Lightning current arresters in dc power supply systems

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Overcurrent and overvoltage protection is in place to protect cables and systems. Very often, we are inclined to think only of ac systems, yet more and more of our challenges are posed by the need to adequately protect dc systems. A common example of a dc system, and one considered in this article, is a telecommunications system. Significantly, these systems often coexist in systems with ac power systems. With regard to surge protection, in particular, the dc system requires special attention.

Lightning current arresters for low-voltage power systems are usually designed and tested only for use in ac power systems. The performance and operational behaviour of a surge protective device, connected to an ac power system, can be completely different from the performance and operational behaviour of the same surge protective device connected to a dc power system.

The requirements and tests for surge protective devices, connected to low voltage power systems, are described in the international standards IEC 61643 1 [1] and EN 61643 11 [2]. The scope of the IEC 61643 1 [1] includes SPDs for ac applications with a rated voltage of up to 1 000 Vac and SPDs for dc applications with a rated voltage of up to 1 500 Vdc. Unfortunately no test procedures for the testing of SPDs connected to dc power systems are included in this IEC standard. There is mention in the standard that the 'testing of dc arresters' is under consideration.

In the scope of the European EN 61643 11 [2], only SPDs for ac applications, with a rated voltage of up to 1 000 Vac are covered. No test procedures, for the testing of SPDs connected to dc power systems, are found in EN 61643 11 [2].

Nowadays dc power systems are frequently used in industries such as photovoltaics, telecommunications and the railway industry. Of these industries the photovoltaic industry currently has enormous growth. Photovoltaic systems, normally positioned in Zone 0 areas, are highly susceptible to overvoltages and lightning damage. Many investigations have been performed in the past to examine the behaviour of SPDs connected to photovoltaic systems. The operational behaviour of dc power systems can differ significantly from one specific application to another application. Since there are currently no test requirements for SPDs connected to dc power systems in the respective product standards, manufacturers of surge protection devices have to prove that the performance of an SPD, connected to a specific dc power system, is suitable for that specific application and the SPD in question can perform safely and effectively.

Considered applications - Telecommunications

Today, many telecommunication systems are powered with 48 Vdc which are normally earthed. Examples of this are 3G radio base stations (Node B) which are equipped with Remote Radio Heads or Remote Radio Units (RRH/RRU). See *Figure 1*.

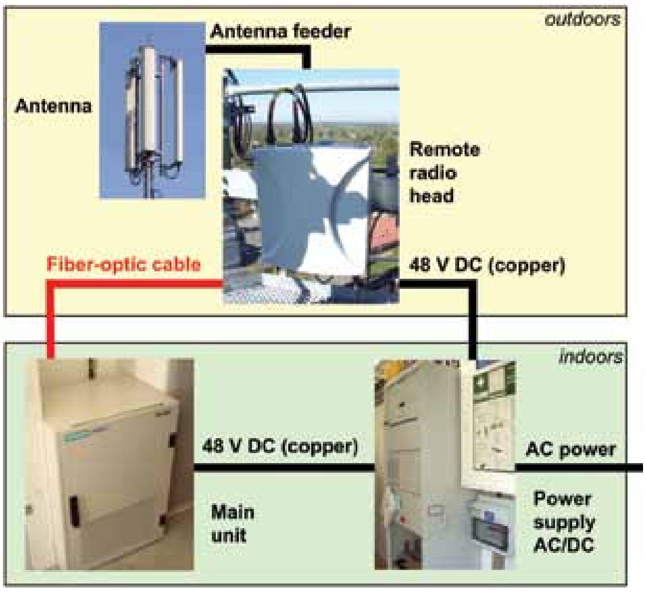

Figure 1: Mobile phone base station with remote radio head (RRH).

The remote radio heads equipped with the RF transceivers are located close to the antennas or they are integrated in the housings of the antennas. For the data communication, fibre optic cables are used for transmission to and from RF transceivers and to and from antennas with integrated RF transceivers. The Remote Radio Heads are powered using copper cables with a 48 Vdc feed. Most mobile phone base stations are located in areas where a direct lightning strike to the base station can be expected (Lightning Protection Zone 0). Therefore, the 48 Vdc lines, which feed the Remote Radio Heads, have to be protected against the effects of direct lightning strikes and therefore require protection using Class I lightning current arresters which are suitable for dc applications.

