CITEL

SURGE PROTECTION FOR ENERGY STORAGE SYSTEMS

TECHNICAL NOTE

Version 1.1.1

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Introduction

Not merely since the signing of the Paris Climate Agreement in 2016 the awareness exists that a change in our energy supply is necessary. This change was driven in the last years mainly by photovoltaic (PV) and wind energy technology.

With the gratifyingly increasing share of so-called „green electricity" in our pan-European transmission grid, several new questions have increasingly gained importance in recent years: How can the generation peaks determined by the sun and the wind be balanced with the consumption peaks which are independent of these? How can the grid be relieved from the increasing demand of electrical energy to charge more and more electric vehicles? How can widely extended grid segments (e.g. in the countryside) be stabilized in voltage and frequency to remain inside the limits, defined by the grid quality standard EN 50160?

Any form of Energy Storage System (ESS) can certainly provide a partial contribution to solve these challenges. In the recent years, a rapidly increasing number of electrochemical storage systems - mostly based on lithium battery technology - have been installed in association with PV or wind energy plants. These have the function of buffering the generation peaks and delivering the produced energy more steadily to the electricity grid ("peak shaving").

In conjunction with charging stations for electrical vehicles, such ESS systems can reduce the need of reinforce the grid connection, which helps to save money and to reduce the needed time for installation until commissioning the charging stations.

Even in regions without a public grid, ESS can reduce the need of diesel generators enormously, which contributes to the reduction of global CO2 emissions and the dependency of external resources. Due to the grid stabilisation ability of those off-grid systems, the black-start ability and the possible load management functions, ESS are able to create and control reliable and robust micro grids.

Another advantage is the ability of these storage systems to support the grid on request in the event of a demand or fault by feeding in additional active but also reactive power, thus maintain the public grid and provides security by stabilizing it. Thereby, battery storage systems are easily able to provide large amounts of energy in a very short time. A time-consuming and sluggish ramp-up or ramp-down of power in the event of sudden load changes, as it is the case with conventional power plants, is entirely omitted here. Large amounts of energy can be delivered to the grid or taken from it within a very short time.

Figure 1: ESS in a renewable energy power plant

System safety

The energy density, and thus the amount of energy available at a constant volume, continuously increases as the development of such storage systems progresses. While classic lead accumulators used to have an energy density of about 30 Wh/kg, modern lithium-based storage technologies already have an energy density of more than 200 Wh/kg.

Nevertheless, what is a positive, desired feature in normal operating mode can lead to challenges in the event of a failure. For example, in the event of a malfunction, like a short circuit, this energy can discharge within fractions of a second. Mechanical damage, overheating or damages caused by surges and overvoltages can result in emergency situations, which can subsequently lead to an unintentional discharge of the entire energy.

While mechanical damages are hardly to be expected within stationary storage systems, special attention must be paid to the consequences of transient surges caused by effects in the power grid or by lightning incidents. A lightning strike into a nearby wind turbine or into the overhead lines of the distribution or transmission grids, as well as the switching of transformers or larger loads such as motors in the grid, leads to voltage spikes which can cause serious damages to the batteries.

Surge Protection

Due to the above-mentioned challenges, a holistic lightning and surge protection concept is urgently needed in such applications. This necessity is also clearly highlighted by the fact that the first standards are currently being created at international level which deals specifically with the protection of DC systems against surges. Standardised testing and application regulations are now being created at this level. The international testing standard for surge protective devices (SPD) in DC applications, IEC 61643-41, is expected to be published in the middle of 2024. The corresponding application standard, IEC 61643-42, is planned to follow. But even before this official publication of the standards, planners, installers and operators of energy storage systems should already deal with this topic.

In general, most battery cell manufacturers require the installation of SPDs for the reasons mentioned before. Even the standards already published, such as the application standards for AC systems (IEC 61643-12) and for PV systems (IEC 61643-32), allow fewer and fewer exceptions where the installation of an SPD may be omitted.

Therefore, the use of SPDs in stationary storage systems can be considered as mandatory on the DC side in a first approach.

