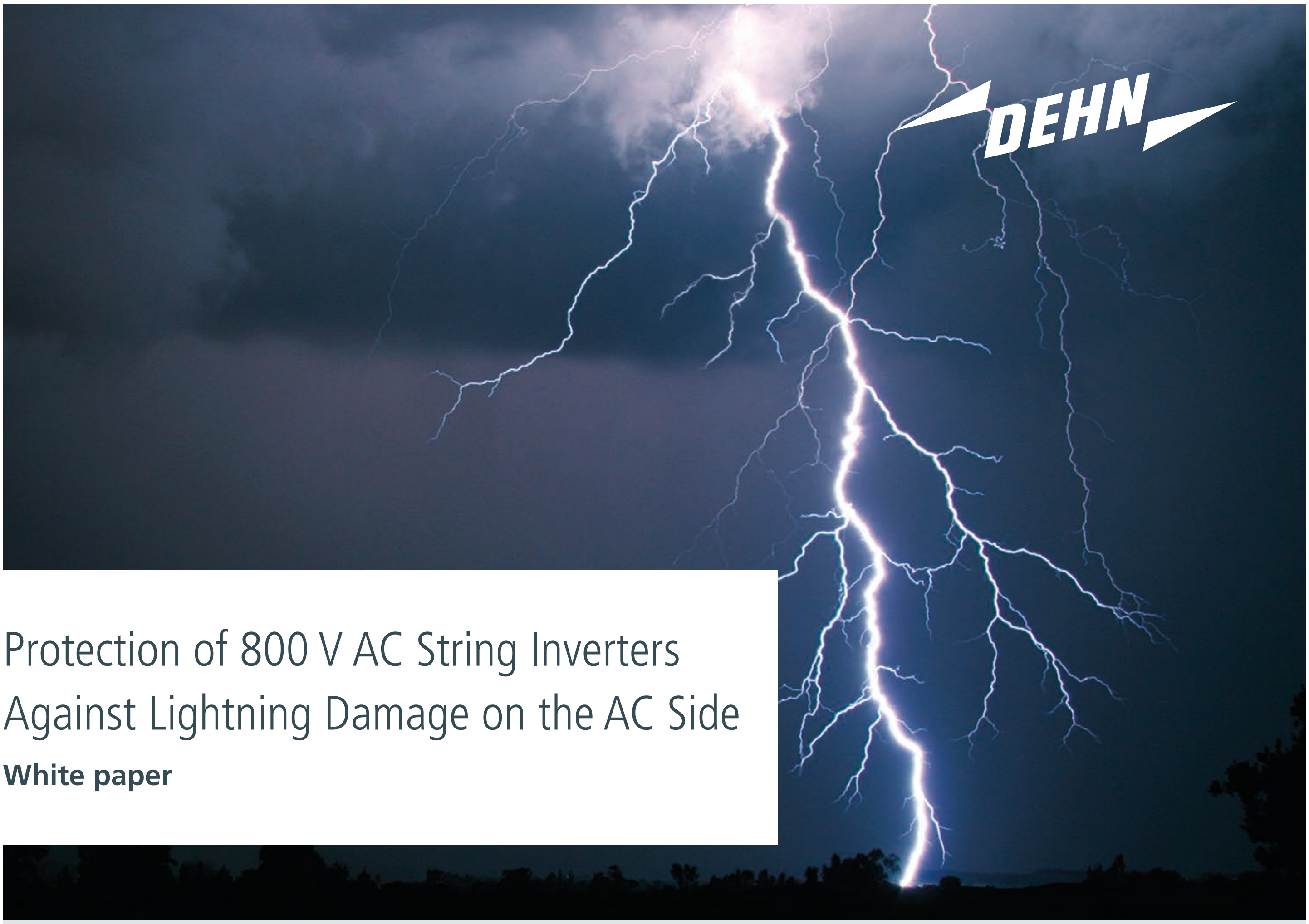


Protection of 800 V AC String Inverters Against Lightning Damage on the AC Side

White paper

Content

Protection of 800 V AC String Inverters Against Lightning Damage on the AC Side

White paper

The progressing energy revolution can no longer be reversed, and the development of PV power generation systems is therefore increasing. New PV systems of around 5.3 GW were installed in 2021 in Germany alone. In order to drive the energy revolution forwards, free-field PV systems play a major role in certain countries. The reliable operation of these systems, and thus stable power generation, must be ensured. It is therefore important to protect these systems against lightning currents and surges. If string inverters are used, it is important to protect them with additional type-1 SPDs (SPD: Surge Protective Device) against partial lightning currents on the AC side, even if they are already equipped with internal surge protection. In the event of lightning strikes within the free-field PV system, partial lightning currents can be injected into the AC side of the string inverter and damage or even destroy it.

