M TT 275 FM	952 310 952 315
Ac output of the inverter/ac, inverter installed in the attic			
2	TN system	DEHNguard M, DG M TN 275 DEHNguard M, DG M TN 275 FM	952 200 952 205
	TT system	DEHNguard M, DG M TT 2P 275 DEHNguard M, DG M TT 2P 275 FM	952 110 952 115
Dc input of the inverter			
3	2 x (each between plus and minus to earth)	DEHNguard, DG PV 500 SCP DEHNguard, DG PV 500 SCP FM	950 500 950 505

Table 9.18.1.1 Selection of the surge protective devices for PV systems on buildings without external lightning protection system

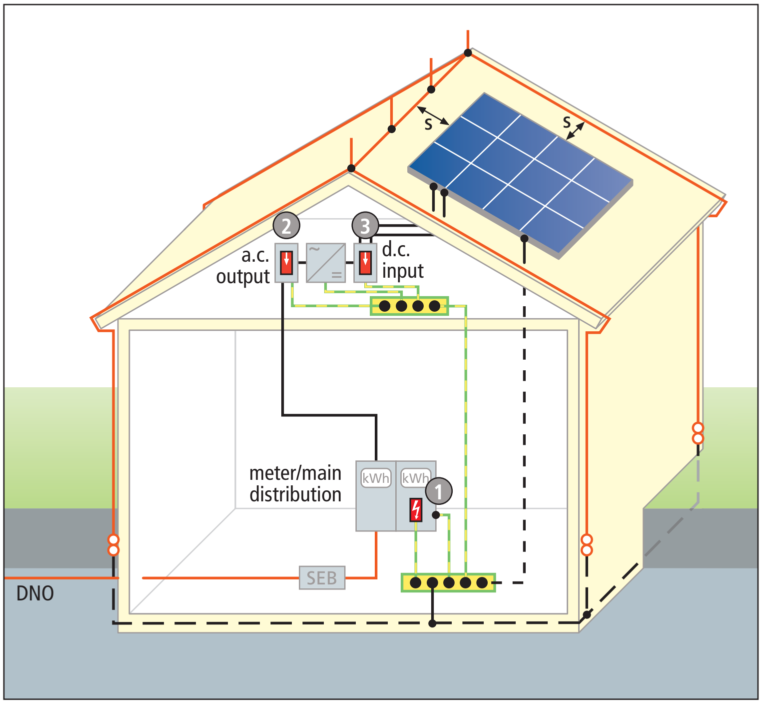

Fig. 9.18.1.7 Surge protection concept for a PV system on a building with external lightning protection system and the separation distance is being kept

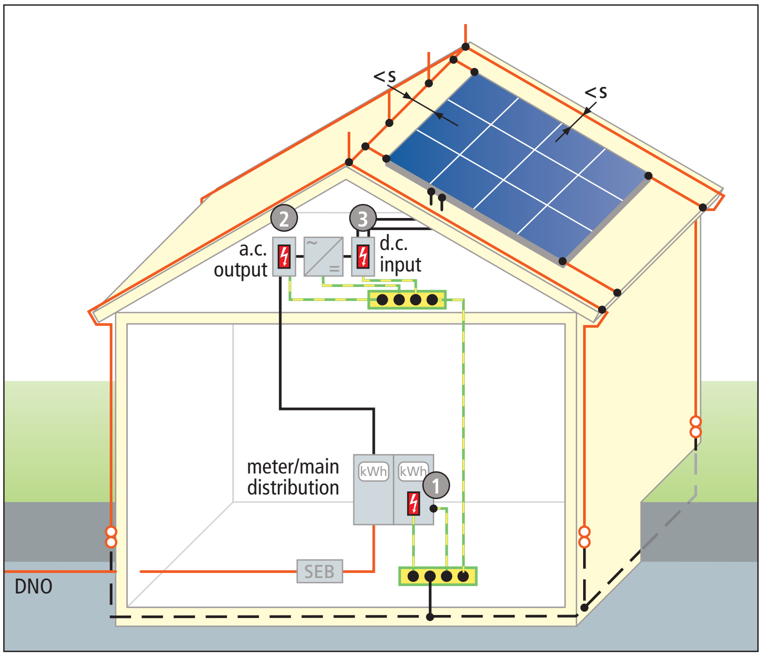

Fig. 9.18.1.8 Surge protection concept for a PV system on a building with external lightning protection system and the separation distance is not being kept

surge protection for a PV system on a building with external lightning protection system and a sufficient separation distance of the PV modules to the external lightning protection system.