When selecting the appropriate SPDs, a technically reliable solution can also be found with a sideways glance at the already existing application standards. In general, a differentiation is made in these standards, whether the building, in which an electrotechnical system has been installed, is equipped with an external lightning protection system or not. If it has been determined during the construction of the building that no external lightning protection is necessary, a category „Type 2" (abbreviated: T2) surge protective device is sufficient in the most cases. If an external lightning protection system exists, a category „Type 1" (T1) arrester, capable of carrying lightning currents, must be installed at least at the feed-in point of the building, which is usually in the AC network. For all devices and electrotechnical installations that are completely within the protected area of this lightning protection system, a T2 surge protection is sufficient in the most cases. Only if the complete protection of the installation is not given or cannot be ensured, T1 protection is also required here.

Stationary energy storage systems are usually located entirely inside a solid building. This means it can be assumed that either no external lightning protection is necessary or the installation is fully located inside the protected area. In both cases, a type 2 SPD is generally sufficient. The presence of external lightning protection thus usually makes a difference only at the feeding point of the building, but not on the DC side of the installation.

CITEL provides with the DDC50 series a surge protector which was explicitly developed and designed for the use in electrochemical storage systems. Picture 2 shows the DDC50-21Y-1500 SPD from this series. The fault-resistant Y-circuit is suitable for system voltages up to 1500 Vdc.

Figure 2: DDC50-21Y-1500

Temporary Overvoltage

A special focus must be placed to the topic of Temporary Overvoltages (TOV). Especially in DC applications, the power system type of the DC grid and the type of connection to an upstream AC grid is relevant. The upcoming IEC 61643-41 differentiates between DC grids, which are fully separated from an underlying AC grid, e.g. by using an isolating transformer, and DC grids, which have an galvanic connection to the AC side (e.g. by using an simple rectifier). Not only a failure on the DC side of this installation must be considered, furthermore it must be taken into account which TOV can be created by a possible fault on the AC side. Analog to the AC grid topologies, the -41 standard defines the well-known TN, TT and IT grid topologies also for DC systems.

Beside the effect of AC induced TOV and the type of grounding topology, the number of active wires must be considered to select the appropriate SPD. It makes a difference, if the DC grid is built as a unipolar (L+ and L-) or a bipolar system (L+, M and L-). The power system types defined by the standard, are visualised in picture 3. While in a unipolar system a voltage rise in case of an short circuit or an earth fault is ruled out, it can easily occur in a bipolar system. In such a case, the voltage drop on the SPD can double. This fault condition must also be considered by the manufacturer in the development of reliable SPDs.

The DDC50 surge arrestor series respects all these requirements and is specifically designed to provide a high-quality solution to the operators of modern energy storage systems.