Investigations

Investigations, with regards to the suitability of surge protective devices for dc power systems, have been carried out with a specific application in mind, namely, in this case, the protection of mobile phone base stations with remote radio heads (RRH).

In this application four dc power supplies (Delta Power System DPS600B) are connected in parallel. Consequently, the following parameters are of importance to the investigation:

- Nominal supply voltage of the RRH - 48 Vdc
- Length of the copper cable between the dc power supplies and the RRH - up to 100 m
- Max output voltage of the dc power supplies in RRH applications - up to 58 Vdc (for the compensation of voltage drop along the dc cables)
- Max power of one dc power supply: 600 W
- Max short-circuit current of one dc power supply: 12,5 A
- Max short-circuit current of four dc power supplies: 50,0 A

The investigation, which includes test procedures for dc arresters has been derived from the well-known test procedures for ac arresters. The operational behaviour of four dc power supplies, connected in parallel, has been taken into consideration as well. Consequently, a new test circuit has been designed for the testing of surge protective devices connected to dc power sources and is capable of simulating worst-case scenarios during the operation of real-world dc power supplies. For this investigation the source characteristic of four DPS600B power supplies has been simulated using an arrangement of batteries. The source characteristic of the batteries is determined by measuring the off-loop voltage and on-load voltages connected to different loads for which the operational behaviour of the batteries can be considered to be linear or nearly linear (see *Figure 2*).

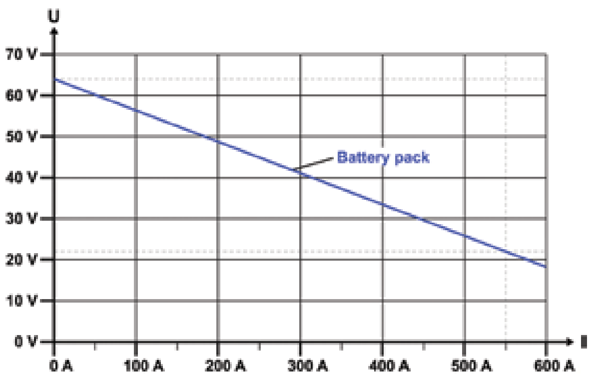

Figure 2: Source characteristic of the battery pack with an off-loop voltage of 64 Vdc.

To make sure that the worst-case behaviour of four DPS600B power supplies can be simulated sufficiently using a battery pack, the source characteristic of the battery pack has to be compared with the source characteristic of four DPS600B power supplies connected in parallel (see *Figure 3*). The nominal supply voltage for remote radio heads is 48 Vdc. To compensate for voltage drop on long dc supply lines, the output voltage of the DPS600B power supplies may be adjusted. For this application it is assumed that the output voltage of the power supplies may be adjusted to up to 58 Vdc. (In the case of long dc supply lines.)

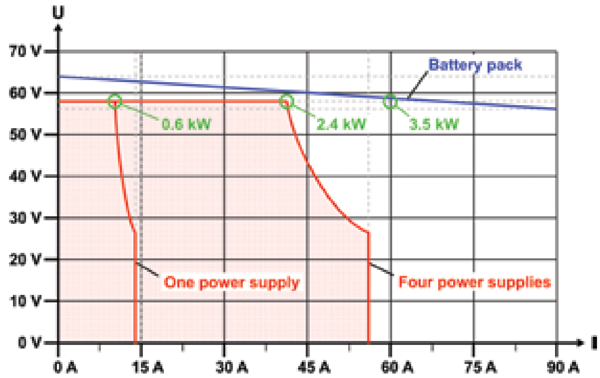

Figure 3: Source characteristics of DPS600B power supplies in comparison with the source characteristic of the battery pack.

The source characteristic of the battery pack is always rated above the source characteristic of four DPS600B power supplies. Therefore it can be assumed that the battery pack can be used to adequately simulate the operational be-haviour of four DPS600B power supplies under worst-case conditions. For the testing of surge-protective devices, connected to dc systems, a special test circuit had been put together (see *Figure 4*).

