CITEL

SURGE PROTECTION

FOR

PHOTOVOLTAIC SYSTEMS

TECHNICAL NOTE

Version 1.2

SURGE PROTECTION IN PHOTOVOLTAIC SYSTEMS

Introduction

Ever since the French physicist Alexandre Edmond Becquerel (1820 - 1891) discovered the photoelectric effect in 1839, generations of scientists, visionaries and entrepreneurs have been working tirelessly on the idea of satisfying our ever-increasing desire for energy with ever-present, life-giving sunlight.

This first spark, which was ignited almost 200 years ago, has developed into one of the cheapest and most sustainable sources of electrical energy today. The global installed capacity of photovoltaic (PV) power plants has reached approximately 1.6 TW (1600 GW) in 2024, demonstrating the growing reliance on solar energy as a critical source of electricity. Europe alone accounts for around 260 GW of this capacity, positioning photovoltaics as a major contributor to the region's energy mix.

In fact, solar power now supplies nearly 10% of Europe's net electricity production. On a global scale, the combined efforts of wind and solar energy have become increasingly significant, collectively providing about 14% of the world's total electricity generation.

This shift underscores the accelerating transition toward renewable energy and the growing importance of PV in addressing global energy needs.

In the interest of being able to generate clean and cheap electricity reliably for more than 20 years with such a photovoltaic power plant, it is extremely important to select high-quality components such as modules and inverters and to plan and install the system accurately. But even if all this has been respected, there are additionally a range of risks during the operation of the power plant, that might disrupt the energy production, damage or in the worst case destroy the key components of the system. Not only for the technical equipment, but also for the owner's financial investment, such a situation can have undesirable, negative consequences. That's why it is important to calculate these risks directly in advance and take measures to avoid them or to protect the installation against them already during the planning phase of the project.

Essential Standards and Protection Strategies

One type of risk is the negative effect of lightning strikes and surges. Even if the probability of a direct lightning strike into the panels or the structure of the PV power plant (scenario S1 in figure 1) is quite low depending on the location and exposure of the installation, such an event will couple partial lightning currents of several thousand of ampere into the wires of the system. Much more likely is a lightning strike in the area surrounding the power plant (S2), surrounding the overhead lines (S4) or into the upstream distribution grid (S3). In this case, a surge voltage is induced into the system through an inductive coupling or through a raise of the ground potential. The most frequent types of surges, however, are those caused by the switching of larger loads in the grid. Compared to lightning strikes, these surges are low in energy but occur multiple times more frequently. Even if these surges rarely lead to directly visible damages, there is still a significantly high stress to the insulation and as a result a significantly reduced service life of the installed equipment. These kinds of risks are demonstrated in figure 1.

To avoid these risks or at least to reduce the risk and the possible influence of those surges to the power plant, there is a wide range of possible measures that are described in numerous standards and regulations. When it comes to the design and installation of lightning protection systems, adherence to established standards is essential. The fundamental guideline in this domain is the IEC 62305 standard "Protection against lightning", along with its corresponding national implementations. IEC 62305 is a comprehensive standard that outlines the essential criteria for determining whether a lightning protection system is required, as well as when and how it should be designed and implemented. This standard is indispensable for ensuring that both the design process and the installation of lightning protection systems meet the necessary safety and performance requirements.

One of the key aspects of IEC 62305 is its inclusion of a detailed risk assessment procedure. This procedure is designed to evaluate the specific needs of a given site or facility, considering factors such as the likelihood of lightning strikes, the potential consequences of such strikes, and the effectiveness of proposed protection measures. The outcome of this risk assessment is critical, as it informs the decision-making process regarding the necessity and extent of lightning protection measures. Only through a thorough understanding of these risks can an effective and efficient lightning protection system be developed.

While the focus is often on external lightning protection measures, such as the installation of lightning rods or air terminals, it is equally important to consider internal lightning and surge protection. Internal protection is vital for safeguarding sensitive electrical and electronic equipment from the damaging effects of surges, which can be caused by both direct lightning strikes and indirect lightning-related phenomena. This internal protection is primarily achieved through the use of Surge Protective Devices (SPDs).