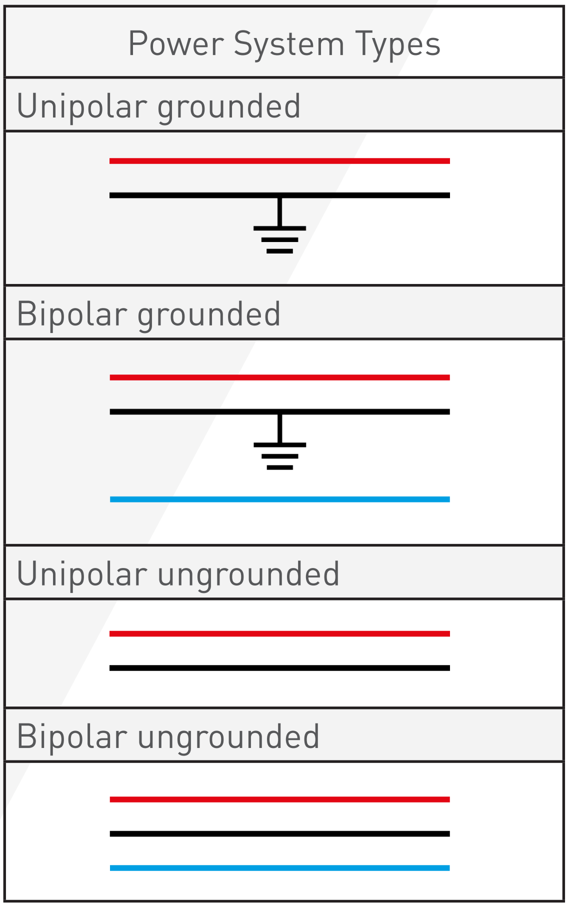

Figure 3: Power System Types according to prIEC 61643-41

Discharge capability

The needed discharge capability depends also on this grid topology, as well as on the above-mentioned question of the need or presence of an external lightning protection system. Due to the fact that a dedicated application standard, which will be the future IEC 61643-42, is still missing, the analogous application standards (IEC 61643-12 for AC and IEC 61643-32 for PV) as well as the lightning protection standard IEC 62305 may be helpful to find the right values.

In accordance with the IEC 61643 family of standards, an SPD type 2 with a discharge capacity of In = 5 kA (8/20µs) per mode of protection is always sufficient as minimum requirement for all installations without a perceivable risk of a direct lightning impact.

In general, to select an SPD with a higher discharge capability than required, will always result in a longer life duration as it is not stressed to its limits. Furthermore, this application standards consider only installations in an undemanding environment. Energy storage systems, especially in the utility-scale, are mostly installed in an industrial environment. All electrical components, which are designed and engineered for the use under such conditions, must withstand higher interference immunity requirements. This is requested for example in the EMC standards, the IEC 61000 series, which defines different EMC immunity limits for residential and industrial environments. Therefore, also the protective devices are exposed to these higher disturbances. It must be also considered that an energy storage system is normally operating with DC power. To feed-in into the AC grid, an inverter is necessary. Such inverters are using normally high frequency pulse width modulation, which causes even more disturbances and additional switching frequent overlays. Even if this are small peaks with low energy, the sum of all these small surges will reduce the lifetime of the SPD noticeable. Altogether leads to the conclusion, that an SPD with a much higher discharge capability should be selected. To have a reliable SPD, which will have a longer service live to reduce the maintenance effort, the nominal discharge capability should therefore be at least In = 20 kA.

For installations, where a risk of a direct or indirect lightning strike exists, the location of the possible impact must be determined. According to the IEC 62305-1, four different possible sources of damages need to be considered. The source of damage "S1" is defined as the direct impact into the building, source "S2" means an impact near by the building, "S3" is dedicated to a direct impact in the supplying grid upstream the building and finally "S4" stands for an impact near the supplying grid. For all four types of damage sources, the current share must normally be determined. That means, the resulting lightning current on the DC wires of our application is depending on the total sum of ground connections of the whole system. As more connections to ground are available, as lower will be the resulting current on the wires. To derive this, a risk assessment must be performed. At this point, a simplification has been introduced by the standards. If not enough information are available and no risk assessment has been performed, it can be assumed, that in S1 scenario 50% of the lightning current is conducted to the building's earthing system directly and 50 % returns via the equipotential bounding SPD. For an unprotected, unipolar DC connection in the Lightning Protection Level 1 (LPL I, according to IEC 62305-1) which is entering a storage building, this means an expected maximum partial lightning current of 50 kA (10/350µs) per wire. (200 kA lightning flash current, 50 % on the equipotential bounding divided by 2 wires). For a bipolar grid, this value will be reduced to 33,3 kA. With these values, it becomes clear how important a holistic lightning protection concept is. By using a distributed, meshed earthing system, by leading the DC cables in metallic cable ducts outside of the building and by having a smart integrated lightning protection concept for the whole installation, this huge energy can be reduced to a minimum instead of trying to handle it. To keep all parts of the DC system inside the area protected by the external lightning system may eliminate completely the risk of partial lightning currents on the DC wires. If only lightning impacts near the building (damage source "S2") and the LPL III must be considered, the expected resulting lightning current on the lines will be reduced to a fraction of the maximum current. In general, it's unlikely that the damage sources 3 and 4 ("S3" and "S4") must be considered on the DC side of the power plant. Normally all these energy storage systems are coupled to the AC distribution or even transmission grid. That means there is no upstream DC grid present. The risk of impact into the upstream AC grid must be handled respecting the well-known installation rules for AC SPDs (like IEC 61643-12).

