ILPS 2018 - International Lightning Protection Symposium
October 24-27, 2018
Shenzhen – China

Surge Protective Devices Standards

State of the art and trends

Alain Rousseau

SEFTIM
Vincennes, France
alain.rousseau@seftim.fr

Fernanda Cruz

Lightning Consultant
Videlles, France
fsousacruz0@gmail.com

***Abstract*— Many new issues need to be covered by SPD standards. The more urgent one was up to now PV applications and by now the standard are published. The next step will be for DC applications and providing more details on specific AC SPD applications. Regarding application of AC SPDs, two main points are addressed: coordination between SPDs and selection of SPD disconnectors. Coordination in voltage protection is a key issue compared to the well-known energetic coordination. Specific SPD disconnector requirements are presented under the umbrella of a project named Specific Surge Disconnector. Such disconnector should not only withstand the same surge current than the SPD but also disconnect as fast as possible to be coordinated with upstream overcurrent protective devices. Smart SPDs are also presented. Theses SPDs appear in the market and provides additional communication and monitoring functions compared to the basic (but important) protection function. Finally, discussion is provided regarding the benefit to consider multi-impulses surge current stress on MOV SPDs.**

Keywords—SPD; surge; smart; disconnector; coordination; standard

I. INTRODUCTION

Standards are often late compared to the market needs and the manufacturers development. A typical 3 to 5 years are needed to get a standard and this means that whenever you start you will be arrive after the first products are in the market. However, a standard is a good indication of what exist in the market and in the case of the SPD standards also of what could be developed in future. There are many issues that need to be covered by SPD standards. The more urgent one was for PV applications and by now the product and application standards are published (IEC 61643-31 and 32). The next step if for DC applications (future IEC 61643-41). Regarding AC SPDs a major reorganization of the product standard IEC 61643-11 is ongoing but will not lead to big technical changes and this is not addressed here. Regarding application of AC SPDs, two points need to be addressed: the coordination between SPDs and the selection of SPD disconnectors. To try answering to the challenging selection of the SPD disconnector a new work item has been launched named SSD. It is not sure at this stage if this will lead to a standard but the technical discussions around this topic is a rather good background to understand the SPD disconnector specification and selection. Another topic is discussed: the smart SPDs. As products of this type already exist in the market, it is needed to investigate if this may become a new standard and what could be the definition of a smart SPD. Finally, discussions occurred regarding a need to standardize multi-impulses surge current stress on SPD.

II. SPD STANDARDS CURRENT STAGE

The list of published standards regarding SPDs is comprehensive:

- IEC 61643-11: “Surge protective devices connected to low-voltage power systems - Requirements and test methods” [1]
- IEC 61643-12: “Surge protective devices connected to low-voltage power distribution systems - Selection and application principles” [2]
- IEC 61643-21: “Surge protective devices connected to telecommunications and signaling networks - Performance requirements and testing methods” [3]
- IEC 61643-22: ”Surge protective devices connected to telecommunications and signaling networks - Selection and application principles” [4]
- IEC 61643-31: ”Requirements and test methods for SPDs for photovoltaic installations” [5]
- IEC 61643-32: “Surge protective devices connected to the d.c. side of photovoltaic installations - Selection and application principles.” [6]

The rest of the document will only concentrate on power SPDs product and application standards as there are little modification to expect at the present time for the telecommunications and signaling SPD standards because these standards are mature and meet the need of the stakeholders (users, manufacturers, laboratories, etc.).

III. PROGRAM OF WORK

By now the AC standards are mature and the PV standards, that were urgently needed by the market are published.

The program of work includes the creation of a DC power product standard (61643-41) as well as a major restructuring of existing power standard. A generic standard should be developed considering all commons parts from the product standard (part 01 of 61643 series). As far as possible, tests, requirements and definition that are common to power and telecommunication/signaling SPDs should be included in 61643-01 for standard user sake. Part 11 of the series would then be dealing with AC power SPDs with specific tests related to AC applications only. Part 31 of the series would deal with PV power SPDs with only the specific tests related to PV and part 41 of the series would be for DC power SPDs specific test. It has been agreed that part 41 will not be produced before part 01 is finalized. For a certain period, when 61643-01 will be published, 61643-11 and -31 will exist in their current format simultaneously before the new version of the standards (with only specific tests and requirements) will be published but the situation seems to be manageable by manufacturers and laboratories.

61643-12 is on its way to incorporate the present changes in 61643-11 and to simplify the text and expand a few clauses or annexes. A 2nd Committee Draft has been produced on 2017-09-11 and a Committee Draft for Vote is scheduled for September 2018. There are of course, no major changes in the document as physics and thus application rules remain the same. However, two parts of the standard need to be emphasized as they are related to need from the market: SPD coordination (both in energy and in voltage) and SPD disconnector selection.

