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APPLICATION PROPOSAL

Lightning and Surge Protection for Photovoltaic (PV) Systems

SV11/E/0112

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1. Lightning and Surge Protection for Photovoltaic (PV) Systems

Photovoltaic systems are booming worldwide. Located and installed in exposed places they are subject to all climatic influence for decades. Measures to protect the sensitive electronic system components from failure due to lightning flashes and surges are therefore absolutely necessary. The system concept of competent installers of PV systems includes and takes into account the expenditures for lightning and surge protection from the start. Causes for surges in PV systems are inductive or capacitive voltages deriving from lightning discharges and switching operations in the upstream a.c. 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, such as assembly places, schools, hospitals, German building regulations request lightning protection systems for safety reasons. For this purpose, buildings or structures are differentiated, whether, according to their location, construction type or utilisation, a lightning strike can easily occur or have severe consequences. Such buildings or structures need protection and have to be equipped with a permanently effective lightning protection system. According to the 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 cannot 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 according to IEC 62305-2 (EN 62305-2) , and to take the results from this into account for the design. 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 provided with as little expenditure as possible.

The German Insurance Association has picked up the risk estimate in their guideline VdS-Richtlinie 2010 "Risikoorientierter Blitz- und Überspannungsschutz für Objekte" (Risk-oriented lightning and surge protection for objects) (taken from IEC 62305-2 (EN 62305-2) and presents lightning protection measures for buildings and 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. In accordance with the German DIN EN 62305-3 (VDE 0185-305-3) Supplement 2 a lightning protection system (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 with 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 cannot be avoided, the effects of partial lightning currents entering the building have to be taken into consideration.

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

Arrester Type 1

Combined lightning current and surge arrester Type 1, DEHNlimit PV 1000

The combined lightning current and surge arrester DEHNlimit PV 1000 (**Figure 1.1**) is a spark-gap-based d.c. extinguishing arrester. Thus DEHNlimit PV 1000 is the ideal arrester for use in photovoltaic power plants. The encapsulated creeping discharge spark gap technology provides safe protection of the PV generator and of the inverter also in case of direct lightning currents. This combined arrester is applicable for PV systems up to max. 1000 V d.c. U_{PV}. DEHNlimit PV 1000 has a high lightning current discharge capability of 50 kA 10/350 µs.

Arrester Type 2

Modular multi-pole surge arrester Type 2, DEHNguard M YPV (FM)

The structure of the DEHNguard M YPV SCI with the proved fault-resistant Y circuit has a three-step d.c. switching element. This consists of a combined disconnecting and short-circuiting device with Thermo Dynamic Control and an additional melting fuse. This integrated fuse disconnects the arresters safely from generator voltage in case of overload and allows for a safe and dead (arcless) replacement of the respective protection modules. The formation of a d.c. switching arc is prevented. Also a possibly required back-up fuse for the DEHNguard M YPV SCI is not necessary.

The synergy of technologies applied in the DEHNguard M YPV SCI reduces the risk of protective devices being damaged due to installation or isolation faults in the PV circuit, clearly reduces the risk of fire at an overloaded arrester and puts it into a safe electrical state without interfering the operation of the PV system.

Examples of application

Buildings without external lightning protection system

Figure 1.3 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 of the building. DEHNguard M as a complete prewired unit is available for each low-voltage system (TN-C, TN-S, TT) (**Table 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 Type 2 are necessary upstream of the a.c. input of the inverter (**Table 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 M YPV SCI (FM) installed between plus and minus. This surge protective device provides safe protection for PV systems on the d.c. voltage side. In case of fault the integrated fuse will safely disconnect the arrester from the further applied generator voltage.

