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Evaluation of different methods to monitoring of SPDs applied to signaling systems

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***Abstract*— Reliable surge protection devices (SPDs) are required to protect telecommunication systems and signaling networks efficiently against lightning-induced surges. SPDs are sometimes exposed to stresses and currents beyond the limits set in the design. This may cause overheating of certain components of the SPDs and consequently may generate relatively high short-circuit currents. To prevent against overheating of certain components, new sophisticated thermal disconnection devices and new short circuit mechanisms have been designed. During their lifetime, SPDs can degrade. It is highly desirable to monitor the "health status" of SPDs so that possible SPD failures can be detected early and reliably. This allows you to replace the SPDs during preventive maintenance. In this article, advanced approaches to online and offline monitoring and SPD testing are discussed - including Smart SPDs with integrated advanced monitoring capabilities, network connectivity, cloud-based "State of Health" evaluation, and cloud-based monitoring.**

Keywords— Measurement, control and signaling systems; signaling network; Telecommunications network; surge impulse; disturbances; surge protective device (SPD); Smart SPD; ageing; degradation; overheating; temporary overvoltage (TOV); leakage current; nuisance tripping, overload; thermal disconnect; short-circuit mechanism; safety performance; availability; function testing; offline testing; high-voltage test device, function monitoring; local indicator; remote indication; remote signaling; smart diagnostic; smart monitoring; health state; state of health; cloud technology; data archive; Internet of Things (IoT); model based data evaluation; data classification; data recording; preventive maintenance

I. INTRODUCTION

The protection effect of surge protective devices (SPDs) is based on the fact that surge protective devices become low-ohmic during the discharge of surges. During the low-ohmic state the main tasks of SPDs are to

- redirect lightning currents and surge currents and to
- limit surge voltage impulses and lightning-induced voltages.

After the discharge of a surge, a surge protective device shall become high-ohmic again. During normal operation the ohmic resistance of surge protective devices is usually so high, that leakage currents can be neglected. Nevertheless, in real-world electrical systems, the occurrence of leakage currents can't be totally ruled out. The main reasons for the occurrence of leakage currents – flowing through surge protective devices – are:

- Degradation of surge protective devices – due to the exposure to surges close-to or beyond the design limits of the respective surge protective device
- Temporary overvoltages

Depending on the kind of electrical system, undesired and potentially dangerous leakage currents, can flow through surge protective devices. In power systems, in telecommunications and signaling networks, such leakage currents can have the following effects on surge-protective devices:

- Overheating of surge protective devices
- Nuisance tripping of residual current devices (RCDs)
- Warnings from residual current monitors (RCMs) and insulation monitoring devices (IMDs)
- Disturbance of analog signals, digital signals or data communications

An overheating of surge protective devices is highly undesirable, because dangerous overheating can start a fire. To be able to prevent dangerous overheating, it's important to detect and to "switch off" leakage currents before a dangerous situation can occur. In low-voltage power systems, the operation voltages and the prospective short-circuit; currents are usually high enough to be able to cause dangerous overheating. Dangerous overheating of electrical equipment can be caused by:

- Operation conditions beyond the design limits of electrical equipment (e.g. short-circuits, overcurrents, [temporary] overvoltages)
- Degradation and wear and tear
- Human error, misapplication, design faults
- Other causes (e.g. rodents, insects, ingress of water, condensation).

Therefore international, national and local electric codes stipulate to use suitable overcurrent protective devices (OCPDs). For certain applications – as well residual current devices (RCDs) or residual current monitors (RCMs) are needed. Overcurrent protective devices are not capable to detect leakage currents. Residual current devices (RCDs), residual current monitors (RCMs) or insulation monitoring devices (IMDs) are only capable to detect leakage currents between active lines and ground, but they can't detect leakage currents between active lines.

It has to be considered that most surge protective components are installed between active lines. Neither OCPDs, nor RCDs, RCMs or IMDs are capable to detect leakage currents flowing through surge protective components installed between active lines.
Surge protective components and surge protective devices have to be designed and tested in a way that – for relevant fault scenarios – dangerous overheating is avoided. Therefore a couple of special safety-related test procedures got incorporated into the product standard for surge protective devices connected to low-voltage systems (IEC 61643-11 [1]). Such safety-related tests are e.g.:

- Testing of disconnectors and evaluation of the safety performance of overstressed SPDs
- Testing of the behavior under temporary overvoltage (TOV)

Many SPDs are equipped with thermal disconnect devices. Commercially available thermal disconnect devices often have only a relatively low discharge capacity for surge currents.