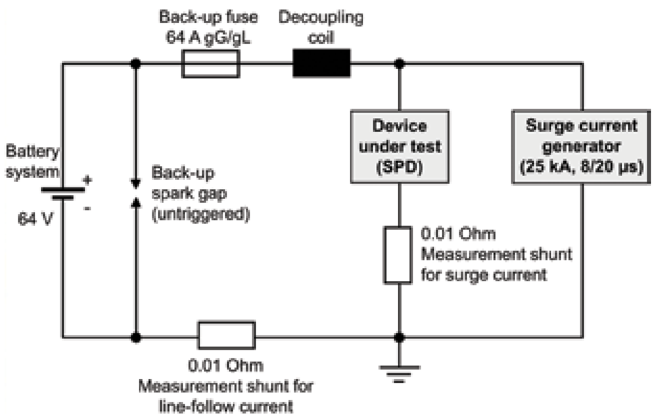

Figure 4: Test circuit for the testing of surge protective devices – connected to dc power sources.

The source impedance of a properly designed battery system is lower than the source impedance of four DPS600B power supplies. Also, battery systems are capable of providing high short-circuit cur rents. This therefore facilitates the comprehensive testing of the dc short-circuit quenching capability of surge protective devices under worst-case conditions.

Up to now spark-gap-based surge protective devices have not been used in dc power systems on a regular basis, as spark gaps are considered to have a low quenching capability with respect to dc line follow currents.

During the discharge of a surge current, there is an electric arc between the main electrodes of a spark gap. The voltage drop along the electric arc is called arc-burning voltage. If the instantaneous value of the supply voltage is higher than the arc-burning voltage, a line-follow current will flow. If a spark gap is connected to a dc power system, the line-follow current can only be quenched by a spark gap if the instantaneous value of the arc-burning voltage of the spark gap is higher than the instantaneous value of the dc supply voltage. For the evaluation of the line follow current quenching capability, Class I spark gaps, connected to a dc supply voltage, are triggered with 25 kA (8/20 µs) surge current impulses of positive and negative polarity.

The arc-burning voltage of a fully established electric arc (> 30 A) is at least 25 Vdc and depends on many different parameters. One of the main parameters is the distance between the electrodes. The higher the distance between the electrodes, the higher the arc-burning voltage (see *Figure 5*).

Figure 5: Arc-burning voltage between the contact pieces of switching devices at standard temperature and pressure.

A straight electric arc, with an amperage of 10 A, between the contact pieces of a switching device, has an arc-burning voltage of approximately 65 Vdc when the distance between the contact pieces is 3 cm. The distance between the electrodes of Class I spark gaps, used for surge protection in low-voltage ac power systems, is usually much lower than 3 cm. This explains why it is challenging to quench dc line-follow currents with spark gaps which have originally been designed for ac power systems.

To extinguish an electric arc, the arc-burning voltage of a spark gap has to be increased to the point at which it is higher than the voltage which drives the electric arc. The following physical principles can be used to increase the arc-burning voltage:

- Lengthening of the electric arc
- Splitting of one electric arc into several sub-arcs
- Electric arc cooling
- Quenching gas
- Increase in pressure in the gap between the electrodes

Currently, in the design of surge protective devices using spark gap technology, one or more of the physical principles are used to increase the arc-burning voltage.

The focus of the investigation has been the evaluation of the line follow current quenching capability in different types of Class I spark gaps. The following spark gaps have been tested:

- Untriggered Class I arc-chopping spark gap without quenching plates (FLT 60-400)
- Triggered Class I arc-chopping spark gap with quenching plates (FLT-PLUS CTRL-0.9)
- Triggered and encapsulated Class I spark gap (FLT-CP-350-ST)
- Triggered and encapsulated Class I spark gap (FLT-CP-350-ST) con-nected in parallel with a Class II varistor (VAL-CP-350-ST)