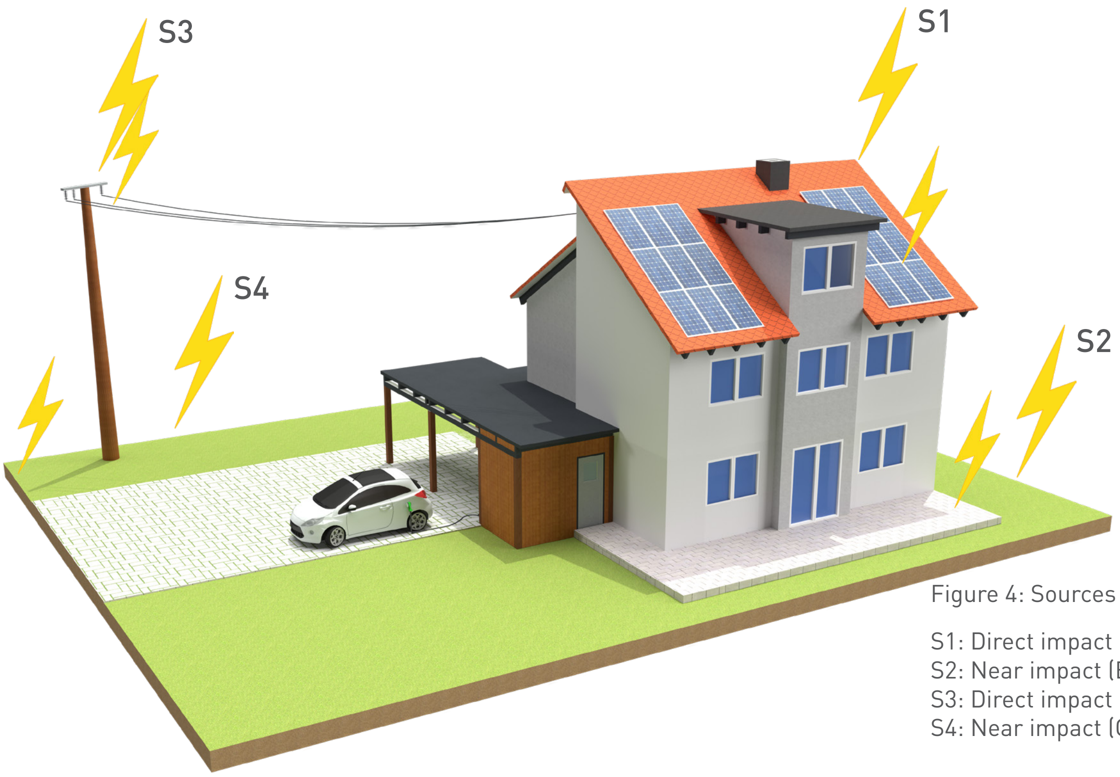

Figure 4: Sources of damage

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

Fuse Protection Concept

The above-described effects in case of failures, the high system voltage and at the same time the extremely high short-circuit current capability makes the usage of fuses indispensable.