Thermal disconnect devices, with a high discharge capacity for surge currents, are not commercially available. Therefore in SPDs, designed in accordance to IEC 61643-11 [1], usually manufacturer-specific thermal disconnect devices are used. Manufacturer-specific thermal disconnect devices are commonly used for Type 1 and Type 2 SPDs and sometimes for Type 3 SPDs. Depending on the specific design of such a thermal disconnect device, some of the manufacturer-specific thermal disconnect devices are even capable to withstand high-energy long-duration lightning currents of the waveshape 10/350 µs.

Surge protective devices, which get connected to telecommunications and signaling networks, are designed and tested in accordance to IEC 61643-21 [2]. The operation voltages and the prospective short-circuit currents in telecommunications and signaling networks are usually so low that the risk for dangerous overheating is relatively low or can be ruled out.
Nevertheless, in telecommunications and signaling networks, sometimes applications can be found with operation voltages and prospective short-circuit currents which might be high enough to cause dangerous overheating (e.g. circuits with solenoids).
Sometimes low-power measurement and control lines get accidentally exposed to voltages or currents for which they are not designed. This can cause dangerous overheating.
Because of such kind of scenarios it's reasonable to design certain types of SPDs, connected to telecommunications and signaling networks, with integrated "protection mechanisms" against dangerous overheating. The following "protection mechanisms" can be used:

- Disconnection from the supply voltage
- Creation of a dead short-circuit – provided that the short-circuit current can be carried without causing overheating

Therefore it's reasonable to test certain SPDs – intended to get used for telecommunication and signaling networks with increased prospective short-circuit currents – as well in a way that they can deal in a safe way with temporary overvoltages and effects of degradation.
Thermal disconnect devices, with a low discharge capacity for surge currents and with a low follow-current interrupt capacity, are commercially available (see fig. 1).

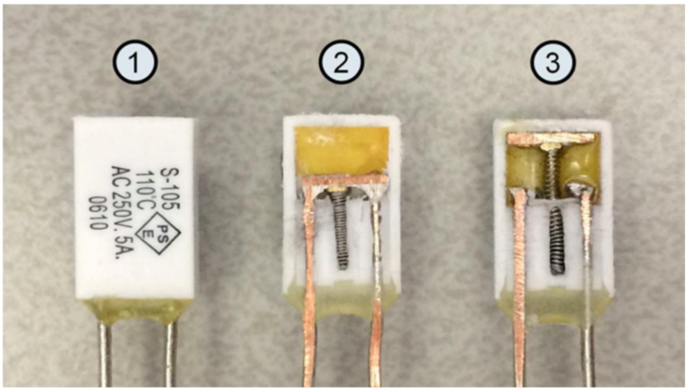

Fig. 1. Thermal disconnect device with a relatively low discharge capacity for surge currents; dimensions of the housing: 6.2 x 9.5 x 2.8 mm; (1) fully functional; housing closed; (2) fully functional; housing partially removed; (3) disconnected state; housing partially removed In this paper newly-designed space-saving thermal disconnect devices are featured.

These newly-designed thermal disconnect devices, for telecommunications and signaling networks, have improved technical characteristics:

- Increased discharge capacity for surge currents
- Increased follow-current interrupt capacity
- Fast response to heat build-up
- Local mechanical status indicator
- No auxiliary circuits or auxiliary power needed for monitoring
- Group signaling (indication) with the help of additional light barrier modules

As already discussed, surge protective devices may degrade during their commercial lifetime. To be able to carry out preventive maintenance on surge protective devices, operators of facilities need information on the "health-state" of the individual surge protective devices installed in a facility.
In this paper different approaches for "status monitoring" are discussed:

- SPDs with integrated thermal monitoring – for local and remote indication
- Smart SPDs with advanced "online" monitoring features, network connectivity, cloud-based evaluation of the "State of Health" and monitoring and recording of surge impulses
- · Sophisticated "offline" testing of pluggable surge protective devices – with the help of a fully-automatic high voltage test device

II. SURGE PROTECTIVE COMPONENTS USED IN SPDS DESIGENED IN ACCORDANCE TO IEC 61643-21

The individual active lines of circuits in telecommunications and signaling networks can be "arranged" in different ways and can be erected with different grounding schemes.
The following grounding schemes are commonly used in telecommunications and signaling:

- Without reference potential
- With reference potential (grounded or ungrounded)

The different grounding schemes of telecommunications and signaling networks/systems are not only important for proper signaling and for proper data transmission – they play as well a very important role in the circuit design of single-stage and multi-stage surge protective devices. To achieve an optimized protection effect, the circuit designs of surge protective devices have to be adapted to the different grounding schemes used in telecommunications and in signaling. Surge protective devices in accordance to IEC 61643-21 [2] can consist of a single protection stage or of multiple protection stages. Depending on the kind of signal, multi-stage surge protective devices can be equipped with decoupling resistors or with decoupling inductors. Fig. 2 shows the circuit diagram of a surge protective device which is e.g. suitable for the protection of an ungrounded 4...20 mA analog signal.