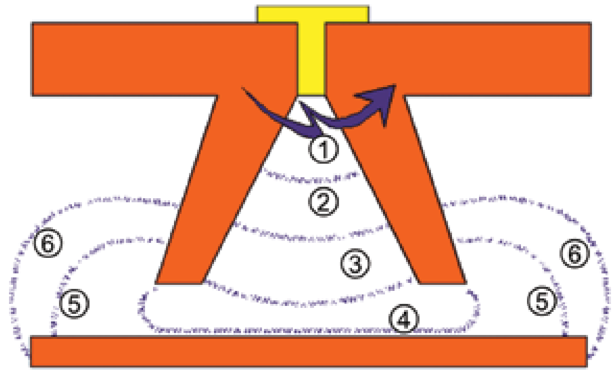

Figure 6: Untriggered Class I arc-chopping spark gap without quenching plates (FLT 60-400). Key: (1) Ignition when arcing voltage is reached (2) Electric arc between the main electrodes (3) Electric arc is driven out of the arcing horns (4) Electric arc hits the baffle plate (5) Development of sub-arcs (6) Rupture and extinguishing of sub-arcs

The untriggered Class I arc-chopping spark gap without quenching plates (see *Figure 6*; FLT 60-400) uses the following principles to increase the arc-burning voltage:

- Lengthening of the electric arc
- Splitting of one electric arc into several sub-arcs
- Quenching gas

Listed below are the test results for the FLT 60-400 connected to a 64 Vdc battery system:

- After triggering with a 25 kA (8/20 µs) surge current impulse, a dc line follow current of 550 A flowed until the back-up fuse (see *Figure 4*) blew.
- The FLT 60-400 was not able to quench the dc line-follow current.
- Therefore the FLT 60-400 is not suitable for the application where four DPS600B power supplies are used – ie 3G radio base stations (node B).

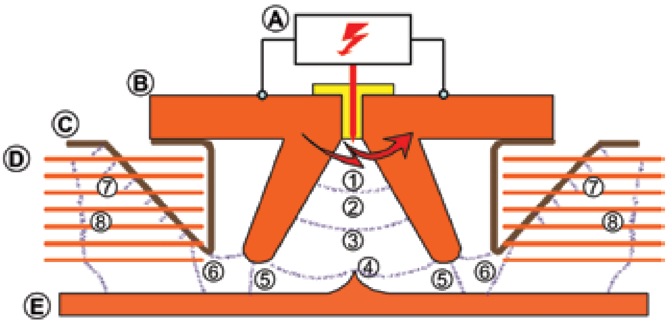

Figure 7: Triggered Class I arc-chopping spark gap with quenching plates (FLT-PLUS CTRL-0.9).
Key: (1) Ignition when the triggering electronics triggers the spark gap (2) Electric arc between the arcing horns (3) Electric arc is driven out of the arcing horns..... (4) and is broken up by the baffle plate. (5) Electric arc is divided into sub-arcs ... (6) and is transferred to the arc-guide plates. (7) The arc-guide plates lead the electric arc to the quenching plates (8) Between the quenching plates sub-arcs are generated. The arc-burning voltages reduce and finally extinguish a possible line-follow current (A) Triggering electronics (B) Main elec-trodes (C) Arc-guide plates (D) Quenching plates (E) Baffle plate

The triggered Class I arc-chopping spark gap with quenching plates (see *Figure 7*; FLT-PLUS CTRL-0.9) uses the following principles to increase the arc-burning voltage:

- Lengthening of the electric arc
- Splitting of one electric arc into several sub-arcs

Test results for the FLT-PLUS CTRL-0.9 – connected to a 64 Vdc battery system:

- After triggering the device with a 25 kA (8/20 µs) surge current impulse, the arc-burning voltage took approximately 300 µs to rise permanently to a level higher than 64 Vdc. No line follow current was detected during or after the 300 µs rise time.
- In light of this the FLT-PLUS CTRL-0.9 is suitable for use when using four DPS600B power supplies (eg 3G radio base stations).