An essential part of a lightning protection system is the lightning equipotential bonding for all conductive systems entering the building from the outside. The requirements of lightning equipotential bonding are met by direct connection of all metal systems and by indirect connection of all live systems via lightning current arresters. The lightning equipotential bonding should be performed preferably near the entrance of the structure in order to prevent a penetration of partial lightning currents into the building. The low-voltage power supply of the building is protected by a DEHNventil ZP, a multi-pole combined lightning current and surge arrester with spark gap technology. It is designed for installation on 40 mm DIN rails on the meter mounting board. The surge protective device has to be chosen according to the type of power supply system (**Table 9.18.1.2**).

This combined lightning current and surge arrester unites lightning current and surge arrester in one device has no interaction limiting reactor and is available as complete prewired unit for every low-voltage system (TN-C, TN-S, TT). There is sufficient protection without additional protective devices between DEHNventil and terminal equipment up to a cable length of < 5 m. For greater cable lengths SPDs Type 2 or 3 have to be used in addition. If the distance between the a.c. output of the inverter and the application site of DEHNventil is not greater than 5 m, no further protective devices are required for the a.c. side.

At the d.c. input of the inverter each of the incoming string conductors has to be protected to earth by a DEHNguard surge protective device Type PV 500 SCP installed between plus and minus.

Buildings with external lightning protection system and separation distance not kept
Often the whole roof is covered with PV modules in order to gain a possibly high economic profit. For the mounting technicians, however, then it is often not possible to keep the required separation distance. At these points a direct conductive connection must be provided between the external lightning protection system and the metal PV components. In this case, however, the effects of the currents carried into the structure or building via the d.c. conductors have to be taken into account and hence lightning equipotential bonding has to be ensured. Meaning that now also the lightning current carrying d.c. conductors have to be included into the lightning equipotential bonding (**Figure 9.18.1.8**). According to IEC 62305-3 (EN 62305-3), surge protective devices Type 1 have to be installed at the d.c. conductors. Here DEHNlimit PV 1000, the combined lightning current and surge arrester is used, which in this case will be connected in parallel with the string conductor. The combined arrester DEHNlimit PV 1000 has been especially developed for application in photovoltaic power plants. The encapsulated creeping spark

Figure 9.18.1.7	Protection for...	SPDs	Part No.
L.v. supply			
1	TN-C system	DEHNventil ZP, DV ZP TNC 255	900 390
	TN-S system and TT system	DEHNventil ZP, DV ZP TT 255	900 391
A.c. output of the inverter/a.c., inverter installed in the attic			
2	TN system	DEHNguard M, DG M TN 275 DEHNguard M, DG M TN 275 FM	952 200 952 205
	TT system	DEHNguard M, DG M TT 2P 275 DEHNguard M, DG M TT 2P 275 FM	952 110 952 115
D.c. input of the inverter			
3	2 x (each between plus and minus to earth)	DEHNguard, DG PV 500 SCP DEHNguard, DG PV 500 SCP FM	950 500 950 505

Table 9.18.1.2 Selection of the surge protective devices for PV systems on buildings with external lightning protection system and the separation distance is being kept

Figure 9.18.1.8	Protection for...	SPDs	Part No.
L.v. supply			
1	TN-C system	DEHNventil ZP, DV ZP TNC 255	900 390
	TN-S system and TT system	DEHNventil ZP, DV ZP TT 255	900 391
A.c. output of the inverter/a.c., inverter installed in the attic			
2	TN-C system	DEHNventil M, DV M TN 255 DEHNventil M, DV M TN 255 FM	951 200 951 205
	TT-S system and TT system	DEHNventil M, DV M TT 255 DEHNventil M, DV M TT 255 FM	951 110 951 115
D.c. input of the inverter			
3	Each string conductor	DEHNlimit, DLM PV 1000	900 330