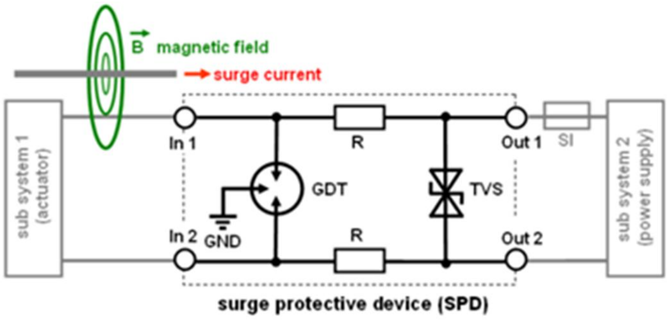

Fig. 2. Surge protective device for differential-mode signals without reference potential; two stages of protection; decoupling resistors between the individual stages of protection; differential-mode and normal-mode protection In surge protective devices, for the protection of telecommunications and signaling networks, the following surge protective components are frequently used:

- Metal-oxide varistors (MOVs)
- Transient voltage suppressor diodes (TVSDs)
- Gas-discharge tubes (GDTs)

III. THERMAL MONITORING AND THERMAL DISCONNECT DEVICES FOR SURGE PROTECTIVE COMPONENTS

Inside surge protective devices "thermally sensitive" disconnect devices are frequently used. The thermal monitoring of electronic components is often carried out with the help of low-temperature solder. If a thermally monitored surge protective component gets heated up by a (leakage) current, then a special solder point (with low-temperature solder) gets heated up. The thermal conductivity between a "heat source" and a low-temperature solder point has to be good enough to allow a fast actuation of the disconnect device. As soon as the melting point of the low-temperature solder is reached, a spring-loaded disconnect mechanism disconnects the thermally monitored surge protective component from the supply voltage.
Metal-oxide varistors (MOVs) are frequently used between conductors with different voltage potentials – e.g. for circuits with solenoids. Due to their relatively high stray capacitance, metal-oxide varistors are not suitable for applications with high-frequency signals. Fig. 3 shows a singlestage SPD with a thermally-monitored metal-oxide varistor (MOV).

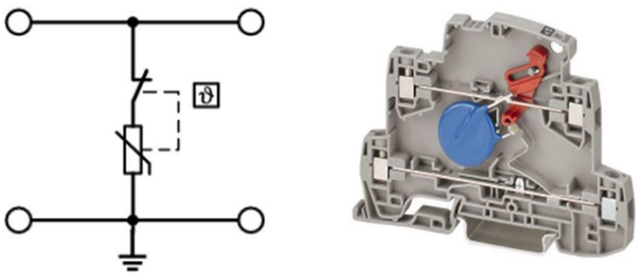

Fig. 3. Single-stage SPD with a thermally-monitored metal-oxide varistor (MOV); thermal disconnect device with a flat spring; local status indicator; optional: remote indication with light barrier modules

Transient-voltage suppressor diodes (TVSD) are frequently used between conductors with different voltage potentials. In surge protection, transient-voltage suppressor diodes are mainly used for applications with Extra Low Voltage (ELV). Due to their relatively low stray capacitance, transient-voltage suppressor diodes are suitable for applications with high-frequency signals. The discharge capacity of transient-voltage suppressor diodes is lower than the discharge capacity of comparable metal-oxide varistors. Fig. 4 and fig. 5 show single-and two-stage SPDs with thermally monitored transient voltage suppressor diodes.

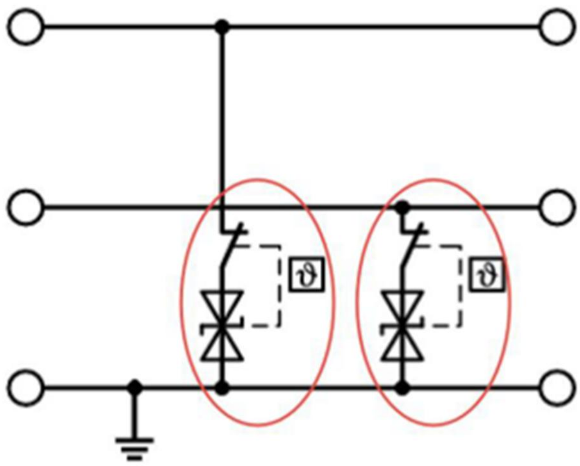

Fig. 4. Single-stage SPD with thermally-monitored transient voltage suppressor diodes (TVS, TVSD)

Fig. 5 shows a SPD with thermally-monitored transient voltage suppressor diodes. If one of the TVS diodes gets overheated, the respective TVS diode will get automatically disconnected. During the disconnection process, the TVS diode and a red piece of plastic will get pushed to the right side (see fig. 5) of the printed circuit board (PCB). When the red piece of plastic has reached its end position, then there is a red status indication on top of the SPD and the red piece of plastic acts as a shutter mechanism for a light barrier.