SPDs are devices designed to be connected to electrical power and data lines where they act as a first line of defence against surges. By diverting excessive voltage away from critical equipment, SPDs help prevent damage, disruption and potential destruction of electronic equipment and systems. The protection provided by SPDs is critical not only to maintaining the integrity of individual devices, but also to ensuring the continued operation of a variety of smaller and larger systems and networks.

S1: Direct impact (Building
S2: Near impact (Building)
S3: Direct impact (Grid)
S4: Near impact (Grid)

Figure 1: Different types of lightning strikes

Key Standards and Guidelines

The standards governing the design, testing, selection, and application of SPDs are outlined in the IEC 61643 series. This series of standards is comprehensive, covering a wide range of aspects related to surge protection. It includes standards that specify the requirements and test methods for the development of SPDs, ensuring that these devices are capable of providing reliable protection under a variety of conditions. Additionally, the IEC 61643 series provides guidance on the selection and application of SPDs, helping professionals choose the most appropriate devices for specific situations. Within the IEC 61643 series, there are standards tailored to different applications, reflecting the diverse environments in which SPDs are used. This includes standards for AC power systems, which are commonly found in residential, commercial, and industrial settings, as well as standards for data communications systems, which are increasingly critical in today's interconnected world. The series also covers SPDs for PV systems, recognizing the growing importance of renewable energy sources, and for DC power applications, which are prevalent in various technological and industrial contexts.

When planning, constructing, and operating a photovoltaic system, the application standards for AC networks (Part 12) and the application standard specifically for PV systems (Part 32) within the IEC 61643 series are of particular importance. These standards provide detailed guidance on how to effectively implement surge protection in both AC and PV systems, ensuring that the entire PV installation is safeguarded against potential surge-related damage.

In addition to the IEC 61643 series, there are other relevant standards that further detail the proper use of SPDs, such as IEC 60364-4-44 and IEC 60364-5-53 for AC grids. These standards play a crucial role in the overall framework for electrical installations, offering additional instructions and requirements for the integration of SPDs into different types of electrical systems. The IEC 60364-7-712 standard should also be mentioned for PV grids.

A fundamental principle that runs through all these standards is the mandate that SPDs must be installed unless a comprehensive risk analysis, carried out by a qualified lightning protection specialist, determines otherwise. This risk analysis is a critical process that evaluates the specific conditions of a site to ascertain whether SPDs are necessary. However, conducting such a risk analysis is often a complex and costly endeavour, typically reserved for critical infrastructure such as schools, hospitals, or other essential facilities where the consequences of surge-related damage could be particularly severe. For most PV installations, a detailed risk analysis is rarely conducted. As a result, in the absence of such an analysis, the standards stipulate that SPDs must be installed on both the AC and PV sides of the system.

Strategic Placement of SPDs for Effective Surge Protection

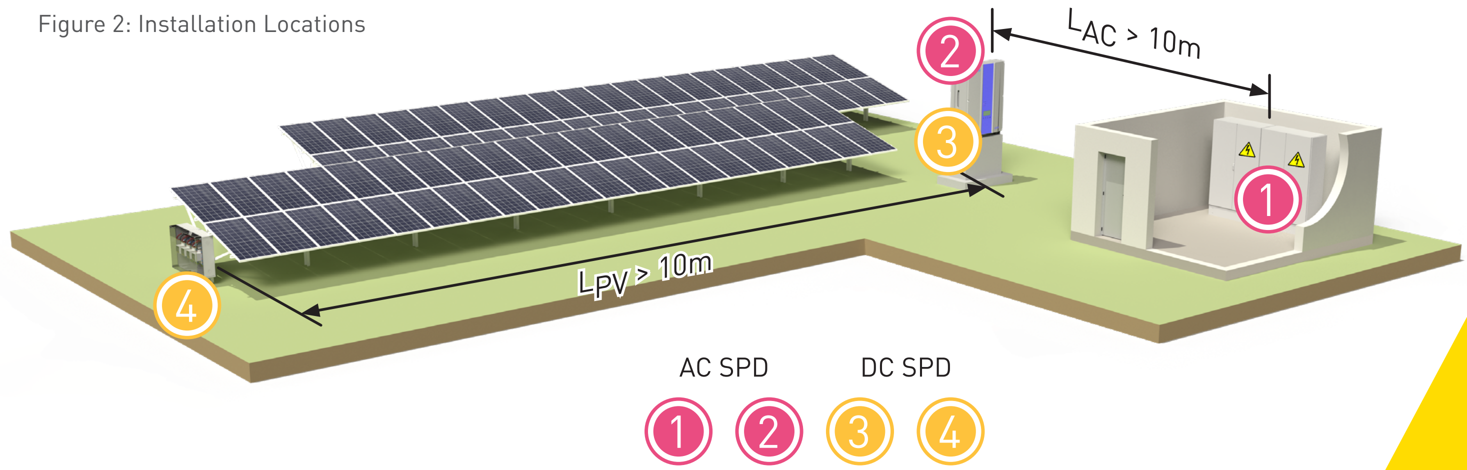
The next critical consideration is determining the precise locations where SPDs must be installed within the system. According to IEC 61643-12, the primary SPD should be installed as close as possible to the point where the AC mains enter the building. This location is typically within the main electrical panel, often referred to as the meter cabinet or low-voltage main distribution board. However, if the distance between this primary SPD and the inverter exceeds 10 meters, it becomes necessary to install a secondary SPD as close to the inverter as possible. This is crucial for maintaining the effectiveness of the surge protection over longer cable lengths.