Structure of a free-field PV system with string inverter

The basic structure of free-field systems with string inverters consists of:

- PV strings
- String inverters
- AC distribution units
- Step-up transformer to the power grid

Nowadays, the voltages of PV strings are as much as 1,500 V DC. In systems with a string inverter design, the majority of the power cabling is on the AC side. The inverters are mostly installed under the module racks of the PV strings. Most of the string inverters available since 2019 for utility-scale PV plants have an output voltage of 800 V (L-L) on the AC side. Cables from the AC

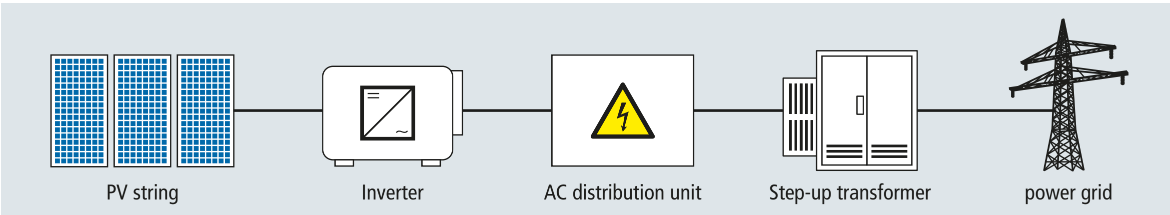
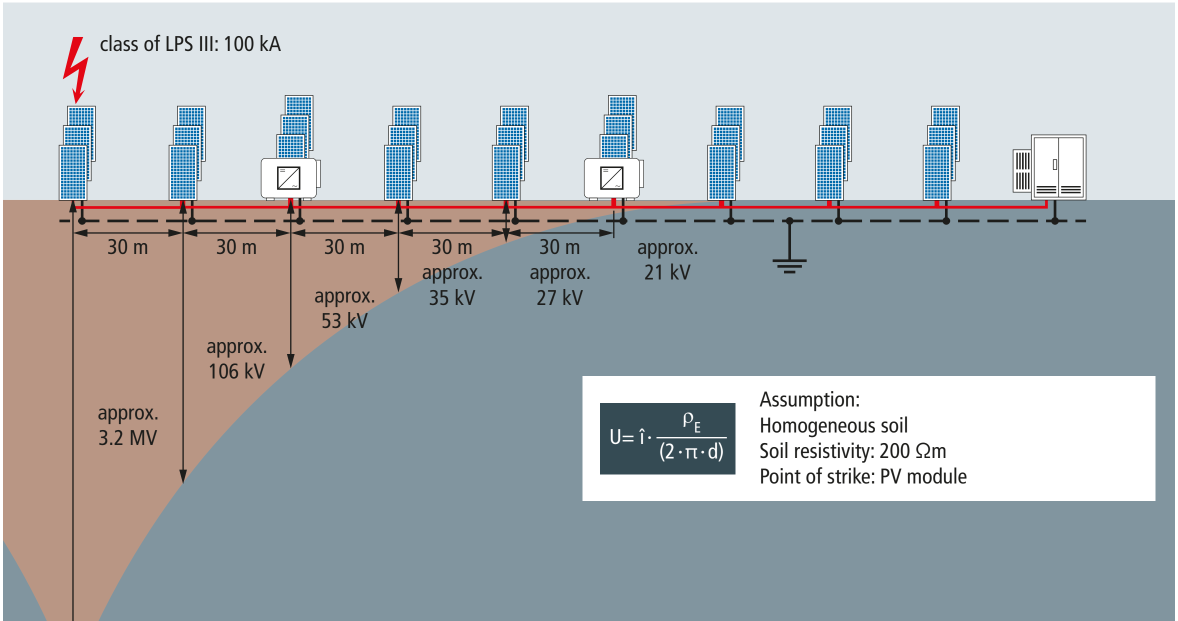


Figure 1 Systematic structure of a free-field PV system with string inverters



Distance	1 m	30 m	60 m	90 m	120 m	150 m	180 m	210 m	240 m	270 m	300 m
Voltage to remote earth in kV	3185 kV	106 kV	53 kV	35 kV	27 kV	21 kV	18 kV	15 kV	13 kV	12 kV	11 kV

Figure 2 Rise in the local earth potential

side of several string inverters are often joined and fused before the transformer in an AC distribution box. The transformer then converts the 800 V AC to levels appropriate for a medium- or high-voltage grid system. (**Figure 1**). In most cases, the electrical connection from the inverter to the transformer station is established as a three-phase IT system. By omitting the neutral conductor, costs associated with wiring are optimised.