Table 9.18.1.3 Selection of the surge protective devices for PV systems on buildings with external lightning protection and the separation distance is not being kept

gap technology provides safe protection of the PV generator, even at direct lightning currents.
Lightning equipotential bonding has to be performed also for the l.v. input. The DEHNventil ZP, a surge protective device with spark gap technology is used there (**Table 9.18.1.3**). If the distance between the PV inverter and the l.v. input is not greater than 5 m, the a.c. output of the inverter is also protected. Surge protection measures always are effective only locally, which applies also for the protection of the PV inverter. The PV inverter being installed in the attic, additional surge protective devices are necessary to protect the a.c. output of the inverter, to be performed in this case also by the DEHNventil surge protective devices Type 1. This protective device is used because the partial lightning currents flowing via the protective conductor and the a.c. supply conductor have to be controlled by the surge protective device.

Note

The surge protection of so-called thin-film module applications possibly requires separate consideration.

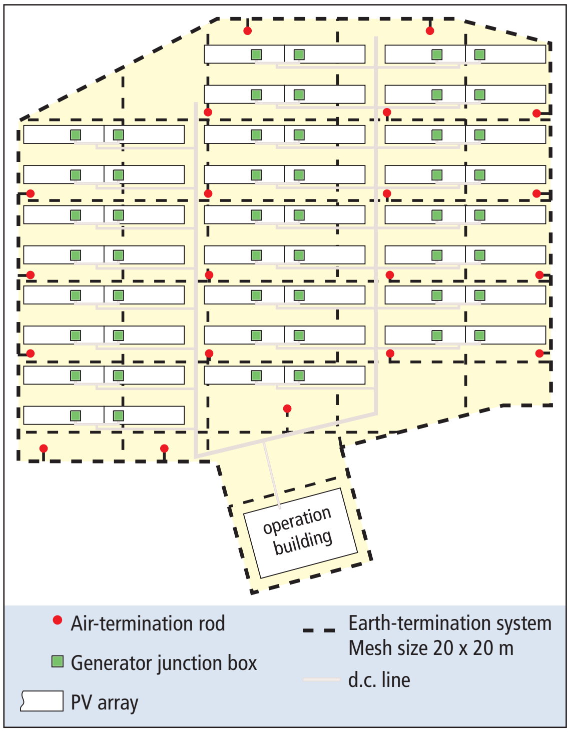

Fig. 9.18.2.1 Layout of a large PV installation in an open area

9.18.2 Lightning and surge protection for solar power plants

For such a complex type of installation as a solar power plant, it is necessary to make an assessment of the damage risk due to lightning strikes according to IEC 62305-2 (EN 62305-2), the result to be taken into account on designing. In case of a solar power plant the aim is to protect both the operation building and the PV array against damage by fire (direct lightning strike), and the electrical and electronic systems (inverters, remote diagnostics system, generator main line) against the effects of lightning electromagnetic impulses (LEMP).

Air-termination system and down-conductor system

For protecting the PV array against direct lightning strikes, it is necessary to arrange the solar modules in the protection zone of an isolated air-termination system. Its design is based on lightning protection system Class III for PV systems greater 10 kW in compliance with VdS guideline 2010. According to the class of lightning protection system, the height and the quality of the air-termination rods required is determined by means of the rolling sphere. Furthermore, it has to be ensured that the separation distance s is kept between the PV supporting frames and the air-termination rods in compliance with IEC 62305-3 (EN 62305-3). Also, the operation building is equipped with an external lightning protection system Class III. The down conductors are connected with the earth-termination system by using terminal lugs. Due to the corrosion risk at the point where the terminal lugs come out of the soil or concrete, they have to be made out of corrosion-resistant material (stainless steel V4A, Material No. 1.4571) or, in case of using galvanised steel they have to be protected by corresponding measures (applying sealing tape or heat-shrinkable tubes, for example).