In the context of PV systems, the application standard IEC 61643-32 identifies the inverter as the most critical component of the installation that must be protected. Consequently, the primary PV-SPD should be positioned as close to the inverter as possible. If the string cables connecting the inverter to the PV panels have a length exceeding 10 meters, a secondary SPD should be installed near the panels to provide additional protection. Figure 2 shows the required installation positions for the primary and secondary SPDs on the AC and PV side based on the IEC standards. For comprehensive protection of the inverter, IEC 61643-32 also emphasizes the need to safeguard data and communication lines. These lines are essential for the operation and monitoring of the PV system and are equally susceptible to surge damage.

To facilitate protection on the PV side, the use of String Combiner Boxes (SCBs) is recommended. These boxes, located near the panels, consolidate individual PV strings into a main cable, offering a practical location to install SPDs that protect the system from surges.

But why is a secondary SPD necessary when cable lengths exceed 10 meters? The answer lies in the physical characteristics of lightning or switching surges. SPDs do not entirely eliminate the surge; instead, they reduce it to a level that is harmless to the installation. However, due to reflections and refractions along the cables, the residual surge can potentially increase to a peak value twice as high. This amplified residual surge can reach levels that are no longer safe for the system. Therefore, it is imperative to dissipate this amplified residual surge before it can cause damage, which is why the secondary SPD is installed close to the device that needs protection.

Figure 2: Installation Locations



Selecting the Right SPD: Understanding Types and Protection Levels

The next essential question is how to select the appropriate SPD for the specific application. The selection process involves understanding the various parameters and ensuring compliance with relevant standards.

The IEC standards classify SPDs into three distinct types, each designed for specific levels of protection:

Type 1 SPDs are engineered to safely discharge direct or indirect lightning strikes. They are marked with a square symbol containing „T1". The standardized test impulse used to approximate the lightning currents for these SPDs is characterized by a „10/350µs" waveform, meaning a rise time of the impulse of 10 µs and a decay to 50% of the peak value within 350 µs. The key parameter associated with Type 1 SPDs is the impulse discharge capability, denoted as „Iimp." The standard mandates a minimum Iimp of 5 kA for both AC and PV applications.

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Type 2 SPDs are designed to protect against surges that are galvanically, inductively, or capacitively coupled into the system. These SPDs are marked with a „T2" symbol in the square.

The test impulse for Type 2 devices is characterized by an „8/20µs" waveform. This waveform, with its much shorter decay time, indicates that the test pulse is significantly less energetic compared to the 10/350µs impulse. The defining parameter for Type 2 SPDs is the nominal discharge capability, denoted as „In." The standard requires a minimum In of 5 kA for both AC and PV applications, although higher values may be necessary for special conditions or installations.

