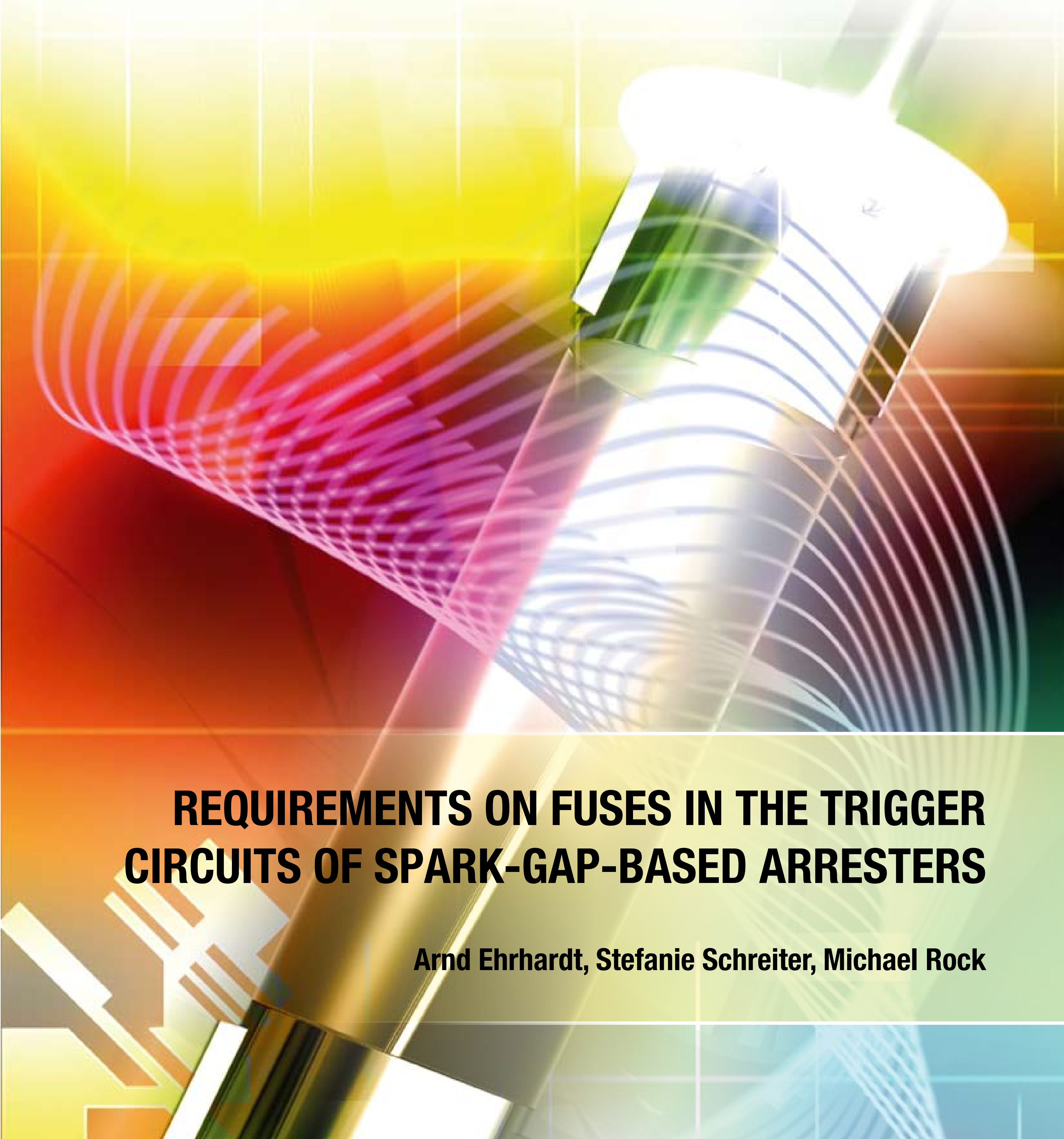
ICEFA 2011

9th INTERNATIONAL CONFERENCE ON ELECTRICAL FUSES AND THEIR APPLICATIONS



REQUIREMENTS ON FUSES IN THE TRIGGER CIRCUITS OF SPARK-GAP-BASED ARRESTERS

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Requirements on fuses in the trigger circuits of spark-gap-based arresters

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Abstract

Electronic trigger circuits are nowadays used in modern lightning current arresters. Due to their mode of operation, considerable impulse currents may occur in these trigger circuits. As a result, the components of the trigger circuit could be overloaded. This article describes a specially designed surge-proof miniature fuse that protects the trigger circuit in a lightning current arrester. The special application-specific requirements on this fuse will be pointed out in detail. The miniature fuse described in this article, which is mounted on a printed circuit board, is adapted to the load capacity of the trigger circuit. The fuse was designed with a high impulse current carrying capability and has a long-time ageing resistance and a high extinguishing capability for line-frequency currents.