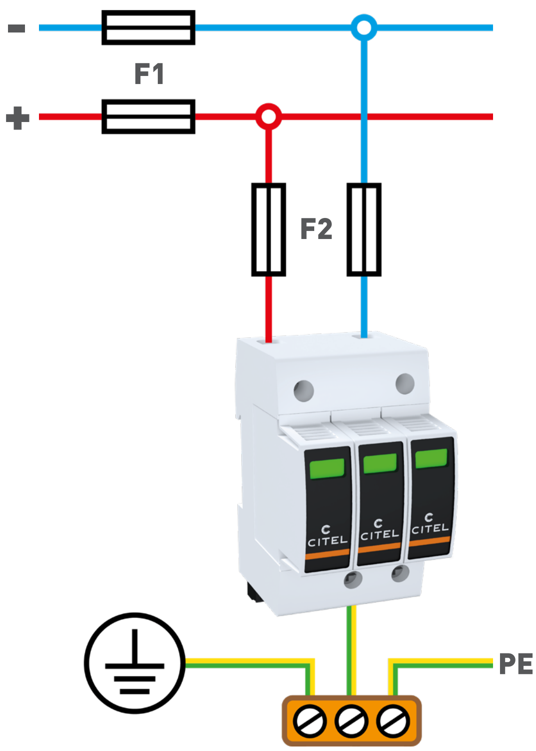

Figure 5: Fuse protection concept

These fuses can be installed inline of the power cables of the batteries (fuses F1 in picture 5) or by pre-fuses that are specifically assigned to the SPD (fuses F2 in picture 5). The first configuration offers the best possible protection, as the entire system switches off in the event of an overload of the SPD, which ensures the best possible system safety. The highest system availability is achieved when so-called „surge fuses" (SFD) will be used. SFDs are special fuses that are non-sensitive to surge pulses but react fast to low short-circuit currents and disconnect the SPD safely. However, ensuring system availability also means, if the SPD is disconnected by the internal disconnecting mechanism of the SFD, the system is no longer protected against surges and overvoltages. Therefore, it is important to notify the SCADA system immediately of any disconnection and sent out an immediate warning, e.g. via the internet.

In order to provide a comprehensive solution, CITEL has special SFDs for this type of application in its range (see picture 6). The SFD50 have been tested under the harshest conditions, passing 1500 Vdc and a short-circuit current of up to 100 kA. With the characteristic gBAT, which has been specifically defined by the IEC 60269-7 for battery protection, these devices meet all the requirements for reliable use within all common energy storage systems. Both components, the DDC50 and the SFD50, are equipped with an optional potential-free contact enabling them to signal their status reliably to any common plant control system.

Figure 6: SFD50-1500DC

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Plant Controller

To operate such applications, to control the grid and to synchronize all involved components, some kind of plant controller is necessary. Even if each part, the PV inverters, wind energy turbines, charging stations and storage systems have their own controller, all those components have to interact with each other in some way. Sometimes they are all connected to the internet, sometimes there is a dedicated communication system installed on site. In any case those controlling and communication units are very vulnerable to surges and induced disturbances. The same is valid for any kind of sensors as well. Irradiation sensors, temperature sensors, wind and precipitation detection are used in nearly every modern installation. Also in these cables, surges can couple in very easily.

Figure 7: DLA-24D3

For this reason, it has become increasingly established in the recent years in the IEC 61643 series of standards that the protection of communication lines against transient surges is no longer just a recommendation but becomes more and more a mandatory requirement. Regardless of whether it is a recommendation or a requirement - in sight of the complexity of today's systems, unprotected operation of communication lines would be highly negligent.

Figure 8: MJ8-C6A


To provide an overall solution, CITEL offers the MJ8 series and DLA series of SPDs to protect any kind of dataline.

Box Concept

To simplify all these aspects, the idea of the "Box Concept" can be used. To evaluate, which protection is necessary, a virtual box must be imagined around the housing of the application. As first approach, all cables and wires, which are crossing this virtual box, needs an investigation.

Pictures 9 and 10 are showing the components of a typical utility-scale installation concept. Due to the large number of batteries, they are normally installed in one or several dedicated buildings. Standard sea-containers are often used for this kind of application. The battery management system (BMS) is located directly beside the battery cabinets normally. In another station, the connection of this battery buildings, the plant controller and the connection and often also the inverter for renewable energy sources (wind energy and / or photovoltaic plant) is installed together with the grid connection. It can be assumed, that the DC cables and a communication cable will pass through the housing of the station and therefore pass through the virtual box. Hence, it must be analysed depending on the routing of those cables (e.g. buried in the ground or ducted overhead) and the overall length of the cables as well as the presence of an external lightning protection system which kind of surge protection is required. If for example the buildings are side by side, the cables are buried in the ground and the cable length is not above 10 m, then a type 2 surge protection should be sufficient normally. If, in contrast, the buildings are distributed all over the whole site (distances above 10 m) and an external lightning protection system is installed on the buildings, it will be highly probable mandatory to use an SPD type 1. The same approach must be used for the main building as well. Here, according to the example above, the AC mains, the PV cables, the DC battery connection and severa