What risks are inverters exposed to?

In the event of a lightning strike into the PV modules or into air-termination systems, the distribution of lightning current is influenced significantly by the power cabling. This is also explained in IEC TR 63227. In systems with a string inverter design, the majority of the power cabling is on the AC side.
This acts as an equipotential bonding conductor between the local earth potential of the modules and the distant equipotential surface of the step-up transformer.
Due to the free-field PV system's intermeshed earthing system as per IEC TR 63227, all components are interconnected for electrical conduction.
If lightning strikes a PV module, or an air-termination rod, the lightning current is channelled through the PV frame into the ground and then spreads in all directions from that point. This leads to a rise in the local earth potential (**Figure 2**). Since the transformer station is located some distance away in most cases, this value is still at "0 potential". Partial lightning currents will take the path of the largest voltage difference and the lowest resistance. Therefore, partial lightning currents will be injected through the SPDs on the inverter AC side and flow towards the transformer station, where they are then distributed through the earthing system of the transformer station (**Figure 3**).
As the inverters are installed close to the modules and are conductively connected with the earthing arrangement through an intermeshed earthing system as per IEC TR 63227, a local equipotential surface is created so that partial lightning currents on the DC side are not expected. Therefore, type-2 SPDs suffice on the DC side, because only induced surges are anticipated.
The fact that partial lightning currents are to be expected on the AC side in PV systems with string inverters is also described in the standard IEC 61643-32. However, as most string inverters are only fitted with integrated type-2 SPDs on the AC side, additional protection with type-1 SPDs is necessary in order to safely dissipate the high-energy partial lightning currents so the inverter is not damaged or destroyed as a result.

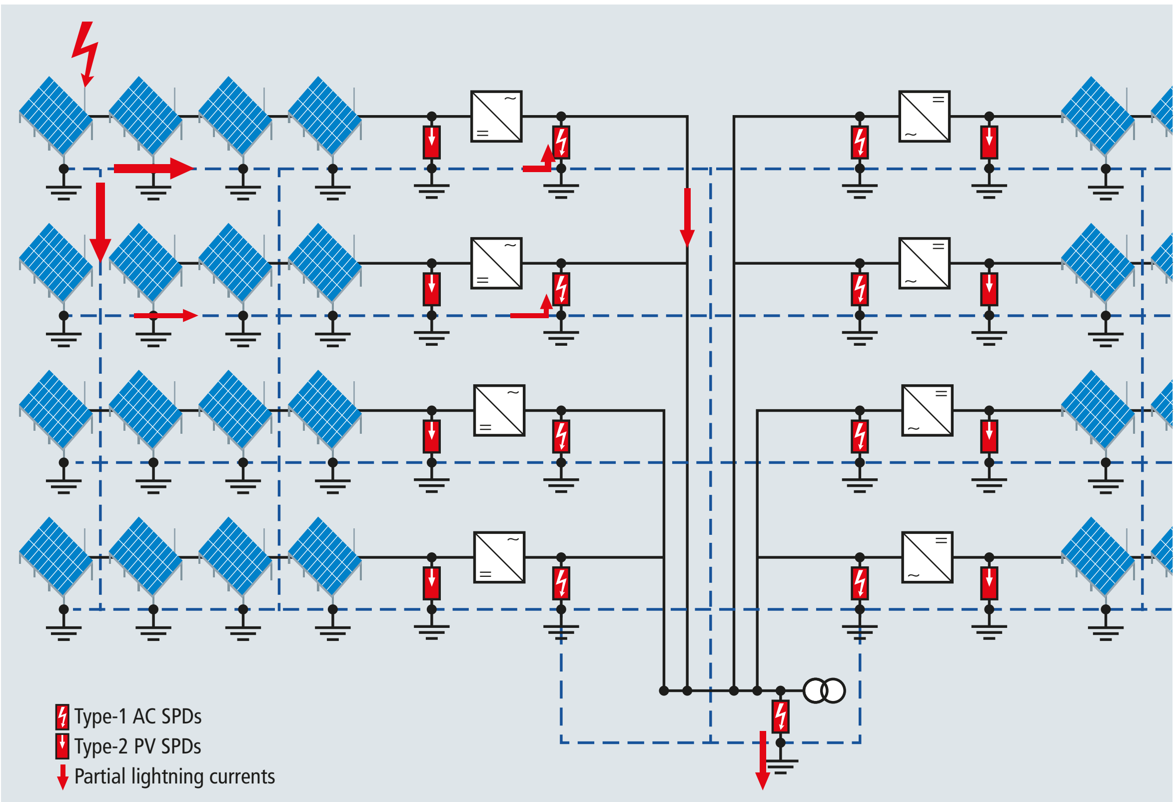


Figure 3 Partial lightning current flow from the point of strike to the earthing system of the transformer station