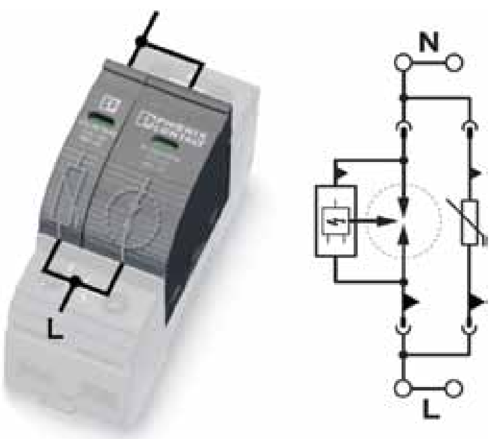

Figure 8: Triggered and encapsulated Class I spark gap (FLT-CP-350-ST) connected in parallel with a Class II varistor (VAL-CP-350-ST).

A Class II varistor, which is connected in parallel to a Class I spark gap (see *Figure 8*), has a maximum continuous operation voltage of 350 Vac (about 455 Vdc). Consequently this Class II varistor is line-current-follow-free in applications using DPS600B power supplies.

The triggered and encapsulated Class I spark gap (see *Figure 8*; FLT-CP-350-ST) uses the following principles to increase the arc-burning voltage:

- Lengthening of the electric arc
- Quenching gas
- Increase in pressure in the arc channel between the main electrodes

Test results for the FLT-CP-350-ST combined with the VAL-CP-350-ST – connected to a 64 Vdc battery system:

- After triggering using a 25 kA (8/20 µs) surge current impulse, no dc line follow current was measured.
- The FLT-CP-350-ST used separately or combined with the VAL-CP-350-ST is capable of quenching dc line-follow currents.
- The FLT-CP-350-ST used separately or combined with the VAL-CP-350-ST is suitable for an application using four DPS600B power supplies.

An electrical effect, which is frequently used in the design of electrical devices which produce electrical arcs or where electrical arcs may occur, is called the 'arc blow effect'. This arc blow effect lengthens an electric arc because of the magnetic field caused by the current flowing through an electric arc (see *Figure 9*).

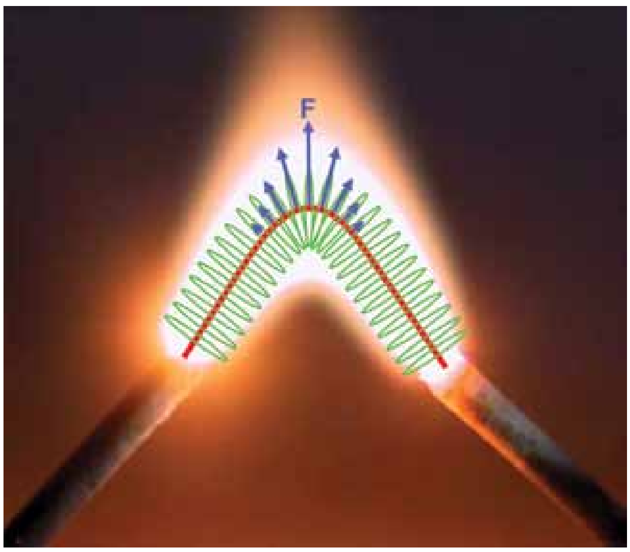

Figure 9: Arc blow effect of a dc arc between electrodes.

This arc blow effect is used in the FLT-CP-350-ST spark gap. The transversal arc channel between the main electrodes of the spark gap has multiple bends – which boosts the arc blow effect (see *Figures 10 and 11*).

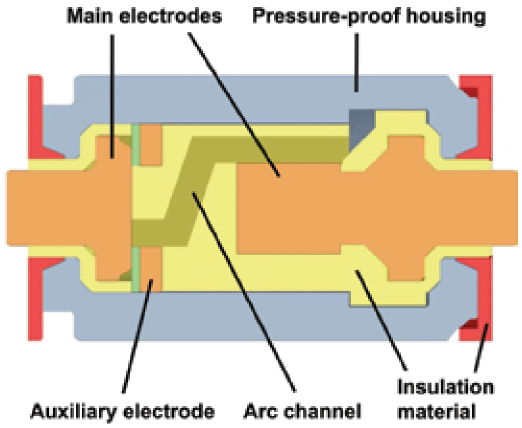

Figure 10: Design of the triggered and encapsulated Class I spark gap of the FLT-CP-350-ST.