Keywords: miniature fuse, lightning current arrester, trigger circuit, impulse current, ageing stability.

1. Introduction

Nowadays integrated electronic trigger circuits are essential to fulfil the variety of requirements placed on modern lightning current arresters. Due to the basic functional principle of the arrester, impulse currents that considerably stress the individual components may occur in these trigger circuits.

This articles describes a specially designed impulse-current-resistant miniature fuse for protecting the trigger circuit in a lightning current arrester and shows the special application-specific requirements this fuse has to fulfil, for example impulse current carrying capability, ageing resistance as well as a high follow current extinguishing capability. Moreover, the functional principle of the fuse under normal operating conditions as well as in case of overload and ageing of the surge protective device is described in detail.

2. Design and functional principle of a modern lightning current arrester

The increasing integration of information technology systems with their electronic components, which are extremely sensitive to overvoltage, fundamentally changed the lightning and surge protection requirements over the last years.

Today's lightning current and surge arresters are mostly mounted on DIN rails in low-voltage systems. For this reason, the low voltage protection levels required for electronic systems frequently cannot be gradually realised by means of large-scale and complex decoupling networks.

The lightning protection zones concept [1] required for optimum lightning and surge protection has to be increasingly applied in confined spaces. Surge protective devices which are supposed to ensure lightning equipotential bonding and the protection of electronic devices against energetic field-related and conducted interference are directly installed at the entrance point of power and data lines into a building or an installation. Lightning equipotential bonding prevents that destructive partial lightning currents enter the electrical installation. For this purpose, lightning current arresters must be able to carry energetic impulse currents of waveform 10/350 µs in case of a direct lightning strike. Coordinated surge protection for the electrical installation and terminal devices connected to it additionally requires that the arresters are able to carry impulse currents of waveform 8/20 µs caused by injections in case of nearby lightning strikes several times without destruction.

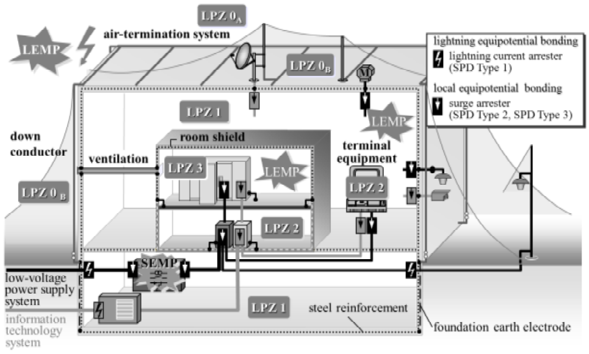

Fig. 1: Lightning protection zones concept

This article deals with spark-gap-based lightning current arresters for use in low-voltage power supply systems. Such lightning current arresters are installed at the entrance point of the electrical supply lines into a building, typically in the main distribution board or upstream of the energy consumption meter.

Figure 1 shows a typical arrangement of surge protective devices (SPDs) in conformity with the lightning protection zones concept [2, 3]. In case of particularly compact installations it is advisable to gradually reduce the voltage protection level by means of a single arrester combining SPD type 1 (2.5 kV) and SPD type 2 (1.5 kV) so that this arrester ensures a direct transition from LPZ (LPZ = Lightning Protection Zone) 0_A to 2.

Due to the required reduction of the voltage protection level from typically 2.5 kV to < 1.5 kV, the spark gap of regular lightning current arresters would trip more often without energetic assessment, for example already in case of switching overvoltage or so-called burst impulses. If modern surge protective devices are activated by means of a low-energy interference as described above, the power supply shall not be interfered with during or after a discharge, for example by means of mains follow currents, supply voltage dips or even activation of the upstream overcurrent protective device resulting in power failure.

To avoid these disadvantages, modern surge protective devices feature a high follow current limitation, ensuring power supply even in case of low-performance supply with rated currents of the power supply fuse ≥ 20 A gG/gL.