An ad-hoc group has also been created to make proposal by the end of 2018 on two main topics: SPD specific disconnector (SSD in short) and "smart" SPDs.

In addition, studies are still going on regarding multi-impulse and their effect on SPDs.

IV. AC SPD COORDINATION

Many applications require the use of two or more SPDs in order to reduce the electrical stress on the equipment to be protected to an acceptable value. Very frequently, a Type 1 SPD is installed at the structure entrance and Type 2 SPDs are used in distribution boards or even near equipment to be protected. Using a Type 1+2 SPD at the entrance doesn't solve the problem, because the protected distance of an SPD is generally limited to a few meters (maximum of 10 m) expect it is of the two-port type that can allow up to 50 m or more (but these SPDs are generally not designed for panel boards).

It is known since a long type that in such a case, these 2 or more SPDs should be coordinated. For a long time, safety was the only issue, and coordination was based on energy. Energy coordination means that the sharing of the stress between the two SPDs is related to their energy withstand in order both SPDs are not destroyed.

But this is not enough nowadays and it is needed to show that the device protected by the second SPD is also effectively protected. This is called voltage coordination or sometimes protection level coordination. Purpose is to ensure that the voltage at the terminal of the second SPD is not exceeding its voltage protective level Up. Furthermore, the residual voltage of this SPD can be reduced below its Up by ensuring that current lower than the nominal discharge current flows through the second SPD. The second SPD can also be a built-in SPD or even surge protective component.

The fact the voltage at the second SPD can be lower and sometimes much lower than its Up is very important for critical installations where protection needs to be demonstrated (data center, nuclear installations). In some cases, it is the only way to provide protection especially when a protective level below 1,5 kV is needed.

Coordination can be demonstrated by tests [7] or simulations.

V. AC SPD DISCONNECTORS

The selection of an SPD disconnector may be difficult. The disconnector may be in the branch of the SPD or upstream and in this last case, it could be already part of the electrical installation. The disconnector should have the same surge withstand than the SPD but this may lead to a too high rating and in such a case, coordination with the upstream overcurrent protective device that are part of the installation may not be achieved and thus the disconnector is useless. If the selection of an SPD disconnector is not a major problem for Type 2 SPDs it is quite a challenge for Type 1 SPDs due to this conflicting requirement: low rating to disconnect asap a failed SPD (and especially before any upstream overcurrent protection) and high rating to withstand 10/350 surge current. Specific fuses can be found on the market that have a low rating and a high surge withstand but there is generally no indication on their time to disconnect making the coordination with other overcurrent protective device impossible. SPD disconnectors are more and more embedded in SPDs but this is available only for a limited number of SPDs. The speed to react of the internal fault current disconnector may also be not known for some technologies. A technical note from Qualifoudre (in French) [8] has clearly explained the problems related to SPD disconnectors, what could be the solutions and what are the possible consequences of the selection of this disconnector when it cannot meet all the requirements. The IEC 61643-12 standard also provides interesting explanations on how to select an SPD disconnector in case of Type 1 SPD. The case of circuit breaker and fuses are addressed. The table for fuses is currently under revision with more values (especially lower values) for the rating of fuses and the minimum surge withstand that can be expected.

The standard IEC 61643-12 also introduces specific requirement for countries that require additional test values for SPD disconnector such as Japan [9], [10]:

- Large surge-withstand capability;
- Low voltage drop due to surge current;
- Low rated current with time-current characteristics for overcurrent coordination with upstream overcurrent protective device and safe disconnection in case of SPD failure.

The SPD disconnector discussion inside standard committees and also in the market, lead to consider a possible new item that is described in next clause.

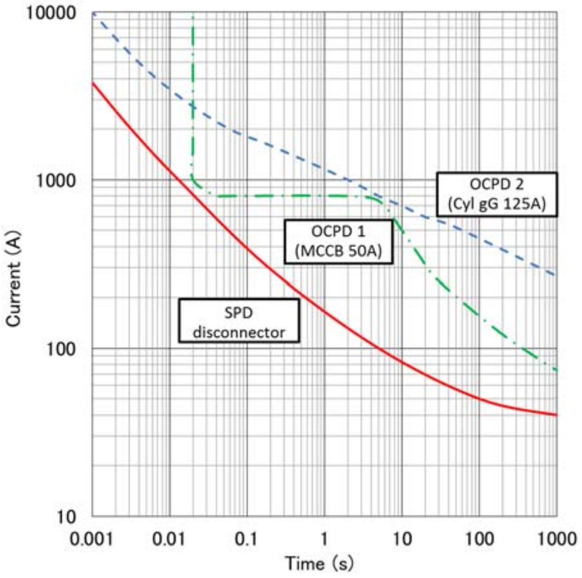

Fig. 1. Example of time-current characteristics of SPD disconnectors according to Japanese standard

VI. SSD

The Ad-hoc group mentioned earlier is presently finalizing its proposal for Specific Surge Disconnector. SSDs are defined as disconnecting devices connected in series with an SPD to protect that SPD should the SPD fails, with a surge withstand coordinated with the discharge current of SPD to be protected.