Protection of 800 V AC String Inverters Against Lightning Damage on the AC Side

White paper

In the DEHN Test Centre, tests have been conducted on commonly used inverters from market leaders. In these tests, a lightning current was fed into the AC side of the inverter to check whether the selected protection solution protected the inverter against damage. It was demonstrated that additional protection on the AC side with type-1 SPDs safely protected the systems from lightning damage and the integrated type-2 SPDs in the inverter were not overloaded.

Protection of the AC side with DEHNbloc Maxi 440 in a "Neptune" (3+1) configuration.

To protect the inverter, a "Neptune" (3+1) configuration is necessary. This consists of 4x DEHNbloc Maxi 440 (DBM 1 440). They are installed on the AC side close to the inverter (**Figure 4**). The DEHNbloc Maxi (DBM) is a robust type-1 SPD based on spark gap technology. Due to the "Neptune" (3+1) configuration, two SPDs are always in series (L-L; L-GND). The DBM 1 440 has a max. continuous operating voltage of 440 V AC. With a series connection, the max. continuous operating voltage of the arrester combination is raised to 880 V AC and is therefore perfectly suited for use in 800 V AC grids.

Things to bear in mind when choosing a type-1 SPD

When using additional type-1 SPDs on the AC side, the coordination of the individual protection stages must be ensured. If there is no coordination between integrated type 2 and external type 1 SPDs, the inverter can become damaged or even destroyed. A tested protection solution should always be used to prevent failure of the inverter and the associated costs (new procurement, installation, losses due to failure, etc.). If there is a threat of power overload to the type-2 SPDs in the inverter, the more powerful upstream type-1 SPD must respond to dissipate the interfering excess energy. In order to test the coordination of the DEHNbloc Maxi 440 with the integrated type-2 SPDs, a coordination test was successfully conducted for this purpose as per CLC/TS 61643-12:2009. One of the advantages of the DEHNbloc Maxi 440 is the integrated spark gap technology. Spark gaps are voltage-switching components with a quick sparkover performance in the nanosecond range. After an extremely short period of time, the voltage drops to the arc voltage (typically in the range of the supply voltage).

This characteristic of the spark gap equates to a kind of wave-breaker function. The lightning current wave is "switched away", thus considerably reducing the impulse duration through the device. This reduction of the impulse duration reduces the remaining current-time area to an extremely low value (**Figure 5**). Even with high impulse currents, only a low amount of power is thus let into the inverter and dissipated by the integrated type-2 SPDs.

Varistors, by contrast, are voltage-limiting components. When using varistor-based type-1 SPDs, the voltage is limited throughout the entire period of the discharge process of the impulse current. During the entire impulse duration, a current thus flows into the inverter (**Figure 5**).