Figure 1.1 Combined arrester Type 1, DEHNlimit PV, to protect photovoltaic inverters from surges also in case of direct lightning strikes

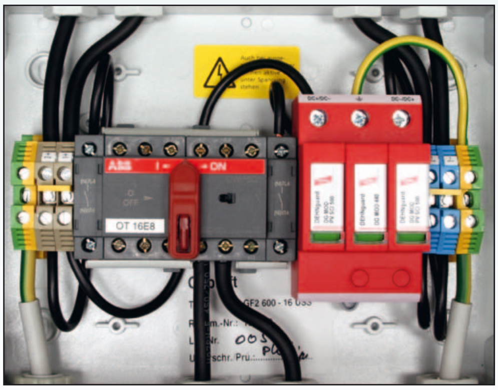

Figure 1.2 Modular surge arrester Type 2 DEHNguard M YPV SCI (FM) with fault-resistant Y circuit and three-step d.c. switching element

Buildings with external lightning protection system and separation distance kept

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 protection system. By using suitable air-termination systems, such as air-termination rods,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 must not cast any 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 ICE 62305-3 (EN 62305-3). The separation distance has to be calculated according to IEC 62305-3 (EN 62305-3).

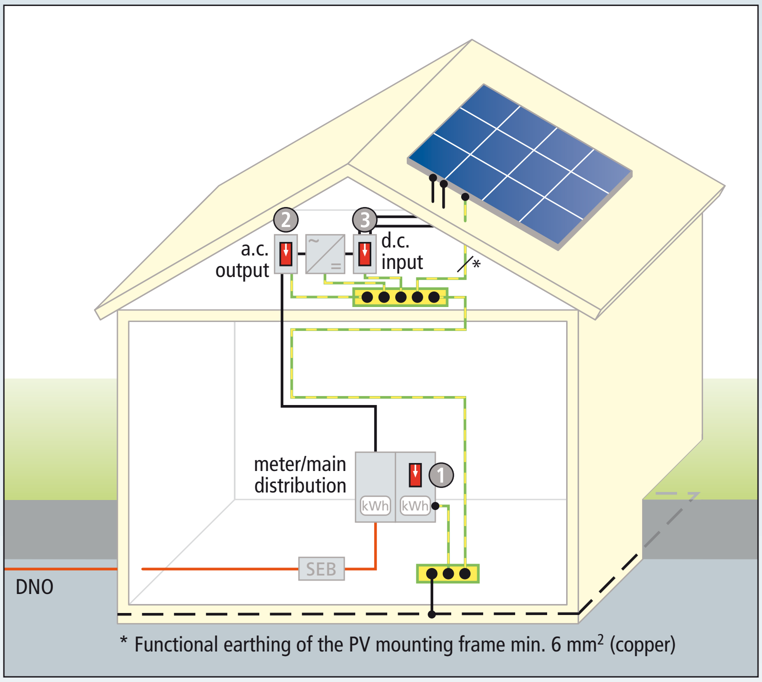

Figure 1.3 Surge protection concept for a PV system on a building without external lightning protection

Figure 1.4 illustrates the concept of 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 and conductors. 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 point of the systems and conductors into the structure in order to prevent a penetration of partial lightning currents into

Figure 1.3	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
a.c. output of the inverter/alternating current, 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 string conductor)	DEHNguard, DG M YPV SCI 1000 DEHNguard, DG M YPV SCI 1000 FM	952 510 952 515

Table 1.1 Selection of the surge protective devices for PV systems on buildings without external lightning protection system