Type 3 SPDs provide fine protection for sensitive equipment. These devices are marked with a square, containing a „T3" symbol. The test impulse for Type 3 SPDs is a combined wave, consisting of a voltage impulse with a „1.2/50µs" and a current impulse with an „8/20µs" waveform. The key parameter for these SPDs is „Uoc" with typical values such as Uoc = 6 kV. Type 3 SPDs are critical for protecting highly sensitive equipment, such as computers or programmable logic controllers (PLCs). In the context of PV installations, sensitive components might include String Combiner Boxes (SCBs) with string current measurement, powered directly from PV voltage. Other sensitive applications might involve sensors, monitoring systems, or communication devices that are decentralized in the PV power plant and powered directly from the energy produced by the panels. Therefore, it is strongly recommended to deploy SPDs that provide fine protection in these scenarios. As summarized in Table 1, the key characteristics and applications of each SPD type are clearly distinguished, aligning with the detailed descriptions provided above.

Today's SPDs often combine different protection levels in one device. Many commercially available SPDs are hybrids of Type 1 and Type 2 (T1+2) protection levels. CITEL has taken this a step further with its DPVN series, becoming the first manufacturer to offer SPDs that combine all three protection levels (T1+2+3) in a single device. This achievement has been independently verified by a renowned testing institute, earning the series the right to bear the KEMA mark.

Table 1: Overview of SPD Types, Symbols and Key-Parameters

SPD Type	Purpose	Symbol	Test Waveform	Key Parameters	Minimum Requirement
Type 1	Safely discharges direct or indirect lightning strikes	T1	10/350 µs	Impulse discharge capability (Iimp)	Minimum Iimp = 5 kA (for both AC and PV applications)
Type 2	Protects against galvanically, inductively, or capacitively coupled surges	T2	8/20 µs	Nominal discharge capability (In)	Minimum In = 5 kA (for both AC and PV applications; higher values for special cases)
Type 3	Provides fine protection for sensitive equipment	T3	1.2/50 µs (voltage) and 8/20 µs (current)	Open-circuit voltage (Uoc)	Typical Uoc = 6 kV (recommended for sensitive devices in PV power plants)