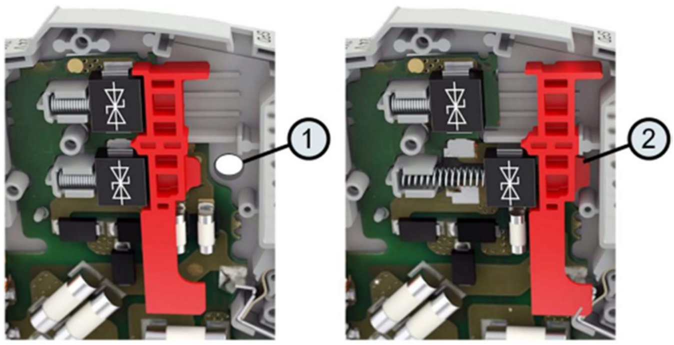

Fig. 5. Two-stage SPD with thermally-monitored transient voltage suppressor diodes (TVS, TVSD); thermal disconnect device with a helical springs (coil springs); local status indicator; optional: remote indication with light barrier modules; (1) fully operational; a beam of light can shine through the round hole in the housing; (2) lower TVSD got disconnected; red shutter moves in front of the round hole; the shutter prevents light from shining through the round hole

For the monitoring of multiple SPDs, installed adjacent to each other, light barrier modules are used (see fig. 6). Such a light barrier consists of a LED transmitter module and a LED receiver module. Fully functional SPDs will not block the beam of light between the transmitter and the receiver module. A damaged SPD with disconnected TVS diode, where the red slider got pushed to its end position, will act as a shutter and it will block the beam of light between the transmitter and the receiver module. If the beam of light doesn't reach the receiver module, then this is indicated by a red LED on top of the receiver module and by a status change of the remote contact of the receiver module.

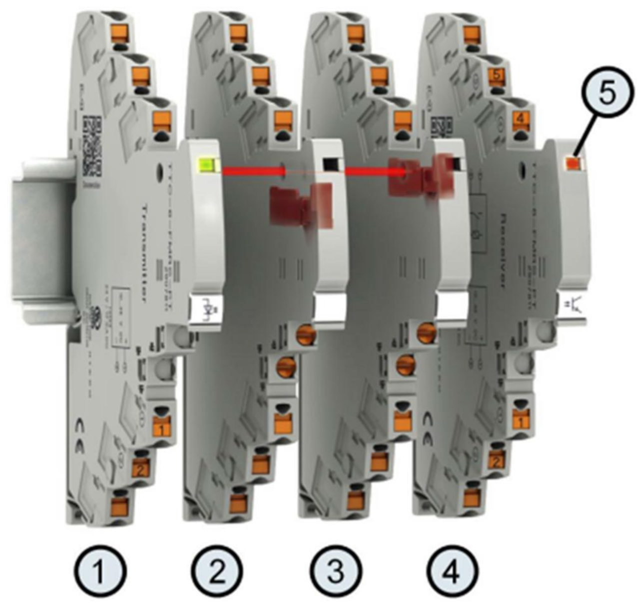

Fig. 6. Monitoring of SPDs with light-barrier modules; (1) LED transmitter module, (2) SPD, fully functional, shutter

lets light through; (3) Defective SPD, red status indicator (mechanical), shutter blocks light; (4) LED receiver module; (5) red status LED

For some applications with transient voltage suppressor diodes (TVS, TVSD), additional functionality is needed – e.g. an electrical status indicator or a short-circuiting function. Fig. 7 shows a PCB-mounted thermal disconnect device with a flat spring, which is suitable for this kind of applications. Depending on the actual hardware design of the printed circuit board, the "thermally sensitive" pre-loaded spring can act as a thermal disconnect device or as a short-circuiting device. The pre-loaded spring can be used to close an auxiliary contact (not shown in fig. 7).

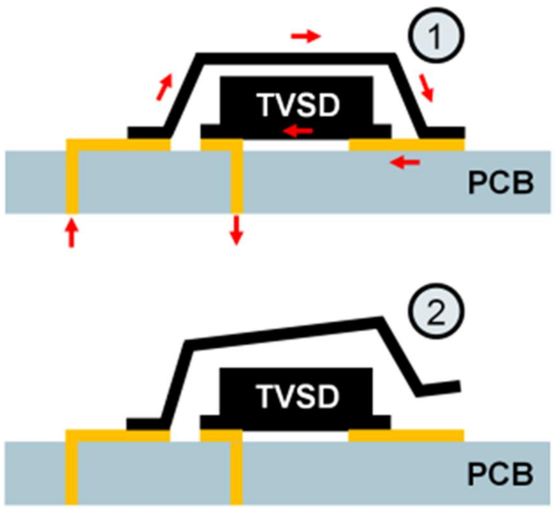

Fig. 7. Function principle of a PCB-mounted thermal disconnect device with a flat spring; (1) normal operation; (2) disconnected state

Gas-discharge tubes (GDTs) are mainly used between conductors with very low voltage differences or between different grounded conductors which are basically at the same voltage level. Because of the relatively low arc-burning voltage and the relatively low power-follow-current quenching capacity, it's not permissible to install gas-discharge tubes between conductors where the prospective short-circuit current exceeds the power-follow quenching capacity of the respective gas-discharge tube. The discharge capacity of gas discharge tubes is always higher than the discharge capacity of MOVs or TVSDs of comparable size.