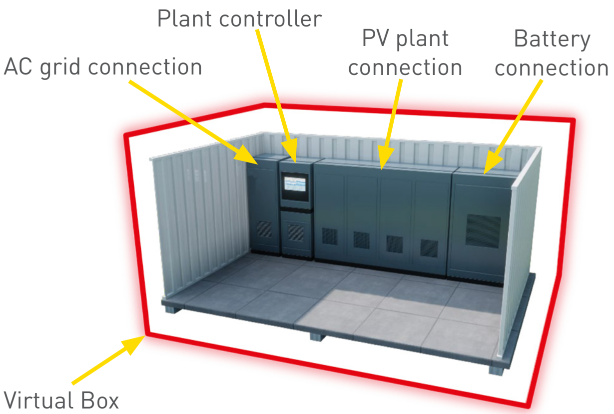


Figure 9: Box concept - Main Cabinet

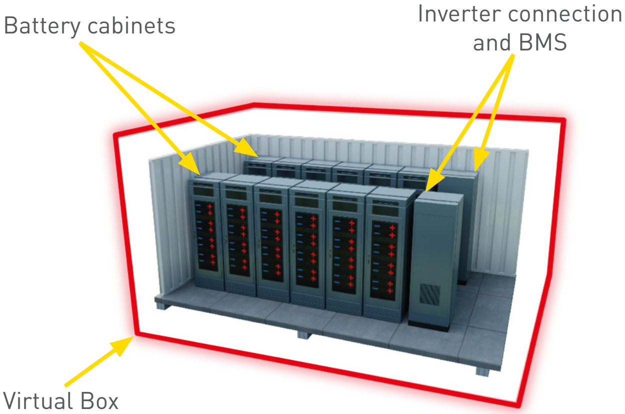
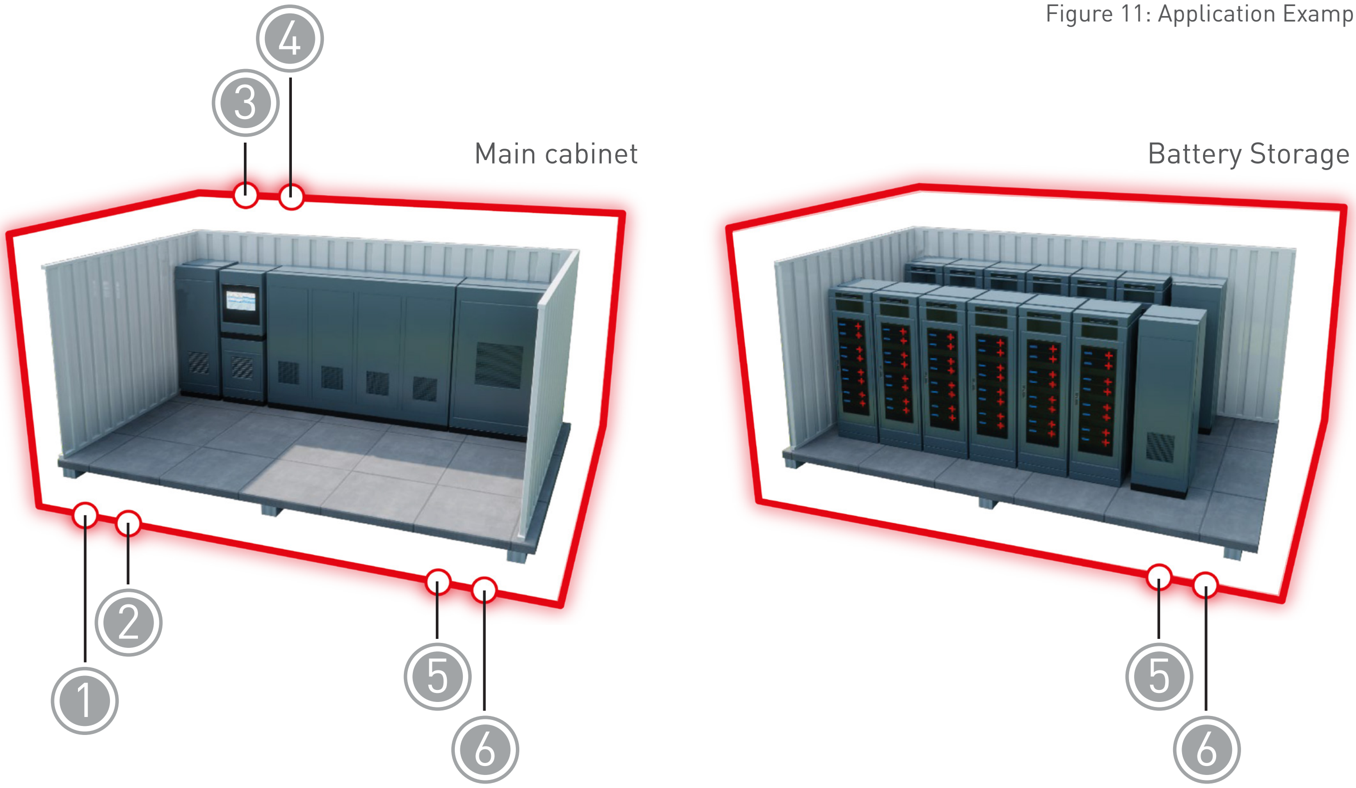