Earthing system

The earthing system of the PV system is designed as a ring earth electrode (surface earth electrode) with a mesh size of 20 m x 20 m (**Figure 9.18.2.1**). The metal supporting frames which the PV modules are fixed onto, are connected to the earth-termination system approx. every 10 m. The earthing system of the operation building is designed as a foundation earth electrode according to DIN 18014 (German standard). The earth-termination

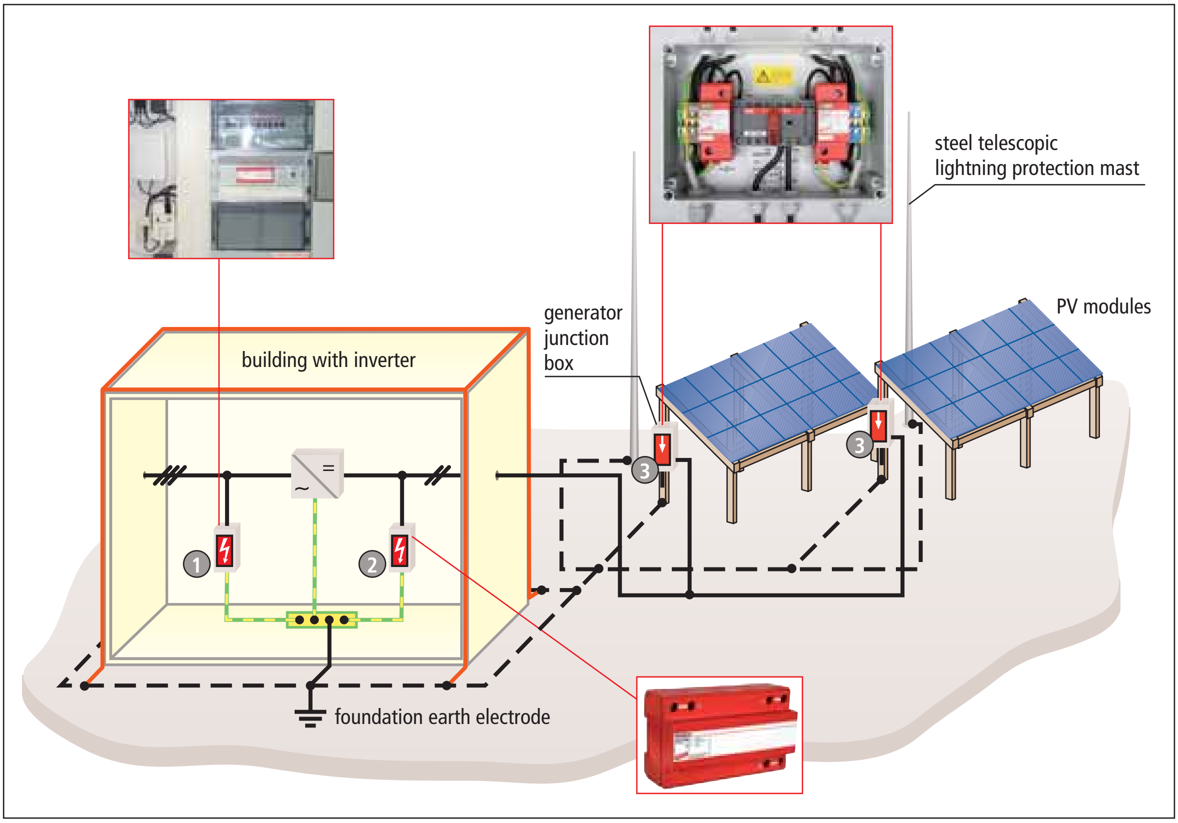

Fig. 9.18.2.2 Basic circuit diagram – Surge protection for a solar power plant

No. in Fig. 9.18.2.2	Protection for...	SPDs	Part No.
1	TN-C system TN-S system TT system	DEHNventil, DV M TNC 255 DEHNventil, DV M TNS 255 DEHNventil, DV M TT 255	951 300 951 400 951 310
2	D.c. input of the inverter	DEHNlimit, DLM PV 1000	900 330
3	Generator junction box	DEHNguard DG PV 500 SCP DEHNguard DG PV 500 SCP FM	950 500 950 505