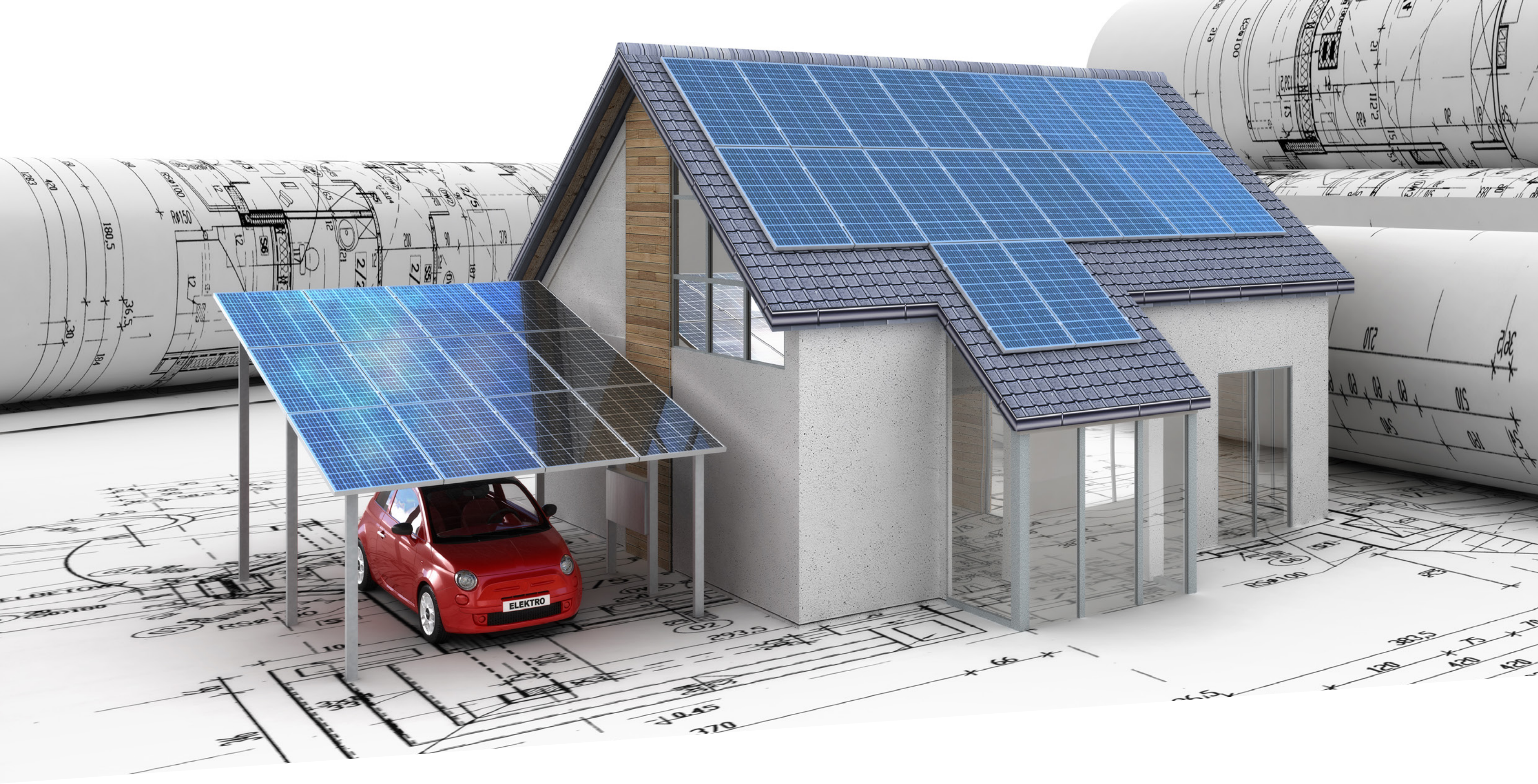
Choosing the right SPD

Which SPD type should be selected now for a PV installation? When selecting the appropriate SPD for a PV system, it is essential to distinguish between rooftop installations and ground-mounted systems (free-field PV power plants).

For rooftop installations, further consideration is required to determine whether an external lightning protection system (LPS) is present or necessary.

If no external LPS is present or required, the current standards indicate that a Type 2 SPD (preferably a T2+3 combination) is sufficient as both the primary and, if necessary, secondary SPD as well on the AC as also on the PV side. However, to achieve optimal protection beyond the minimum requirements, a combined Type 1+2+3 SPD is recommended.

If an external LPS is present, the primary AC protection at the building's entry point must be a Type 1 SPD (preferably a combined T1+2+3 device). If the PV system is entirely within the protective range of the LPS and the separation distance „s" between the PV system and the LPS is strictly



maintained, Type 2 devices are sufficient for the PV side and any secondary AC protection that may be required. Nevertheless, the use of Type 1 devices is still advisable to ensure comprehensive protection.

If the separation distance between the PV system and the external LPS is not maintained, all SPDs must be of Type 1 (better T1+2+3).

For free-field, ground-mounted PV installations, the situation is slightly different. Due to their large area and the fact that the mounting structure of the PV modules act like a well-meshed external LPS, these installations are always considered to have an external LPS. Consequently, Type 1 SPDs with a minimum discharge capability of Iimp = 5 kA must be used at all positions.

Using SPDs that not only meet the minimum discharge capability requirements but also offer higher discharge ratings can significantly extend the lifespan of these devices. This enhanced durability contributes to the long-term reliability and safety of the entire PV installation.