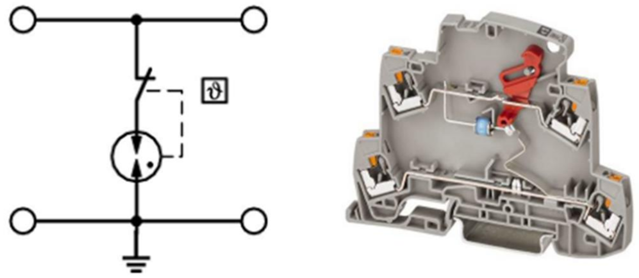

Fig. 8. Single-stage SPD with a thermally-monitored gas-discharge tube (GDT); thermal disconnect device with a flat spring; local status indicator; optional: remote indication with light barrier modules

IV. SMART MONITORING FOR SURGE PROTECTIVE DEVICES

When SPDs are connected to telecommunications and signaling networks, it's not possible to carry out electrical testing of surge protective components during normal operation. Nevertheless there are "indirect" methods for the "online" monitoring of SPDs connected to telecommunications and signaling networks. The microprocessor-based Smart SPD PT-IQ is able to evaluate surge currents, to measure leakage currents and to detect malfunctions of a SPD (see fig. 9). The smart evaluation of sensor data is based on a data model and on empirical data on the ageing behavior of surge protective components.

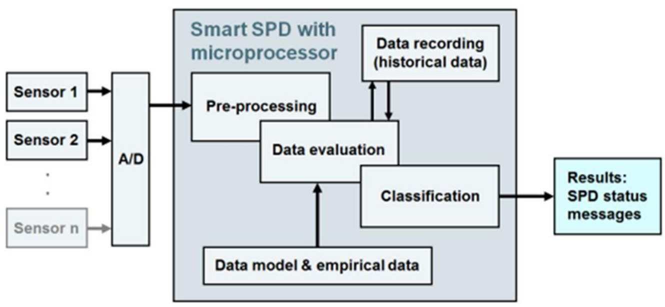

Fig. 9. Smart SPD with microprocessor-based monitoring circuits (Phoenix Contact PLUGTAB PT-IQ...)

Fig. 10 show the circuit diagram of a Smart SPD for "indirect" monitoring. This Smart SPD PT-IQ consists of

- surge protective components,
- an arrangement of phototransistors, A/D converters,
- a custom-designed microprocessor,
- local status indicator and
- remote indication circuit.

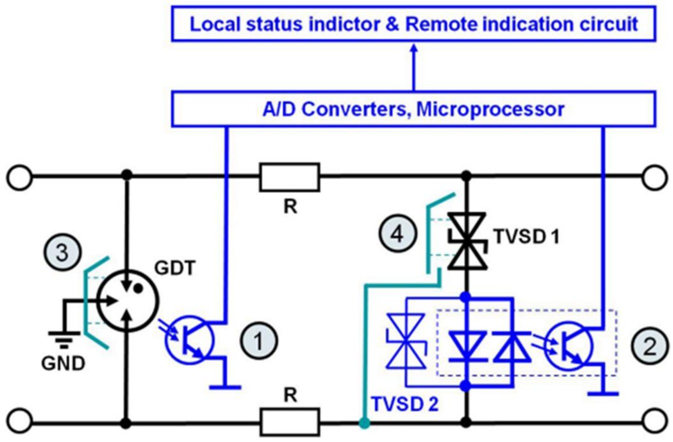

Fig. 10. Two-stage SPD with microprocessor-based smart monitoring circuits for gas-discharge tubes and transient voltage suppressor diodes (Phoenix Contact PT-IQ); (1) phototransistor for the detection of light emitted by GDTs during the discharge of surge currents; (2) phototransistor for the detection of light emitted by LEDs during the discharge of surge currents flowing through TVSD; (3) temperature-sensitive short-circuiting mechanism for the GDT; (4) temperature-sensitive short-circuiting mechanism for TVSD 1 & TVSD 2 .

The custom-designed microprocessor and the their parts of the monitoring circuits got "hardened" against surges. These electronic circuits work properly, even if a 20 kA surge current gets diverted by the surge protective components of the SPD.