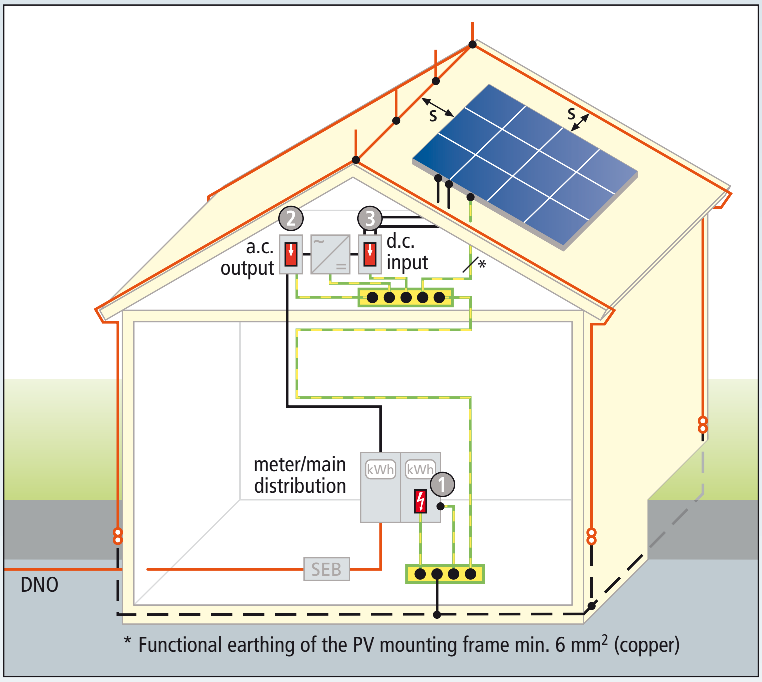

Figure 1.4 Surge protection concept for a PV system on a building with external lightning protection system and the separation distance s being kept

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 been chosen according to the type of power supply system (**Table 1.2**). This combined arrester unites lightning current and surge arrester in one device. 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 the DEHNventil ZP 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 M YPV SCI (FM) protective device installed between plus and minus.

Buildings with external lightning protection system and separation distance not kept

Often PV modules cover the whole roof in order to generate the highest possible profit. For the mounting technicians, however, then it is often not possible to keep the separation distance. At these points a direct conductive connection must be provided between the external lightning protection system and the metal PV com-

Figure 1.4	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/alternating current, 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 string conductor)	DEHNguard, DG M YPV SCI 1000 DEHNguard, DG M YPV SCI 1000 FM	952 510 952 515

Table 1.2 Selection of the surge protective devices for PV systems on buildings with external lightning protection system and the separation distance s being kept

ponents. In this case, however, the effects of the currents carried into the structure 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 1.5**). According to IEC 62305-3 (EN 62305-3) SPDs Type 1 have to be installed at the d.c. conductors. Here DEHNlimit PV 1000, a 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 developed especially for application in photovoltaic power plants. Lightning equipotential bonding has to be implemented also for the l.v. input. There, the DEHNventil ZP, for example, a surge protective device with spark gap technology is used (**Table 1.3**). If the distance between PV inverter and l.v. input is not greater than 5 m, also the a.c. output of the inverter is protected. Surge protective measures always are effective only locally, which applies also for the protection of the PV inverter. If the PV inverter is installed in the attic, the a.c. output of the inverter has to be protected by additional surge protective devices, namely by DEHNventil Type 1. This protective device is used because partial lightning currents can also flow through the protective conductor and the a.c. supply and have to be controlled by the surge protective device.

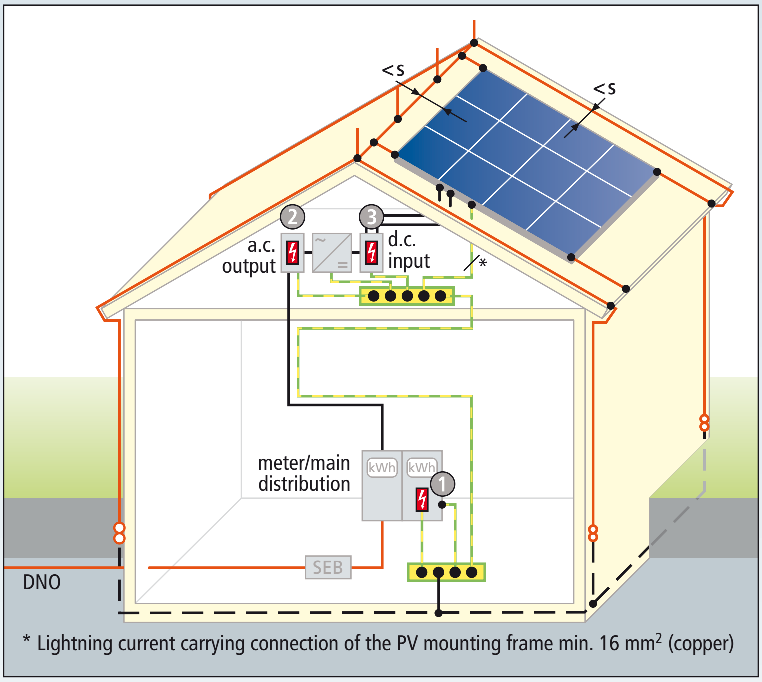

Figure 1.5 Surge protection concept for a PV system on a building with external lightning protection system and the separation distance s not being kept