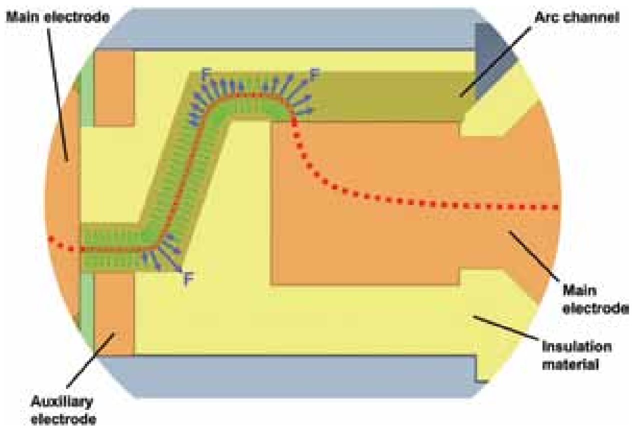

Figure 11: Arc blow effect inside the arc channel of the triggered and encapsulated Class I spark gap of the FLT-CP-350-ST.

The arc blow effect lengthens the electric arc in the arc channel and pushes the electric arc from the centre of the arc channel towards the insulation material (see *Figure11*). The closer the electric arc is to the insulation material, the more quenching gas released by the insulation material. Because of the special transversal design of the arc channel, with multiple bends and the usage of quenching-gas-releasing insulation material, the arc-burning voltage is always higher than 200 Vdc – even when testing using high-energy 10/350 µs surge currents (see *Figures 12 and 13*).

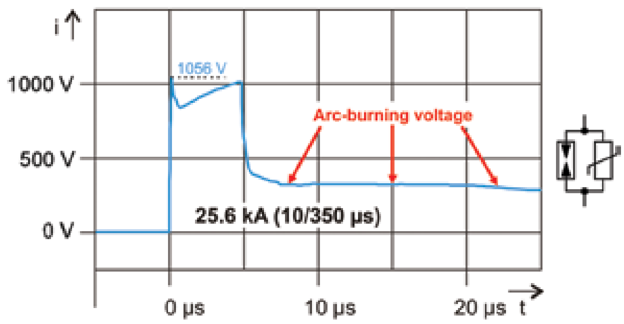

Figure 12: Course of the residual voltage during testing with 10/350 µs surge currents (FLT-CP-350-ST together with VAL-CP-350-ST); time resolution: 5 µs/ div.

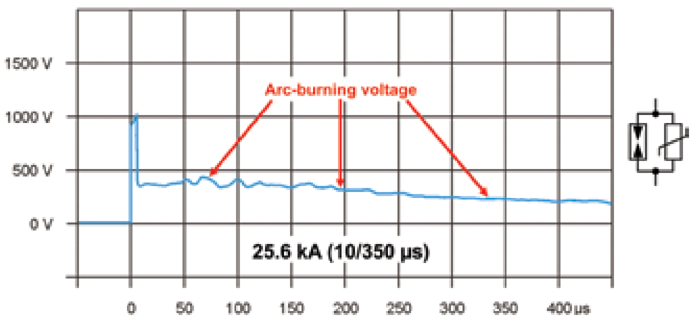

Figure 13: Course of the residual voltage during testing with 10/350 µs surge currents (FLT-CP-350-ST together with the VAL-CP-350-ST); time resolution 50 µs / div.

The response behaviour of the FLT-CP-350-ST spark gap, to fast-rising transients, had been tested with the help of 6 kV 1,2/50 µs hybrid impulses – 2 ohm (see *Figure 14)*.

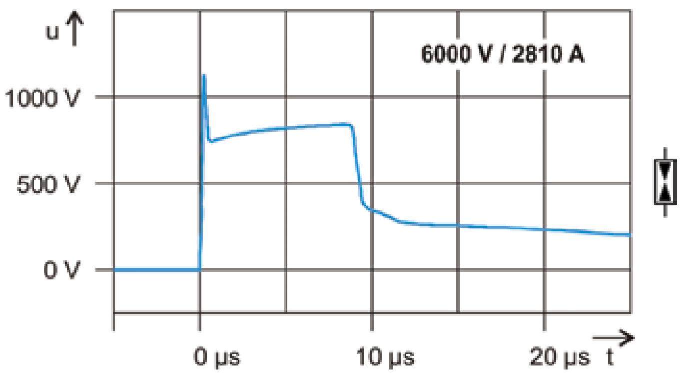

Figure 14: Course of the residual voltage during testing using a 6 kV 1,2/50 µs (2 ohm) hybrid impulse (FLT-CP-350-ST).