Table 9.18.2.1 Selection of surge protective devices for solar power plants

system of the PV system and the one of the operation building have to be connected with each other via at least one conductor (30 mm x 3.5 mm steel strip V4A, Material No. 1.4571 or galvanised steel). The interconnection of the individual earthing systems reduces considerably the total earthing resistance. The intermeshing of the earthing systems creates an equipotential surface which reduces considerably the voltage load of lightning effects on the electric connecting cables between PV array and operation building. The surface earth electrodes are laid at least 0.5 m deep in the soil. The meshes are interconnected with four-wire connectors. The joints in the soil have to be wrapped with an anticorrosive band. This also applies to V4A steel strips laid in the soil.

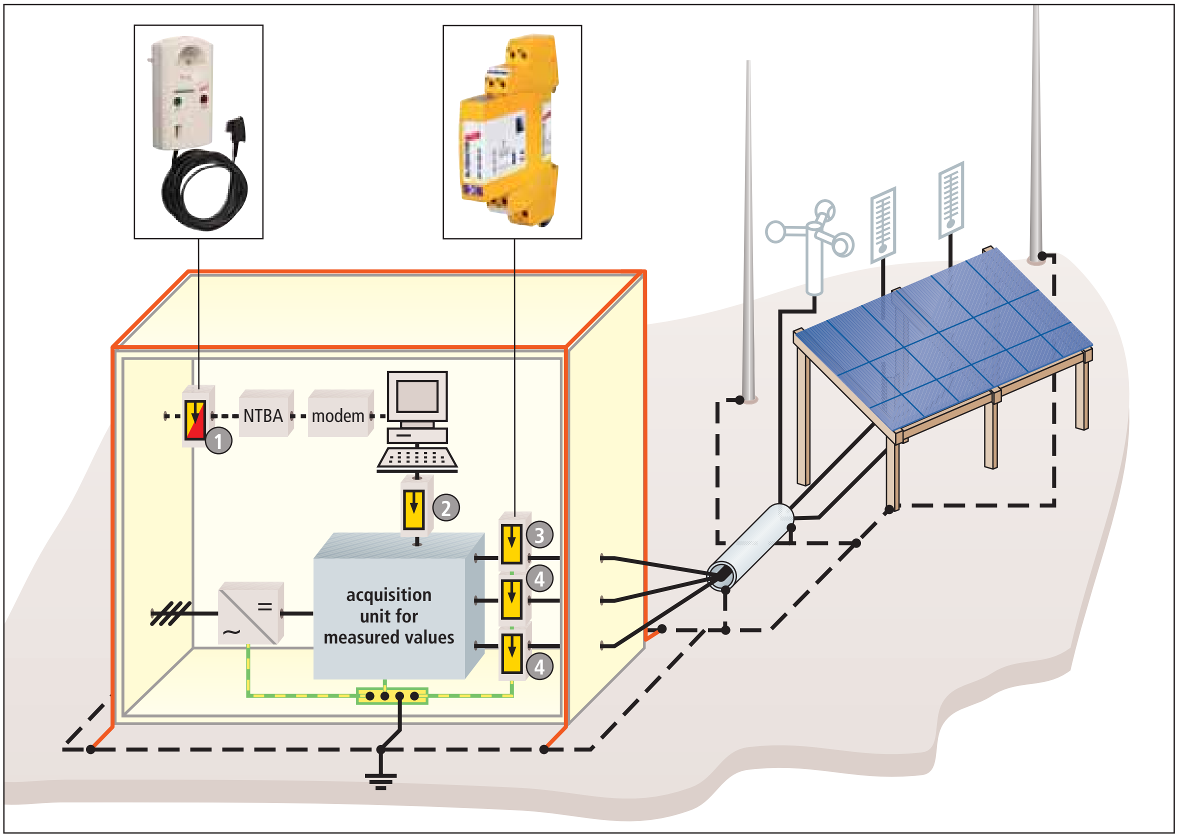

Fig. 9.18.2.3 Protection concept for data acquisition and evaluation

No. in Fig. 9.18.2.3	Protection for…	SPDs	Part No.
1	Network and data input of an NTBA	NT PRO	909 958
2	Measuring and control systems and devices with four-wire data transmission e.g. RS 485 bus systems	BLITZDUCTOR VT, BVT RS 485 5	918 401
3	Wind direction indicators, e.g. analogue transmission of measured values 4 to 20 mA	BLITZDUCTOR XT, BXT ML4 BE 24 + Base part BXT BAS	920 324 920 300
4	Sensor for environment and module temperature	BLITZDUCTOR XT, BXT ML4 BE 5 + Base part BXT BAS	920 320 920 300

Table 9.18.2.2 Surge protective devices for data acquisition and evaluation

Lightning equipotential bonding

In principle, all conductive systems, entering the operation building from outside, have to be generally included into the lightning equipotential bonding. The requirements of lightning equipotential bonding are fulfilled by the direct connection of all metal systems and by the indirect connection of all live systems via lightning current arresters. Lightning equipotential bonding should be performed preferably near the entrance of the structure in order to prevent partial lightning currents from penetrating the building. In this case (**Figure 9.18.2.2**), the low voltage power supply in the operation building is protected by a multi pole DEHNventil combined lightning current and surge arrester (**see Table 9.18.2.1**).

Furthermore, the d.c. lines entering the PV inverter in the operation building have to be protected by a suitable spark-gap-based lightning current arrester, such as DEHNlimit PV 1000, a combined lightning current and surge arrester.

Surge protective measures in the PV array

In order to reduce the load on the isolation inside the solar modules at a lightning strike into the isolated air-termination system, thermally controlled surge protective devices are installed in a generator junction box as close as possible to the PV generator. For generator voltages up to 1000 V d.c., a DEHNguard PV 500 SCP type of surge protective device is installed here between plus and minus to earth. In this case surge protective devices Type 2 are sufficient because the PV modules are within the protective area of the external lightning protection.