Leakage-Free SPD Technology for Enhanced System Reliability

Another critical factor to consider is the technology used in the SPDs. The most widely used SPDs are based on Metal-Oxide Varistors (MOVs). While these components are effective in managing surges, they come with certain disadvantages. One of the primary drawbacks of MOVs is that they inherently exhibit a leakage current, no matter how minimal. This leakage current causes the MOV to age over time, leading to an increase in the leakage current, which in turn accelerates the aging process even further. Additionally, this leakage current can reduce the insulation resistance of the installation through parasitic capacitive effects. While these effects may not significantly impact small PV installations, they become more substantial in medium to large-scale power plants. In extended PV installations, where multiple SPDs are deployed, the parasitic leakage capacitances caused by these leakage currents can accumulate to a level where the overall insulation resistance of the system is significantly reduced. When combined with environmental factors, such as changes in humidity due to morning dew or rain, the insulation resistance can drop even further. This reduction can cause the installation's mandatory insulation monitoring system to trigger a shutdown, or it may prevent the system from starting up in the morning. The result is unnecessary production losses, even though the system is technically sound, fault-free, and installed in compliance with all applicable standards. To mitigate these issues, it is advisable to use leakage-free SPDs instead of those solely based on MOVs. A notable solution is CITEL's patented VG Technology, which utilizes gas-filled spark gaps (GSGs) that provide galvanic isolation. This technology not only effectively prevents creepage and leakage currents to earth, thereby eliminating the parasitic capacitances that reduce insulation resistance, but it also prevents unwanted creepage currents between the phases. As a result, the insulation monitoring of inverters is not negatively affected, regardless of the number of SPDs installed in the system. Additionally, since VG Technology eliminates leakage currents, there is no passive aging of the MOVs, which significantly extends the lifespan of SPDs based on this technology compared to conventional designs. The use of VG Technology ensures that the PV system maintains a stable insulation resistance, reduces unnecessary shutdowns, and extends the operational life of the protection devices, ultimately leading to a more reliable and efficient solar power generation system.

Limitation of Integrated SPDs in PV Inverters

In recent years, it has become increasingly common for manufacturers of PV inverters to include built-in surge protection devices within their equipment. These integrated SPDs are typically classified as Type 2 only.

However, this built-in protection is often more of a marketing feature than a reliable surge protection solution. One of the main issues with these integrated SPDs is the lack of detailed technical specifications. Critical information, such as the impulse discharge current rating (In) and the maximum discharge current (Imax), is frequently omitted or inadequately specified.

Without this data, installers, system operators and plant owners cannot determine whether the SPDs meet the relevant standards, such as those outlined in IEC 61643, or if they are capable of withstanding the specific environmental and operational conditions at the installation site. Even when the integrated SPDs do meet all the required standards, they typically only comply with the minimum requirements. This minimal compliance may be insufficient in scenarios where local conditions demand higher discharge capacities. For example, if the local environment is prone to more severe surges due to frequent lightning activity or if the installation includes an external LPS, a Type 1 SPD may be necessary. In such cases, the integrated Type 2 SPD alone would not provide adequate protection, necessitating the installation of an additional external SPD upstream of the inverter.

Only a few inverter manufacturers collaborate with well-known SPD manufacturers that ensure their products not only meet but exceed normative requirements. These collaborations often result in SPDs with higher discharge ratings, ensuring more robust protection and extended device lifespan.

Additionally, these manufacturers may obtain external certifications that validate the quality and compliance of their SPDs with the standards, providing an extra layer of assurance to the end-user.

It is rare to find an inverter that includes an integrated Type 1 SPD, even as an optional feature. However, when a Type 2 SPD is sufficient for the application, opting for such a solution within the inverter offers several advantages. Notably, this configuration can provide a significantly enhanced level of protection against surges, ensuring that the sensitive components within the inverter are better shielded from potential damage. Additionally, the lifespan of integrated Type 1 SPDs is much longer if the environmental conditions indicate that only switching surges will be expected. This extended longevity reduces the need for frequent maintenance or replacement, contributing to the overall reliability and efficiency of the solar power system.

Even when integrated SPDs are meticulously designed and correctly implemented by the manufacturer, they come with a significant inherent limitation. The process by which surges and partial lightning currents are managed involves these high-energy events first entering the inverter. Only after this initial entry does the surge protection device work to divert and ground these potentially harmful currents. This sequence creates a substantial vulnerability.

Surges are characterized by their high-frequency nature, meaning they can propagate through an inverter in complex and unpredictable ways. As these surges pass through the inverter, they can induce voltages in nearby sensitive components, not necessarily through direct electrical connections but via inductive or capacitive coupling. This means that the surge energy can be transferred into critical parts of the inverter's circuitry without direct contact, simply through the electromagnetic fields generated by the high-frequency surge.

The unpredictability of these effects makes it challenging to fully mitigate the risks, even with a well-designed integrated SPD. The sensitive nature of modern inverter electronics further exacerbates this issue, as even minor disruptions can affect performance or lead to failure.