The preliminary study report of that group shows that there is a contradiction between the need for OverCurrent Protective Devices having a high surge current rating to ensure that an incoming surge does not operate the OCPD and a fast acting OCPD that protects an SPD also at relatively low fault currents. The requirements for SSDs should be as follows:

- a sufficient surge withstand capacity (at least the same than the SPD to be protected)
- a low voltage drop, when tested with surge currents to provide a good overall protection (effective protection).
- a low tripping current, to protect overloaded SPDs
- a time-current characteristic which is coordinated with the upstream installed OCPD to ensure the SSD operates first

In addition to the Japanese standards mentioned above, A Chinese industry standard [11] is in preparation to cover that specific item.

VII. SMART SPDS

The name “Smart SPD” appeared in working groups of the IEC 37A SPD committee, for the first time in 2015. Since then everybody tries to find a good definition for these SPDs even if a few people think that the name itself is confusing and should be changed. The original need for Smart SPDs appeared in China.

The first intent to define what is a Smart SPD was as follows: “an SPD able to communicate with its surroundings (user, maintenance company etc.)”. But it raised immediately other questions: communicate for which purpose?

The best way to answer to that question is to investigate what the user needs are:

- be informed on the state of the SPDs (fine, becoming faulty, partially faulty or already faulty and disconnected)
- what are the stresses the SPD, system and equipment to be protected have been submitted to, for a better selection of next SPD (if the SPD fails it may be because the stress has been underestimated and this need to be corrected)

Of course, all SPDs should communicate and not only the power SPDs (telecom, data, …). The place to receive information is also important. It could be

- local, when SPDs are installed in a single factory or a single building
- remote for a company having a group building located in many different places
- far away for a manufacturer, installer, insurance company who want to follow the state of many SPDs in many places

There are also possible additional functions in addition to monitoring:

- surge counting (able for example to differentiate single pulses, multipulses, continuous current associated with direct lightning strikes, partial lightning current or induces surges)
- power quality (not only surge but also harmonics, under or overvoltages …)
- estimated life expectancy based on cumulated energy and number of impulses the SPD experienced …

Based on what exist in the market, there are also possible limitations or drawbacks:

- many devices consider only AC SPDs with measurement of leakage current used as an indicator of the state of the SPD – mainly for MOV based SPDs- made through a coil) when DC application becomes more and more important.
- communication facilities and protocol may be different from one manufacturer to another one: for user sake it should be good that all smart SPDs use the same principles for communicating but it is not realistic. An internet platform, could be used to deliver the SPD status to the user. Whatever the communicating protocol used by the SPD manufacturer, the user could get information by simply connecting to the internet. An app on mobile phone/computer could be used to reduce the cost and avoid the burden to purchase a specific received for each

SPD brand used in a factory (even if very often SPDs are from the same brand when a facility is protected, it is a fact that the surge protection plan evolves with time and many brands exist in the same place. In addition, more and more devices have built-in SPDs and in this case the probability to have to manage many brands is high). A dedicated emitter need of course to be developed for each SPD that will allow connection to the internet

- Smart SPDs should justify their use based on a cost/benefit comparison (for example maintenance and inspection cots can be reduced by using smart SPDs). By using a minimum of equipment and if possible existing equipment (computer, mobile phone …) the price could be lowered.
- Smart SPD functions should be adaptable to all SPDs of a manufacturer and if possible to SPDs from different manufacturers based on common rules, even if this is probably difficult to achieve.
- Smart SPD concept should include coaxial SPDs and telecom SPDs based on GDTs and more generally all SPD (such as ISG) that are presently difficult to test on site and have quite often no embedded fault indicator.
- Smart SPD functions could probably be provided by "intelligent" surge counters in series with SPDs. Should this assembly (SPD + intelligent surge counter) be considered as smart SPD?

As many products exist already in the market, it was considered by a few members that it was more than urgent to make a specific standard or technical specification for Smart SPDs.