Figure 1.5	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/alternating current, 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 2P 255 DEHNventil M, DV M TT 2P 255 FM	951 110 951 115
d.c. input of the inverter			
3	Each string conductor	DEHNlimit, DLM PV 1000	900 330

Table 1.3 Selection of surge protective devices for PV systems on buildings with external lightning protection system and the separation distance s not being kept

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 (inverter, 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 a 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 method. 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 sleeve, for example).

Earth-termination system

The earth-termination 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 2.1**). The metal supporting frames which the PV modules are fixed onto, shall be connected to the earth-termination system approx. every 10 m. The earth-termination system of the operation building is designed as a foundation earth electrode according to DIN 18014 (German standard). The earth-termination 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 earth-termination system reduces considerably the total earthing resistance.

The intermeshing of the earth-termination system 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.

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

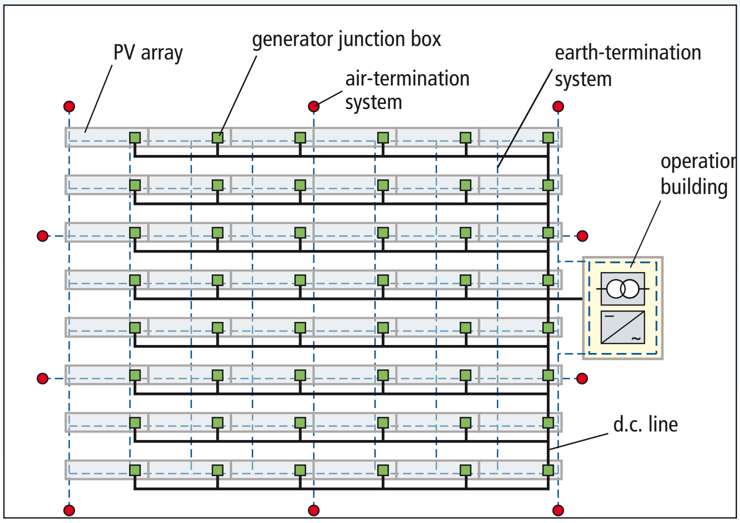

Figure 2.1 Layout of a large PV installation in an open area

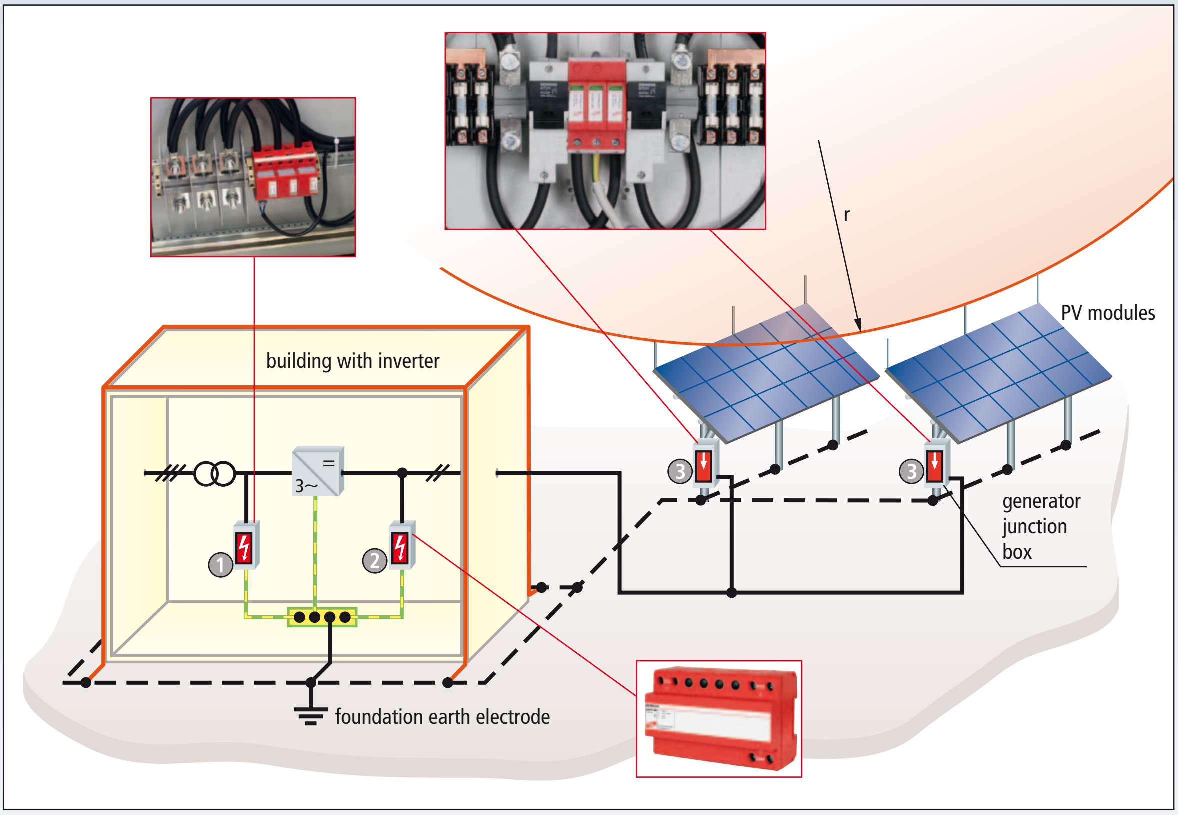

Figure 2.2 Basic circuit diagram of the surge protection for a solar power plant

No. in Fig. 2.2	Protection for...	SPDs	Part No.
1	TN-C system TN-S system TT system	DEHNventil, DV M TNC 255 FM DEHNventil, DV M TNS 255 FM DEHNventil, DV M TT 255 FM	951 305 951 405 951 315
2	D.c. input of the inverter	DEHNlimit, DLM PV 1000	900 330
3	Generator junction box	DEHNguard, DG M YPV SCI 1000 DEHNguard, DG M YPV SCI 1000 FM	952 510 952 515

Table 2.1 Selection of surge protective devices for solar power plants

be performed preferably near the entrance of the structure in order to prevent partial lightning currents from penetrating the building. In this case (**Figure 2.2**), the low-voltage power supply in the operation building is protected by a multi-pole DEHNventil combined lightning current and surge arrester (**Table 2.1**). Furthermore, the d.c. lines entering the PV inverter have to be protected in the operations building by a suitable spark-gap-based lightning current arrester, such as DEHNlimit PV 1000, a combined lightning current and surge arrester.

Surge protection 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 monitored surge protective devices are installed in a genera-