To mitigate these risks, it is always advisable to prevent surges and partial lightning currents from entering the inverter in the first place. This can be achieved by installing an external SPD ahead of the inverter, outside of the device. By doing so, any surge energy is diverted directly to the ground before it can enter the inverter. Using an external SPD also provides the benefit of easier maintenance, because they are typically easier to inspect and replace than integrated ones.

In summary, while integrated SPDs in PV inverters provide a basic level of protection, they are often insufficient for ensuring the long-term reliability and safety of the system, especially in environments with higher surge risks. To achieve optimal protection, it is always highly recommended to install additional external SPDs that are appropriately rated for the specific installation conditions, thereby safeguarding the entire photovoltaic system from potential damage.

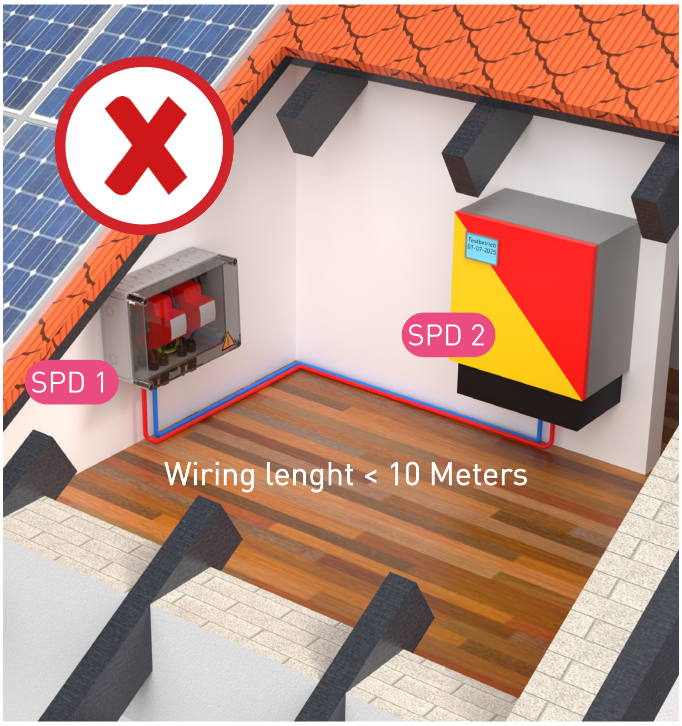
Ensuring Effective Coordination with Additional SPDs

The key point to consider when installing an additional protection device upstream of the inverter, alongside the integrated SPDs, is ensuring proper coordination between the devices. When the protection of an electrical device, such as an inverter, relies on multiple cascaded SPDs, it is essential to confirm that the first, and therefore strongest, protective element is activated first when a surge arrives. This ensures that the highest energy surge is absorbed or diverted by the initial SPD, preventing it from reaching downstream devices, which are typically more sensitive and less capable of handling large surges. Proper coordination helps maintain the effectiveness of the overall surge protection system and safeguards the entire photovoltaic installation.

To ensure effective coordination between cascaded SPDs, installers and end users typically need access to detailed technical specifications for each device. This information is crucial for determining the appropriate configuration to safeguard electrical equipment. However, as previously mentioned, such detailed data is often unavailable for SPDs that are integrated into inverters. This lack of information can make it difficult to guarantee proper coordination between different protective devices, increasing the complexity of the installation process and the risk of insufficient protection. CITEL addresses this challenge with its patented VG Technology, which offers a straightforward and reliable solution. Unlike traditional systems that may require additional measures or complex configurations to achieve proper coordination between SPDs, VG Technology ensures seamless protection without the need for supplementary adjustments (This fact is illustrated exemplary in Figure 3). The technology allows the surge protector to react more quickly than any downstream SPDs, meaning it can divert harmful, high-energy surges to ground before they can reach the subsequent SPDs. This ensures that the downstream SPDs are not overloaded, which could otherwise compromise the entire protection system. The ability to manage and distribute energy effectively guarantees an optimized level of protection across all components, preventing overloads and maintaining the integrity of the entire system. In addition to safeguarding the equipment, VG Technology also enhances the long-term reliability and performance of the installation. By ensuring that energy is appropriately divided and managed, it reduces wear and tear on the downstream protection devices, thereby extending their operational life and minimizing maintenance needs. In essence, CITEL's VG Technology provides a comprehensive, high-performance solution for surge protection, simplifying the installation process while ensuring robust, coordinated protection across the entire system.