A preliminary advanced definition for Smart SPDs, based on an industry meeting with mainly Chinese manufacturers was at this time:

"an SPD providing monitoring of its environment and communication capability (either locally or remotely) to provide status of the SPD as well as lifetime expectancy and possibly other functions such as surge counting, power quality etc.

Note: environment may include surge counting, surge energy and waveforms, system voltage, type of signal, system frequency, temperature etc."

Of course, many people wonder why such SPDs would be called "smart". It is reasonable to consider that a "simple" SPD is only providing protection that is its basic function. Many SPDs incorporate disconnector and thus local fault indicator. A few of them also incorporate a switch that can provide a remote information but this remote information remains generally inside the structure or the industrial site for maintenance purpose. These SPDs may be considered as "smart" even if smart implies probably two things: interaction with other devices based on faraway communication (internet of things) and when possible a type of analysis (to inform a user that is SPD has failed in nice, but why it has failed is smarter). Smart is usually associated to devices with monitoring, control and communication functions. Smart SPD usually includes three functions: surge protection, monitoring and communication.

Chinese standards either industry or national [12] [13], are in preparation to cover that specific item.

VIII. MULTIPULSES

The protective ability and the safety performance of the high voltage arresters and of the LV Surge Protective Devices are more and more important in the power system. At the same time, the progress of the definition of lightning parameters for engineering applications has been presented since 2013 by CIGRE. There are more than 80% of lightning that are composed of 3 to 5 surges, and the geometric mean interval time of the surges is about 60 ms.

It is known [14] [15] [16] [17] since work made from one side by Prof. Matt Darveniza and from another side by Rick Gumley, both of them from Australia, that an MOV based SPD that can withstand 20 kA 8/20 can be destroyed by multi-impulses at 5 kA 8/20 only. This was explained by the fact that the time is so short between two impulses, the grain boundary in the MOV block has no time to cool down before a new impulse occur. They had both developed a generator able to produce these multi-impulses very easily by using the various capacitors of a usual 8/20 µs generator and triggering each of them one after the other. One of the generators was using a pendulum to trigger each impulse by passing in front of each capacitor. This was efficient and very simple but at this time limited to low energy cumulated stress (a few kA with a 8/20 µs waveform).

Progress in generator design and manufacturing allow by now to perform these multi-pulse tests with various waveshapes including 10/350 µs. A new lightning current test system has been developed in China and is available in almost every Chinese SPD manufacturer laboratory. The test system can generate a maximum of 10 surges and the interval time is from 1ms to 999ms. The waveform, charge and the energy of the lightning can be recorded for further analysis. Fig. 2 presents one of the generators and Fig. 3 a typical waveshape when test is performed on a MOV.

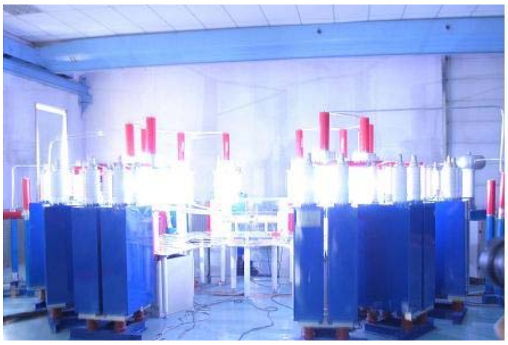

Fig. 2. Multiple Surge Test System

Single surge and the multiple-surges are used for comparison to find the difference in performance. According to standards, a few single surges are applied to the SPD or Surge Arrester during the type tests (operating duty test). This generator allows to use multiple surges to replace many single surges and compare the behavior of the SPD or SA and mainly of the varistor block. The heating transfer and the temperature gradient can also be measured immediately after each impulse.

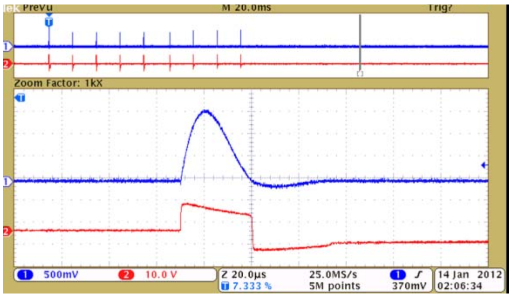

Fig. 3. Current and Voltage Waveform for a MOV during multi-impulse test

Tests have shown that with multi-pulse, MOV blocks can catch fire or be destroyed. This can explain failure modes encountered in field but other causes can also explain these failure modes such a Temporary Overvoltages.