Figure 10: Box concept - Battery Storage

data lines (communication with the grid operator, control cables for PV, several sensor wires and the communication to the BMS) will cross the virtual box. Now the same survey must be performed as described above. How long is each cable and how is it routed? Is an external lightning protection system necessary or present? In general, each cable must be protected as close as possible to the entry point of the building. Picture 11 visualises the application of the Box Concept. For all lines, which are crossing the virtual box, an example of an appropriate SPD is shown.

Figure 11: Application Example



Points of transition from applications to virtual box

1. AC low-voltage grid
2. Data line
3. Sensors
4. PV installation
5. DC connection Main cabinet <-> Battery Storage
6. Data line Main cabinet <-> Battery Storage

Installation points of Surge protection devices (SPD)

1. Combined AC SPD Type 1+2+3
2. Data line SPD C2+D1
3. Measurement and control technology SPD C2+D1
4. Combined PV SPD Type 1+2
5. Combined DC SPD Type 1+2
6. Data line SPD C2+D1

Conclusion

The amount of renewable energy power plants of any scale is increasing year by year and have to speed-up even more if the world wants to keep the temperature and CO2 limits, which have been negotiated and signed in the Paris Climate Agreement. In parallel to the use of renewable energies, those power plants are providing more and more services to support the stability of the public grid. This applies especially for Energy Storage Systems, which nowadays are mainly based on electrochemical storages like Lithium-Ion batteries. To protect this power plants and storage systems against the effects of transient surges and lightning strikes, a holistic lightning and surge protection concept must be elaborated. With the Box Concept method, a simple approach has been introduced, to evaluate which kind of surge protection is needed in a dedicated installation. Especially the protection of the DC part, the batteries, has its own special challenges not only due to the high voltages in combination with very high short circuit current capability. To ensure a high plant availability with a reliable protection of the sensitive equipment, high quality protective components must be used. In the ideal case, this will be respected directly during the planning and engineering phase of each project.Further information to this and other topics are available on our international websites and in our thematic brochures. More Information about ESS applications are available in the brochure "Surge Protectors for Energy Storage Systems".

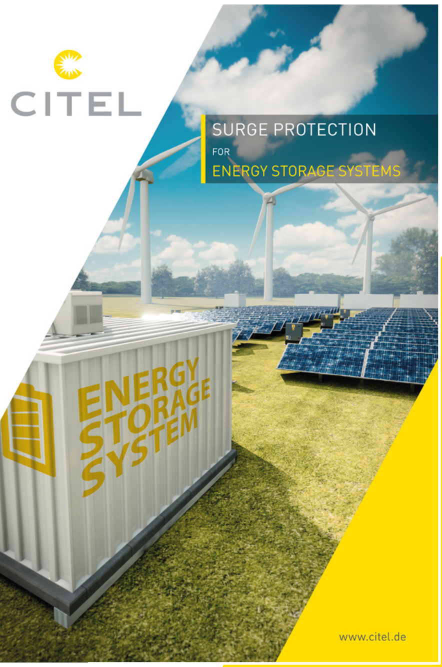


Figure 12: Brochure "Surge Protectors for Energy Storage Systems"

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