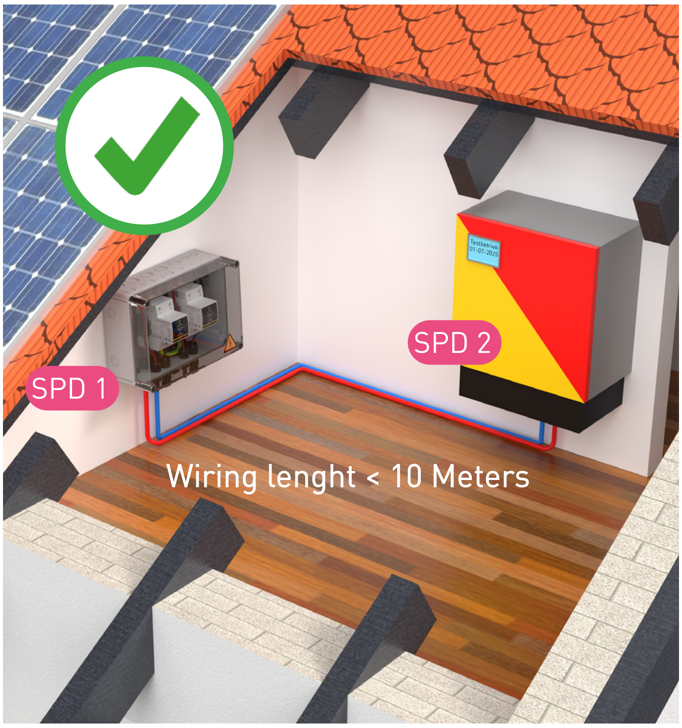
Figure 3

Conventional SPDs



Coordination between two conventional SPDs
not guranteed

CITEL VG-Technology



Coordination is provided
with CITEL´s VG-Technology

Summary

Since the days of Becquerel, the pursuit of harnessing sunlight as a reliable energy source has evolved into a critical pillar of global electricity generation. Today, the selection of high-quality components and the implementation of rigorous protection measures are essential for maintaining the long-term performance of PV systems.

Despite meticulous planning and high-quality equipment, risks such as lightning strikes and surges can still compromise the operation of PV plants, potentially leading to significant financial and operational consequences. These surges, particularly from indirect lightning strikes or switching events, can stress insulation and reduce equipment lifespan, making surge protection crucial.

The IEC 62305 and IEC 61643 standards offer comprehensive guidelines for designing effective lightning and surge protection systems. These standards emphasize the importance of both external and internal protection measures, including Surge Protective Devices (SPDs), to safeguard sensitive components from damage.

While integrated SPDs in inverters are becoming more common, they often provide only basic protection and may not always meet higher, site-specific requirements. These integrated devices can also inadvertently expose inverters to surge-related damage before they can react, due to their location within the inverter itself. Thus, using an external SPD is advisable to ensure optimal protection, as it diverts surge energy away from the inverter before it can cause harm.

For optimal protection and longevity of PV systems, it is critical to not only adhere to industry standards but also to carefully evaluate and implement external SPDs with appropriate ratings. This approach not only enhances system reliability but also minimizes potential downtime and maintenance costs, ultimately ensuring the long-term efficiency and safety of solar power installations.

			
DACN1-25CVG Series Iimp=12,5 kA /Pole Uc up to 385 Vac	**DAC50VG Series** In=20 kA /Pole Uc up to 320 Vac	**DPVN1-6CVG Series** Iimp=6,25 kA /Pole Ucpv up to 1500 Vdc	**DPVN40CVG Series** In=20 kA /Pole Ucpv up to 1500 Vdc
AC-Applications		**DC-Applications**	
Combined SPD			
Type 1+2+3	**Type 2+3**	**Type 1+2+3**	**Type 2+3**
No follow currents (short-circuit currents)			
VG-Technology			
		CTC-Technology	
Operating and leakage current-free			
No passive ageing			

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