Testing using fast-rising hybrid impulses has shown that the course of the residual voltage is lower if a Class II varistor (VAL-CP-350-ST) is connected in parallel to the Class I spark gap (FLT-CP-350-ST). See *Figures 15 and 16*.

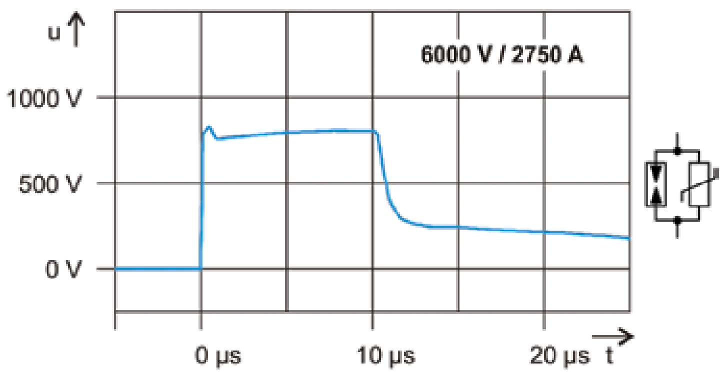

Figure 15: Course of the residual voltage during testing using a 6 kV 1,2/50 µs (2 ohm) hybrid impulse (FLT-CP-350-ST combined with the VAL-CP-350-ST).

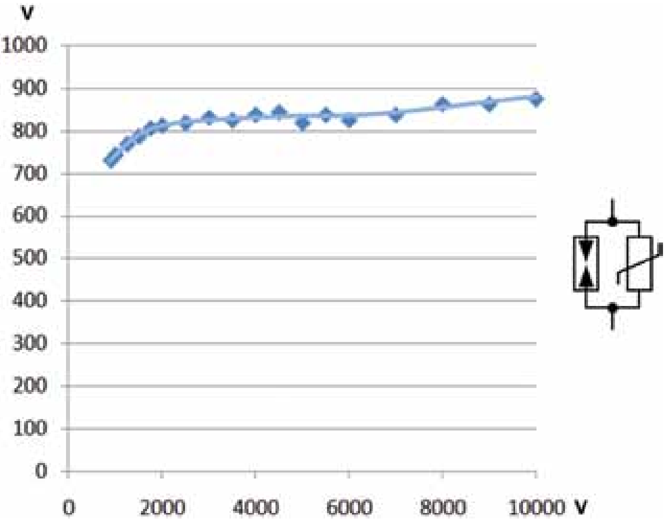

Figure 16: Protection levels during testing using 1.2/50 µs (2 ohm) hybrid im-pulses of different voltage amplitudes (FLT-CP-350-ST combined with the VAL-CP-350-ST).

Conclusions

Based on the investigation, which has been carried out using Class I spark gaps and Class II varistors, the following conclusions are noted:

- Forcing an electric arc to make multiple bends inside a spark gap – increases the arc-burning voltage and increases the line follow current quenching capability.
- The arc-burning voltage of the spark-gap based Class I SPD (FLT-CP-350-ST) is permanently higher than 200 Vdc.
- During the testing at 64 Vdc – no line-follow current flowed through the FLT-CP-350-ST spark gap.
- The FLT-CP-350-ST spark gap is therefore suitable for applications which use 48 Vdc remote radio heads and four DPS600B power supplies connected in parallel.
- A combination of a Class I spark gap and a Class II varistor reduces the level of the residual voltage, lowers the protection level and improves the protection effect.

References

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[2] EN 61643-11: 2007. Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and tests.

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[2] Finis G, Heckler H, Wosgien J. Blitz- und Überspannungsschutz-Konzept für PV-Anlagen, etz Elektrotechnik + Automation, S. 54-57, Ausgabe 1/2010.

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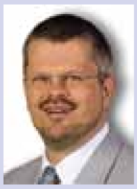

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