The transient voltage suppressor diodes of the Smart SPD PT-IQ are monitored indirectly, with the help of an additional diode (TVDS 2) – together with an antiparallel arrangement of light emitting diodes (LEDs), phototransistors and a microprocessor-based monitoring circuit (see fig. 10).

Based on a data model and on empirical data – a light impulse, emitted by a LED, gets analyzed by a microprocessor.

TVSD monitoring functions of the microprocessor:

· Number of surges – the diode TVSD 1 is exposed to

· Duration of the current – flowing through the diode TVSD 1

· Leakage currents – flowing through the diode TVDS 1

· Thermal disconnection of the diode TVSD 1

The diode TVSD 1 is equipped with a temperature sensitive mechanism, which solidly short-circuits the suppressor diode in the case of a serious overheating – e.g. caused by an accidental exposure to a higher voltage or to a short-circuit current beyond the design limits of the diode TVSD 1. The short-circuiting mechanism of such a TVS diode is capable to carry the nominal current, the respective SPD is rated for.

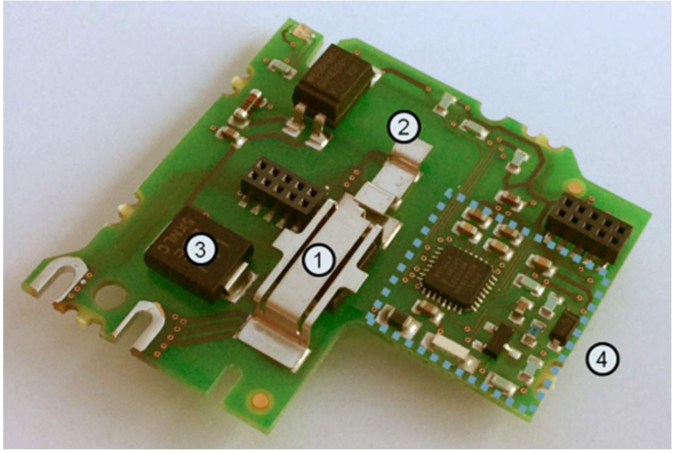

Fig. 11. Transient voltage suppresor diode with monitoring circuits (Phoenix Contact PT-IQ); (1) TVSD 1 with temperature-sensitive short-circuiting mechanism; (2) short-circuiting contact for TVSD 1; (3) TVSD 2 used for the monitoring of TVSD 1; (4) microprocessor-based monitoring circuit;

Gas discharge tubes (GDTs) have a partially translucent ceramic housing. When a surge current flows through a GDT, the electric arc inside the GDT will emit visible light. This emitted light can be detected with the help of a photo-transistor, which is mounted close to the GDT. The brightness and the duration of the emitted light depend on the amplitude, waveform and charge of the surge current. Based on a data model and on empirical data – a light impulse, emitted by a GDT, gets analyzed by a microprocessor. The number of surges, a GDT is exposed to, is saved in the microprocessor of the SPD. The GDTs are equipped with temperature-sensitive brackets. Such a temperature-sensitive bracket solidly short-circuits all three connectors (electrodes) of the GDT in the case of a serious overheating. A serious overheating can e.g. be caused by exposing a GDT to a higher voltage or by a short-circuit current beyond the design limits of the respective GDT. The short-circuiting bracket of such a GDT is capable to carry the nominal current, the respective SPD is rated for.

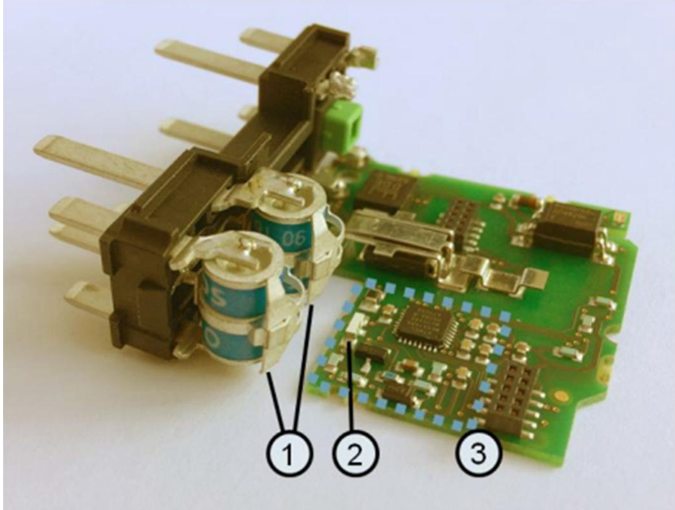

Fig. 12. Gas-discharge tubes with monitoring circuit (Phoenix Contact PT- IQ); (1) GDTs with temperature-sensitive short-circuiting brackets; (2) phototransistor; (3) microprocessor-based monitoring circuit

V. ELECTRICAL TESTING OF SURGE PROTECTIVE DEVICES

Comprehensive electrical testing of surge protective devices, connected to telecommunications and signaling networks, is not possible during normal operation. For the electrical "offline" testing, SPDs have to be disconnected from the network. Some commercially available SPDs consist of a base element and a plug with surge protective components – this allows easy and convenient testing.