Further studies then include measurement in field both for HV network and LV systems of the probability of occurrence of this type of stress. It is clear that lightning discharge can be multi-impulse but it needs to be demonstrated that these surges can propagate to the LV system from the power lines and be a significant source of stress. HV arresters installed in line on HV pylons and Type 1 SPD are close to the lightning current source and are probably more affected by others. In line HV arresters are often used in series with spark gap and Type 1 SPD are often also of the gap type. Study should then determine if the gap type SA or SPD are also influenced by this type of stress that is so far concentrating on the MOV heating failure process.

Chinese either national or industry or association or company standards [18] [19] [20] [21], are in preparation to cover that specific item and even published for some of them.

ACKNOWLEDGMENT

The Authors would like to thank their colleagues from IEC SC37A and CENELEC TC37A SPD Committees for fruitful and challenging discussions leading to standards covering not only general applications but as far as possible specific applications.

REFERENCES

[1] IEC 61643-11:20011 Edition 1.0 (2011-03-09). Low-voltage surge protective devices - Part 11: Surge protective devices connected to low-voltage power systems - Requirements and test methods

[2] IEC 61643-12:2008 Edition 2.0 (2008-11-13) Low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles

[3] IEC 61643-21:2000+AMD1:2008+AMD2:2012 Edition 1.2 (2012-07-27) Low voltage surge protective devices - Part 21: Surge protective devices connected to telecommunications and signaling networks - Performance requirements and testing methods

[4] IEC 61643-22:2015 Edition 2.0 (2015-06-25) Low-voltage surge protective devices - Part 22: Surge protective devices connected to telecommunications and signaling networks - Selection and application principles

[5] IEC 61643-31:2018 Edition 1.0 (2018-01-10) Low-voltage surge protective devices - Part 31: Requirements and test methods for SPDs for photovoltaic installations

[6] IEC 61643-32:2017 Edition 1.0 (2017-09-20) Low-voltage surge protective devices - Part 32: Surge protective devices connected to the d.c. side of photovoltaic installations - Selection and application principles

[7] Alain Rousseau, Qibin Zhou, Yang Zhao "Further coordination tests between SPDs and between SPD and Equipment" 2014 International Conference on Lightning Protection (ICLP), Shanghai, China

[8] Note Qualifoudre N°3 Note d'informations aux professionnels de la protection contre la foudre "Choix et installation des déconnecteurs pour les parafoudres BT de Type 1" 17th December 2013

[9] JEITA RC4501: "SPD disconnectors for low-voltage surge protective devices performance requirements and test methods for SPD fusing disconnector (SFD)" Japan

[10] JEITA RC4502: "SPD disconnectors for low-voltage surge protective devices selection and application principles for SPD fusing disconnector (SFD)"NB/T 42150-2018 (Energy Industry Standard) "Specific protective devices for low-voltage surge protective devices" Japan

[11] YD/T XXXXX (under writing, Telecommunication Industry Standard) "The External Circuit Breaker for Surge Protective Devices Used in Telecommunication Equipment" China

[12] NB/T XXXXX (under writing, Energy Industry Standard) "SMART SPD" China

[13] GB/T XXXX—XXXX SPD (under writing, national standard) "SPD with smart parts" China

[14] Alain Rousseau, Xuyun Zang, Lihua Zhang, Ming Tao "Multiple shots on SPDs- Test Methods and Results", 2012 International Conference on Lightning Protection (ICLP), Vienna, Austria

[15] Alain Rousseau, Xuyun Zang, Ming Tao "Multiple shots on SPDs – additional tests" 2014 International Conference on Lightning Protection (ICLP), Shanghai, China

[16] Alain Rousseau, Fernanda Cruz, Xuyun Zang, Lu Dongbo, "Degradation Analysis of MOV Type SPDs With Surge Superposing AC Operating Voltage" 2015 International Symposium on Lightning Protection (XIII SIPDA), Balneário Camboriú, Brazil,

[17] Yuwei He, Zhengcai Fu, Jian Chen "Investigation of the Effects of Multi-waveform Multipulse Impulse Currents on MOV for Class I SPD Through Operating Duty Tests" 2014 International Conference on Lightning Protection (ICLP), Estoril, Portugak

[18] T/CHTS XXXXX-XXXX (under writing, Expressway system standard) "Technical guide for multi-pulse lightning protective design and construction of expressway" China

[19] T/MSPD-201X (under writing, China architecture Association standard) "Performance requirements and test methods for multi-stroke surge protective devices connected to low-voltage power systems" China

[20] PfG 2634/08.17 (company standard) "Additional test for Multi-pulses Surge protective devices connected to low-voltage power systems – Requirements and test methods" China

[21] Q/MSPD 001—2016 (company standard) "Multi-pulse Surge protective devices connected to low-voltage power systems –Requirements and test methods" China