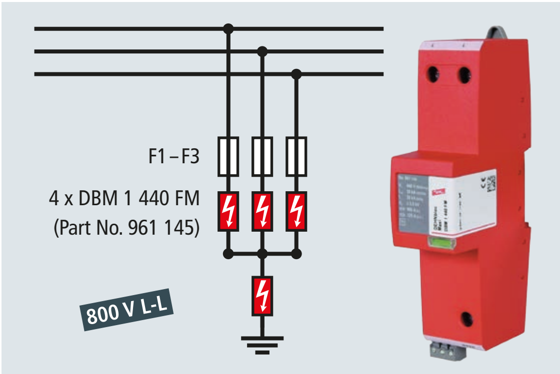


Figure 4 Protection solution with DBM 1 440 FM in "Neptune" (3+1) configuration

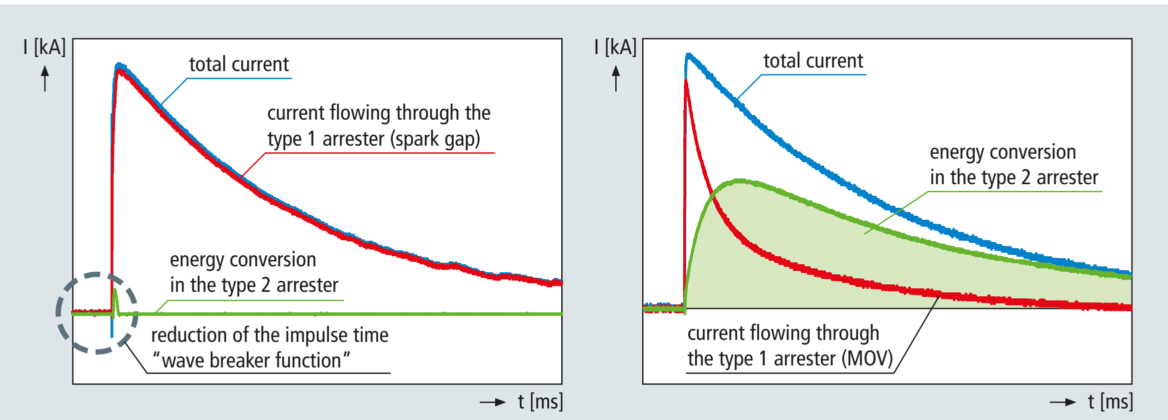


Figure 5 Comparison of a spark-gap-technology based type-1 SPD with a varistor-technology-based type-1 SPD

If the quantity of energy let through exceeds the value W_{max} (max. energy that may flow through the varistor) of the varistor integrated in the inverter (type-2 SPD), then the integrated type-2 SPDs will be damaged or even destroyed. The inverter is then no longer protected. In order for the type-2 SPDs integrated in the inverter to be protected in the event of an overload, upstream spark-gap-based type-1 SPDs, like the DEHNbloc Maxi 440, are required.

IT system cabling in systems with string inverters

According to IEC 60364-4-44, TOVs (Temporary Overvoltages) can be carried over to the low-voltage side in IT systems in the event of an earth fault in the high-voltage system. These voltages are limited to 1,200 V AC for a maximum of 5 seconds. For an AC system with 800 V, the maximum permitted TOV in the low-voltage system would thus be 2,000 V (1,200 V + nominal AC inverter voltage). Standard SPDs are not usually designed for these voltages. Due to the system design of free-field PV systems, however, these high TOVs can, under certain conditions, be ignored.
According to IEC TR 63227, an intermeshed earthing system must be set up. Here, the individual components (PV frame, string inverter, transformer station, etc.) are conductively linked to the intermeshed earthing system. In addition, it is also the case that the neutral point on the low-voltage side of the transformer does not have a direct link to earth. That is why, in the event of an earth fault on the high-voltage side, there will be no direct voltage increase on the 800 V secondary side of the transformer.
If there is an earth fault on the high-voltage side, there is indeed a local potential increase on the transformer station, but this has no effects on the PV system. The reason for this is that this rise in potential generates currents of less than 100 A in the ground. Due to the intermeshed earthing system, these small currents do not lead to any significant potential difference in the earthing system, and thus no high TOVs appear on the AC side. This is why SPDs can be installed for a mains voltage of merely 800 V without them becoming overloaded.

Tested protection solution

In order to verify the protective effect of the DBM 1 440 and thus to protect the AC side of the inverter against lightning and surges, the following tests were performed in the DAkkS-certified DEHN Test Centre.

- Coordination test for the integrated type-2 SPD (CLC/TS 61643-12:2009 Annex J)
- Test with increased voltage for use with an integrated anti-PID unit

Coordination test of the DBM 1 440 with pre-integrated SPDs in the inverter

In order to reliably protect systems during surges, it may be necessary, depending on the impulse withstand voltage of the equipment to be protected (e.g. inverters) and the cabling of the electrical system (cable length, routing etc.), to use two or more SPDs. In such cases, effective coordination of the SPDs must be considered, so that downstream SPDs are not overloaded with power.
Furthermore, the overvoltages that arise must be limited so that the limiting voltage is below the dielectric strength of the electrical equipment to be protected.
In order to verify this, a coordination test was performed in line with CLC/TS 61643-12:2009 and successfully passed. Therefore, coordination of the DMB 1 440 with the type-2 SPDs integrated in the inverters is ensured..