To achieve high system availability, system operators must inspect and maintain lightning protection systems on a regular basis. This is stipulated by legislators, supervisory authorities or professional associations. Regular testing and maintenance of lightning protection systems (external and internal lightning protection) is required according to the lightning protection standard IEC 62305-3 Appendix E.7.1 [3] (see table I). The maximum period of time between inspections depends on the respective Lightning Protection Level (LPL) and the specific kind of installation. Proper documentation of the inspection and the testing is stipulated in the international standard IEC 62304-3 [3]. For local application should be used the standard NBR5419-3:2015 as the recommended document to be a base of the testing and maintenance of the LPS systems. This standard was developed in the same base of the international standards. The regular testing and maintenance details would be found at NBR5419-3:2015 : chapter 7.

TABLE I. MAXIMUM PERIOD BETWEEN INSPECTION OF AN LPS; ADAPTED FROM IEC 62305-3 (2010), ANNEX E.7.1, TABLE E.2

Protection level LPL	Visual inspection year	Complete inspection year	Critical situation [a b] complete inspection year
I and II	1	2	1
III and IV	2	4	1

a Lightning protection systems utilized in applications involving structures with a risk caused by explosive materials should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year. An acceptable exception of the yearly test schedule would be to perform the tests on a 14 to 15 month cycle where it is considered to be beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.

b Critical situation could include structures containing sensitive internal systems, office blocks, commercial buildings or places where a high number of people may be present.

The following points are particularly important to note (see IEC 62305-3 (2010) Annex E.7: Maintenance and inspection of the Lightning Protection System – Scope of inspections [3]):

- Lightning protection systems, in applications with a risk caused by explosive materials, should undergo a visual check at least every 6 months.
- "Critical situations complete inspection" relates as well to structures containing sensitive internal systems, office blocks, commercial buildings or places where a high number of people may be present. The electrical test of the installations should be carried out at least once a year.
- For systems with strict requirements in terms of required safety (e.g. petrochemical facilities, nuclear power plants), national authorities or institutions can prescribe a comprehensive check. This can be e.g.necessary if there had been a lightning strike within a certain radius of the respective system.
- Specialist knowledge is required in order to carry out professional inspection and testing of lightning protection systems. For this reason, this inspection and testing must be carried out by a lightning protection specialist. Inspecting the SPDs is also part of this.

During a visual inspection it's not possible to assess the status of a SPD properly and completely. A proper and complete assessment is only possible by carrying out electrical testing in accordance with the manufacturer's guidelines and equipment provided by the manufacturer.

Some Smart SPDs are equipped with monitoring circuits which are e.g. able to detect leakage currents, short-circuits, disconnect states, number of surges, over-temperature or overheating.

Manufacturers of surge protective components consider the following technical properties to be the most relevant properties for the evaluation of the "State of Health" of surge protective components:

- Voltage drop at a current of 1 mA (only for voltage-limiting components)

- Spark-over voltage (only for voltage-switching components)
-

Unfortunately Smart SPDs are neither capable to determine the voltage drop at a current of 1 mA, nor are they capable to determine spark-over voltages. These technical parameters can only be determined when the respective surge protective device is disconnected from the supply voltage or from the respective telecommunications or signaling network.
For the comprehensive evaluation of the voltage drop at a current of 1 mA or for the measurement of the spark-over voltage, a suitable high-voltage test device is needed. The levels of the test voltages, which are needed during testing, exceed extra low voltage (ELV) clearly. For some of the tests procedures, during testing of low-voltage SPD components, test voltages of up to 2000 V (DC) are needed. Such test voltages can be highly dangerous for humans.
The test voltages of commercially available hand-held SPD component testers usually don't exceed a voltage of 1000 V DC. Nearly all commercially available SPD component testers are only suitable for use in a laboratory by specially trained employees. When selecting a suitable SPD component test device, it's therefore important to choose a test device which got designed to be used not only in a laboratory environment but as well on site and which allows a touch-safe testing of surge protective devices and components – without accidentally exposing employees to potentially lethal test voltages.
When electrical testing is carried out on SPDs, the test voltage has to be selected such that the SPD becomes partially conductive. The measured values have to be compared to reference values and have to be evaluated. For a specific technical parameter of a surge protective component there is always a (permissible) tolerance band. As long as a measured value stays in the tolerance band, it can be assumed that the respective surge protective component is still fully functional. Surge protective components may degrade during their commercial lifetime. Due to degradation the measured values, determined with SPD component testers, may come close to the boundaries of the respective tolerance band, which is applicable for a certain surge protective component. This "drifting away" is an indication for a pre-aged or pre-damaged surge protective component. The detection of preaged or pre-damaged components allows a replacement before the component or device actually reaches its end of commercial lifetime.
To be able to test SPDs comfortably and in a safe way it's recommended to use pluggable SPDs. Figure 13 shows a fully automatic high-voltage test device, which allows touch-safe and comprehensive testing of pluggable surge protective devices in the laboratory and on site. Measurement results are automatically evaluated and stored in the test device. Pre-aged and pre-damaged SPDs are detected, and replacement of such SPDs is recommended. For proper documentation, the test results and customer-specific designations and descriptions can be transferred to a personal computer. This is done via an USB interface and an USB thumb drive.