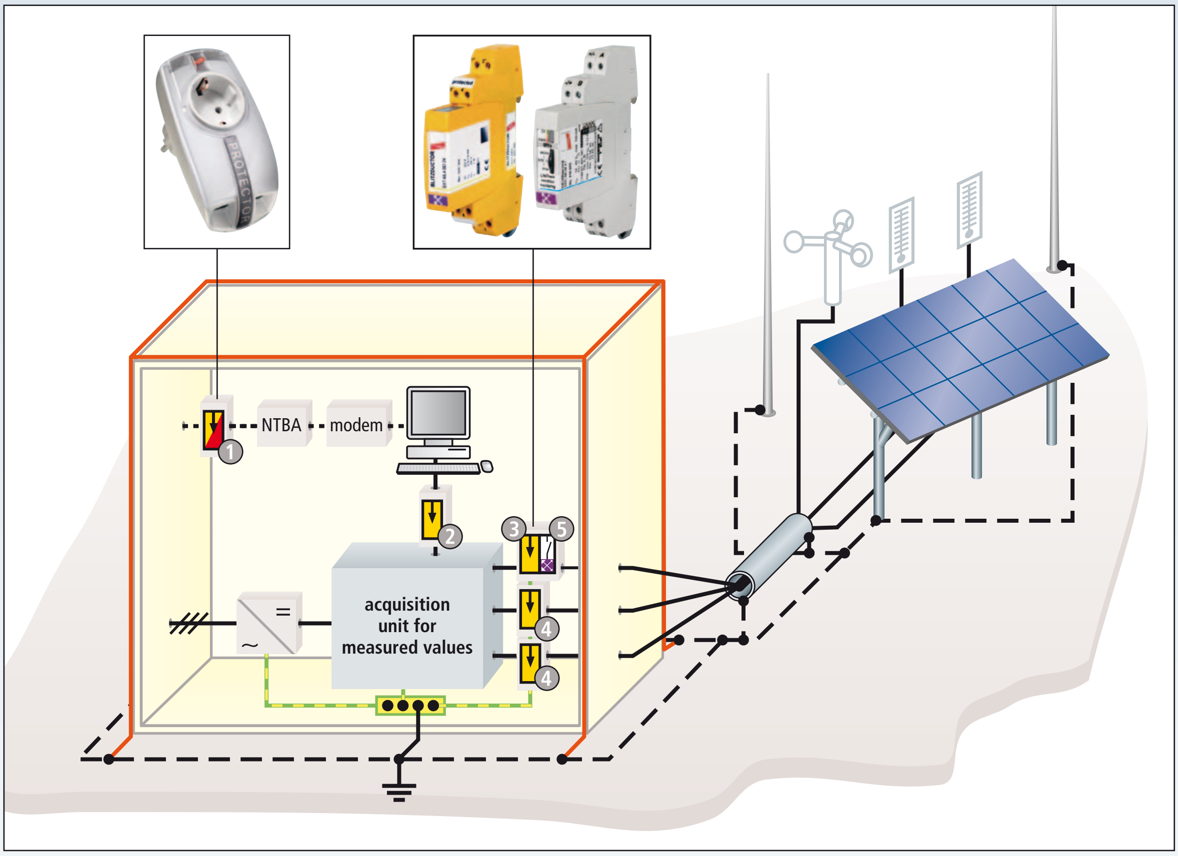

Figure 2.3 Protection concept for data acquisition and evaluation

No. in Fig. 2.3	Protection for...	SPDs	Part No.
1	Network and data input of an NTBA	DEHNprotector, DPRO 230 NT	909 310
2	Connection of a data logger with PC	DEHNpatch, DPA M CAT6 RS45S 48	929 100
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 ambient and module temperature	BLITZDUCTOR XT, BXT ML4 BE 5 + Base part BXT BAS	920 320 920 300
5	State orientated monitoring of max. 10 BXT protection modules	DRC MCM XT	910 695

Table 2.2 Surge protective devices for data acquisition and evaluation

tor junction box as close as possible to the PV generator. On the d.c. side, a surge protective device of type DEHNguard M YPV 500 SCI (FM) is installed in each generator junction box. 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 onsite 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.

Surge protection measures for IT systems

The operation building provides a remote diagnostics system, which is used for an easy and quick function check of the PV systems. This allows the operator to recognise and remedy malfunctions at an early stage. 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 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 an Ethernet interface, 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 2.3** is connected to the network termination for ISDN basic rate access (NTBA). 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 2.2).

Surge arresters of Type BLITZDUCTOR XT with LifeCheck can be monitored in connection with the DEHNrecord MCM. Failures detected by the DEHNrecord MCM can be integrated into the remote diagnostics by remote signalling contact or bus connection.

When choosing the protective devices, it has to be ensured that the measurements cannot be impaired. Safety in the forwarding of the measured data via the telecommuncation network per ISDN modem must be given as well in order to provide a continuous monitoring and optimisation of the performance of the installation. For this purpose, the U_{k0} interface upstream 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.

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