Test with increased voltage for the use of an anti-PID unit

PID stands for "Potential-Induced Degradation". This is an effect that occurs with PV modules with crystalline Si cells and can lead to a gradual loss in performance. If the PV modules

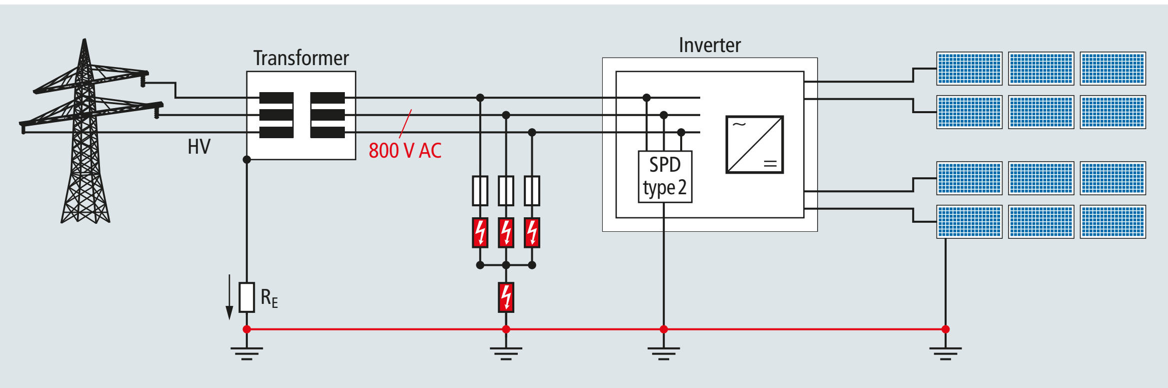


Figure 6 Neutral point of the low-voltage side without earth connection

in operation have a negative potential to earth, a correspondingly high negative voltage arises between the individual cells of the PV module and the earthed aluminium frame. It can therefore be the case that electrons from the PV module follow this electric field and ultimately flow out via the earthed aluminium frame.
This flow of electrons has a significant influence on the properties of the Si cells and impairs the efficiency of the modules. As a counter-measure, "anti-PID units" are used. Depending on the manufacturer and the type of inverter, these units might already be integrated. Otherwise, there are anti-PID units that can be additionally installed. How such anti-PID units function can vary depending on the manufacturer. The tested inverters already have such units integrated. These anti-PID units feed in DC voltage between the phases and earth on the AC side. As a result, the virtual negative voltage on the DC side is raised to earth potential. The DC voltage fed by the anti-PID unit can be up to 50 % of the string voltage. In the event of a voltage of 1,500 V DC, up to 750 V DC of offset voltage can thus arise on the AC side. Such superimposed voltage will affect SPDs on the AC side. These SPDs must not trip in the case of increased voltage through the use of the anti-PID unit. In the DEHN Test Centre, a superimposed voltage with peaks of 1,450 V was reconstructed and connected to the AC side of the inverter.
Our "Neptune" (3+1) configuration made up of DBM 1 440 SPD units was tested with such increased voltages. It successfully passed the test and did not trip.

Conclusion
Through the use of the DBM 1 440 in a "Neptune" (3+1) configuration on the AC side of the inverter, the inverter was protected against injected partial lightning currents. By means of the spark gap technology, the majority of the lightning current is discharged through the DBM 1 440
and the type-2 SPDs in the inverter are not overloaded. This was tested by means of a coordination test in line with CLC/TS 61643-12:2009. Also, when using an anti-PID unit, the protection of the inverter is ensured without the SPDs tripping.

The "Neptune" (3+1) configuration for protecting the inverters can be implemented with the following products.

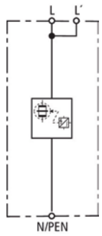
Protective device	Part no.
DBM 1 440	961 140
DBM 1 440 FM	961 145
DBM 1 CI 440 FM	961 146

For a system design with a central inverter, you can find a protection solution at: Free-field PV systems – Lightning protection from DEHN

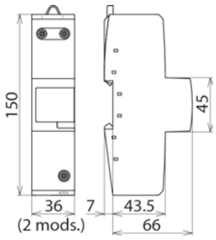
DBM 1 440 (961 140)

- Extremely high lightning current discharge capacity
- High follow current extinction and limitation due to RADAX Flow technology
- Directly coordinated with DEHNguard surge protective devices without additional cable length

Figure without obligation



Basic circuit diagram DBM 1 440



Dimension drawing DBM 1 440

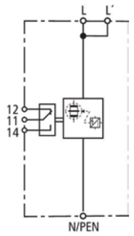
Coordinated single-pole lightning current arrester with high follow current limitation for U_C = 440 V.