Fig. 13. Fully automatic high-voltage test device for the safe electrical testing of pluggable SPDs; barcode scanner for the identification of SPDs; USB interface for data transfer

VI. CLOUD-BASED MONITORING OF SMART SPDS

If it comes to monitoring functions, most commercially available SPDs are only equipped with relatively simple means of monitoring. More or less smart monitoring circuits, for "indirect" monitoring, can be found in some commercially available SPD. Only very few commercially available SPDs are equipped with a microprocessor for the smart evaluation of the "State of Health" of a SPD [5].
Microprocessors – integrated in SPDs – can e.g. be used for the following tasks:

- Counting of surge impulses
- Registration of time and date
- Determination of technical parameters: amplitude, duration, waveform, charge, specific energy, wear and tear

Even if a SPD is equipped with a microprocessor, then most of the information gathered from the microprocessor stays inside the respective SPD, because – up to now – there are only simple status indicators which provide only binary information for higher-level control systems.
Some of the most popular buzzwords are the terms "Industry 4.0" and "Cloud". In the future we will probably see more and more industrial products which are equipped with microprocessors and which will have the ability to communicate with higher-level control networks and with data clouds. This kind of integration of smart equipment into networks is often called "Internet of Things" (IoT). Internet

of Things means that each "object" is uniquely identifiable and is able to use industrial networks or even existing Internet infrastructure.

Up to now the remote contacts of surge protective devices are only connected to digital input circuits of control systems or to other alarm system. This means that all the valuable data and information, collected in Smart SPDs, is not available in higher-level networks.

In the future it's very likely that many of the sensors, actors, controllers and other industrial equipment will be as well a part of the Internet of Things and will be connected directly to a data cloud. Therefore it seems highly appreciable to have in the future as well Smart SPDs with microprocessors – which can communicate with other devices in the Internet of Things and with cloud-based services. This allows sophisticated cloud-based monitoring of Smart SPDs.

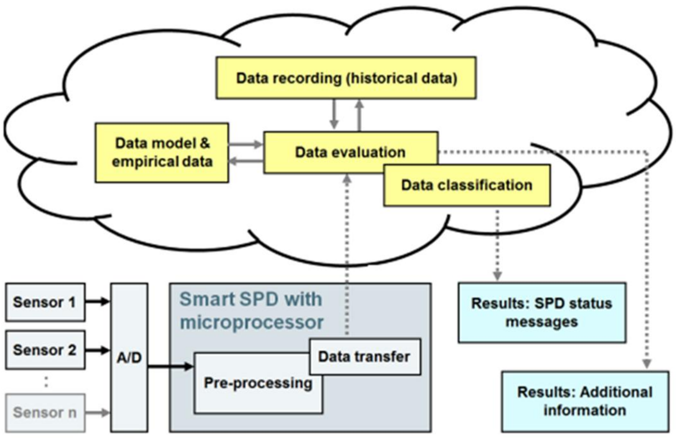

Fig. 14. Smart SPD with microprocessor and cloud-based data evaluation and data classification

Cloud-based services can gather all the valuable data collected by Smart SPDs (see fig. 14). This has some benefits for owners or operators of facilities which are equipped with Smart SPDs:

- Sophisticated model-based data evaluation and data classification
- Data recording (of surge events, pre-damaged or damaged SPDs)
- Access to historical data
- Status-monitoring of each SPD
- Fast detection of SPDs which are defective or close to the end of their commercial life
- Better planning of activities for preventive maintenance

VII. CONCLUSIONS

For the safe and reliable operation of surge protective devices, the following is of great importance:

- Safe behavior in the case of accidental overload – due to reliable thermal disconnect devices
- Smart monitoring circuits – for "online" monitoring
- Ability for comprehensive electric testing – when disconnected from the network (offline testing)

The integration of the next generation of Smart SPDs into the Internet of Things (IoT) can help to make the operation and maintenance of SPDs much easier. The cloud-based processing of data from Smart SPDs can help to create an early-warning system for unwanted surges in power system and in telecommunications and signaling networks.

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