In practice, it is a proven method to use surge protective devices with floating contacts to indicate the operating state of the thermal disconnection device. Thus, the intervals between the regular on-site inspections of the protection devices are extended.

The surge protective devices in the generator junction boxes assume the protection for the PV modules locally and ensure that no sparkovers caused by conducted or field-related interferences come up at the PV modules.

Note

The surge protection of so-called thin-film module applications possibly requires separate consideration.

Surge protective measures for data processing systems

The operation building provides a remote diagnostics system, which is used for a simple and quick function check of the PV systems. This allows the operator to recognise and remedy malfunctions in good time. The remote supervisory control system provides the performance data of the PV generator constantly in order to optimise the output of the PV system.

As shown in **Figure 9.18.2.3**, measurements of wind velocity, module temperature and ambient temperature are performed via external sensors at the PV system. These measurements can be read directly from the acquisition unit. The data acquisition unit provides interfaces like RS 232 or RS 485, which a PC and/or modems are connected to for remote enquiry and maintenance. Thus, the service engineers can determine the cause of a malfunction by telediagnosis and then directly eliminate it. The modem in **Figure 9.18.2.3** is connected to the network termination unit (NTBA) of an ISDN basic access.

The measuring sensors for wind velocity and module temperature are also installed in the zone protected against lightning strikes like the PV modules. Thus, no lightning currents come up in the measuring leads, but probably conducted transient surges resulting from induction effects in the event of lightning strikes into the isolated air-termination system.

In order to provide a reliable trouble-free and continuous transmission of the measured data to the measuring unit, it is necessary, to lead the sensor cables entering the building via surge protective devices (**Table 9.18.2.2**). When choosing the protective devices, it has to be ensured that the measurements cannot be impaired. The forwarding of the measured data via the telecommunication network per ISDN modem must be provided as well, in order to provide a continuous control and optimisation of the performance of the installation. For this purpose, the U_{k0} interface upstream of the NTBA which the ISDN modem is connected to, is protected by a surge protective adapter. This adapter ensures additional protection for the 230 V power supply of the NTBA.