Type **Part No.**	**DBM 1 440** **961 140**
SPD according to EN 61643-11 / IEC 61643-11	type 1 / class I
Nominal voltage (a.c.) (U_N)	400 V
Max. continuous operating voltage (a.c.) (U_C)	440 V
Lightning impulse current (10/350 µs) (I_{imp})	35 kA
Specific energy (W/R)	306.25 kJ/ohms
Nominal discharge current (8/20 µs) (I_n)	35 kA
Voltage protection level (U_P)	≤ 2.5 kV
Follow current extinguishing capability (a.c.) (I_{fi})	50 kA_{rms}
Follow current limitation / Selectivity	no tripping of a 32 A gG fuse up to 50 kA_{rms} (prosp.)
Response time (t_A)	≤ 100 ns
Max. backup fuse (L) up to I_K = 50 kA_{rms} (t_a ≤ 0.2 s)	500 A gG
Max. backup fuse (L) up to I_K = 50 kA_{rms} (t_a ≤ 5 s)	250 A gG
Max. backup fuse (L-L')	125 A gG
Temporary overvoltage (TOV) (U_T) – Characteristic	760 V / 120 min. – withstand
Operating temperature range (parallel connection) (T_{UP})	-40 °C ... +80 °C
Operating temperature range (series connection) (T_{US})	-40 °C ... +60 °C
Operating state / fault indication	green / red
Number of ports	1
Cross-sectional area (L, L', N/PEN) (min.)	10 mm^2 solid / flexible
Cross-sectional area (L, N/PEN) (max.)	50 mm^2 stranded / 35 mm^2 flexible
Cross-sectional area (L') (max.)	35 mm^2 stranded / 25 mm^2 flexible
For mounting on	35 mm DIN rails acc. to EN 60715
Enclosure material	thermoplastic, red, UL 94 V-0
Place of installation	indoor installation
Degree of protection	IP 20
Capacity	2 module(s), DIN 43880
Approvals	UL, CSA
Extended technical data:	Use in switchgear installations with prospective short-circuit currents of more than 50 kA_{rms} (tested by the German VDE)
– Max. prospective short-circuit current	100 kA_{rms} (220 kA_{peak})
– Limitation / Extinction of mains follow currents	up to 100 kA_{rms} (220 kA_{peak})
– Max. backup fuse (L) up to I_K = 100 kA_{rms} (t_a ≤ 0.2 s)	500 A gG
– Max. backup fuse (L) up to I_K = 100 kA_{rms} (t_a ≤ 5 s)	250 A gG
Weight	516 g
Customs tariff number (Comb. Nomenclature EU)	85363090
GTIN	4013364116269
PU	1 pc(s)

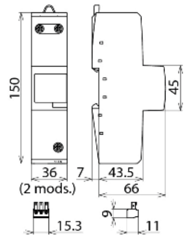
DBM 1 440 FM (961 145)

- Extremely high lightning current discharge capacity
- High follow current extinction and limitation due to RADAX Flow technology
- Directly coordinated with DEHNguard surge protective devices without additional cable length

Figure without obligation



Basic circuit diagram DBM 1 440 FM



Dimension drawing DBM 1 440 FM

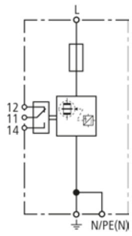
Coordinated single-pole lightning current arrester with high follow current limitation for U_C = 440 V.

Type **Part No.**	**DBM 1 440 FM** **961 145**
SPD according to EN 61643-11 / IEC 61643-11	type 1 / class I
Nominal voltage (a.c.) (U_N)	400 V
Max. continuous operating voltage (a.c.) (U_C)	440 V
Lightning impulse current (10/350 µs) (I_{imp})	35 kA
Specific energy (W/R)	306.25 kJ/ohms
Nominal discharge current (8/20 µs) (I_n)	35 kA
Voltage protection level (U_P)	≤ 2.5 kV
Follow current extinguishing capability (a.c.) (I_{fi})	50 kA_{rms}
Follow current limitation / Selectivity	no tripping of a 32 A gG fuse up to 50 kA_{rms} (prosp.)
Response time (t_A)	≤ 100 ns
Max. backup fuse (L) up to I_K = 50 kA_{rms} (t_a ≤ 0.2 s)	500 A gG
Max. backup fuse (L) up to I_K = 50 kA_{rms} (t_a ≤ 5 s)	250 A gG
Max. backup fuse (L-L')	125 A gG
Temporary overvoltage (TOV) (U_T) – Characteristic	760 V / 120 min. – withstand
Operating temperature range (parallel connection) (T_{UP})	-40 °C ... +80 °C
Operating temperature range (series connection) (T_{US})	-40 °C ... +60 °C
Operating state / fault indication	green / red
Number of ports	1
Cross-sectional area (L, L', N/PEN) (min.)	10 mm^2 solid / flexible
Cross-sectional area (L, N/PEN) (max.)	50 mm^2 stranded / 35 mm^2 flexible
Cross-sectional area (L') (max.)	35 mm^2 stranded / 25 mm^2 flexible
For mounting on	35 mm DIN rails acc. to EN 60715
Enclosure material	thermoplastic, red, UL 94 V-0
Place of installation	indoor installation
Degree of protection	IP 20
Capacity	2 module(s), DIN 43880
Approvals	UL, CSA
Type of remote signalling contact	changeover contact
Switching capacity (a.c.)	250 V / 0.5 A
Switching capacity (d.c.)	250 V / 0.1 A; 125 V / 0.2 A; 75 V / 0.5 A
Cross-sectional area for remote signalling terminals	max. 1.5 mm^2 solid / flexible
Extended technical data:	Use in switchgear installations with prospective short-circuit currents of more than 50 kA_{rms} (tested by the German VDE)
– Max. prospective short-circuit current	100 kA_{rms} (220 kA_{peak})
– Limitation / Extinction of mains follow currents	up to 100 kA_{rms} (220 kA_{peak})
– Max. backup fuse (L) up to I_K = 100 kA_{rms} (t_a ≤ 0.2 s)	500 A gG
– Max. backup fuse (L) up to I_K = 100 kA_{rms} (t_a ≤ 5 s)	250 A gG
Weight	520 g
Customs tariff number (Comb. Nomenclature EU)	85363090
GTIN	4013364116276
PU	1 pc(s)

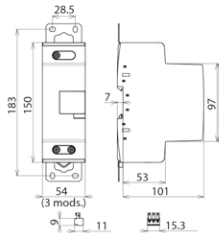
DBM 1 CI 440 FM (961 146)

- Spark-gap-based lightning current arrester with integrated backup fuse
- Maximum system availability thanks to RADAX Flow follow current limitation
- Directly coordinated with DEHNguard surge protective devices without cable length

Figure without obligation



Basic circuit diagram DBM 1 CI 440 FM



Dimension drawing DBM 1 CI 440 FM

Coordinated single-pole lightning current arrester with integrated backup fuse for 400 / 690 V TN systems and 400 V IT systemss; with remote signalling contact for monitoring device (floating changeover contact).

Type	**DBM 1 CI 440 FM**
Part No.	**961 146**
SPD according to EN 61643-11 / IEC 61643-11	type 1 / class I
Nominal voltage (a.c.) (U_N)	400 / 690 V (50 / 60 Hz)
Maximum continuous operating voltage (a.c.) (U_C)	440 V (50 / 60 Hz)
Lightning impulse current (10/350 µs) (I_{imp})	35 kA
Specific energy (W/R)	306.25 kJ/ohms
Voltage protection level (U_P)	≤ 2.5 kV
Follow current extinguishing capability (a.c.) (I_{fi})	50 kA_{rms}
Follow current limitation / Selectivity	no tripping of a 35 A gG fuse up to 50 kA_{rms} (prosp.)
Response time (t_A)	≤ 100 ns
Max. mains-side overcurrent protection	not required
Temporary overvoltage (TOV) (U_T) – Characteristic	760 V / 120 min. – withstand
Operating temperature range (T_U)	-40 °C ... +80 °C
Operating state / fault indication	green / red
Number of ports	1
Cross-sectional area (L, N/PE(N)) (min.)	10 mm^2 solid / flexible
Cross-sectional area (L, N/PE(N)) (max.)	50 mm^2 stranded / 35 mm^2 flexible
For mounting on	35 mm DIN rails acc. to EN 60715 or mounting plate (using the two mounting brackets provided)
Enclosure material	thermoplastic, red, UL 94 V-0
Place of installation	indoor installation
Degree of protection	IP 20
Capacity	3 module(s), DIN 43880
Type of remote signalling contact	changeover contact
Switching capacity (a.c.)	250 V / 0.5 A
Switching capacity (d.c.)	250 V / 0.1 A; 125 V / 0.2 A; 75 V / 0.5 A
Cross-sectional area for remote signalling terminals	max. 1.5 mm^2 solid / flexible
Supplementary data:	--------------------
– Nominal discharge current (8/20 µs) (I_n)	35 kA
Weight	946 g
Customs tariff number (Comb. Nomenclature EU)	85363090
GTIN	4013364250062
PU	1 pc(s)

Surge Protection
Lightning Protection / Earthing
Safety Equipment
DEHN protects.

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