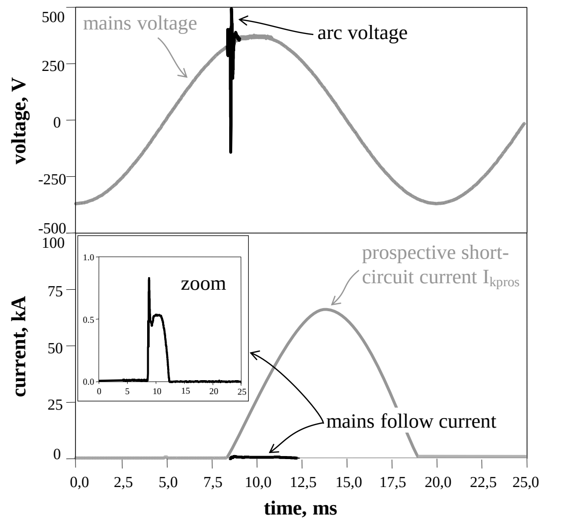

Fig. 2: Follow current limiting capacity of a lightning current arrester in case of a prospective short-circuit current of 50 kA

Figure 2 shows a current-voltage characteristic for the activation of a lightning current arrester with high follow current limitation.

The prospective follow current of e.g. 50 kA is reduced to a negligible residual current of e.g. lower than 1 kA.

Since a repeated activation due to the required low voltage protection level would accelerate ageing of such a lightning current arrester, it is advisable to prevent that the spark gap trips frequently, particularly in case of small, low-energy interference. In case of a modern lightning current arrester this is achieved by an energetic assessment of the interference by means of the integrated trigger circuit of the lightning current arrester according to Figure 3. Due to its components, the trigger circuit fulfils the function of a surge arrester and a certain amount of energy is needed to activate the powerful spark gap by an ignition impulse.

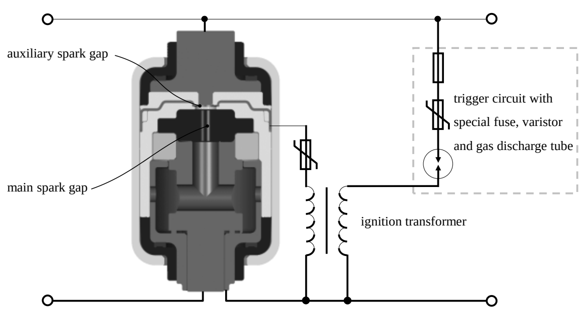

Fig. 3: Schematic diagram of the spark-gap-based lightning current arrester and the trigger circuit

The trigger circuit arranged in parallel to the spark gap consisting of a varistor connected in series to a gas discharge tube (see Figure 3) protects against overvoltage independent of the spark gap. Low interference such as burst impulses, low-energy switching impulses, but also impulse currents of waveform 8/20 µs (injections) up to several kA are directly discharged via this trigger circuit without igniting the spark gap. The load on the spark gap, particularly in case of mains follow currents, is thus considerably reduced and premature ageing due to frequent switching is prevented.

Not only the spark gap, but also the surge protection elements of the trigger circuit are subject to ageing. Moreover, the lightning current arrester may be exposed to a temporary overvoltage (TOV = Temporary Overvoltage) resulting in overload of individual elements and/or malfunctions, for example due to incorrect installation.

For this reason, a special overcurrent protection fuse is integrated in the path of the trigger circuit. This article particularly deals with this special fuse which is integrated into the trigger circuit of a modern lightning current arrester. The design of this special fuse is harmonised with the overall function of the arrester and is described below.

3. Requirements on the overcurrent protection elements in the trigger circuit

The special fuse in the trigger circuit is supposed to protect the circuit elements from energy overload and to safely disconnect the trigger circuit from the power supply in case of faults. In addition, the status of the special fuse is to be indicated.

The space available in a DIN rail mountable lightning current arrester only allows relatively small fuse sizes. Therefore a 5 x 20 mm type in accordance with the IEC 60127-1 [4] standard is used.

Common mounting of a miniature fuse (cartridge fuse) on a printed circuit board by means of a separate fuse holder requires a lot of space on the trigger printed circuit board. If a miniature fuse is mounted on a printed circuit board by means of wired connection caps, mounting and welding is complex and results in an additional high voltage drop, which unnecessarily increases the so-called voltage protection level of the arrester. Therefore a special double connection cap was designed for the special fuse which is shown in Figure 4 and which provides an additional reinforcement of the cap base of the fuse.

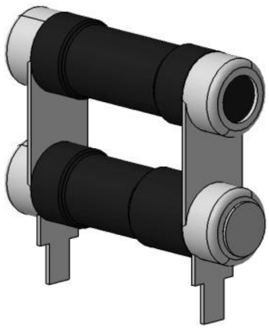

Fig. 4: Fuse combination with special connection caps

In order to ensure the required arrester performance, high melting integrals and thus fuse elements with a large cross-section are necessary. The fuse element cannot be designed as a round wire since the required wire sizes prevent safe mechanical installation of the connection caps. For this reason, the fuse element is designed as a strip. It is not soldered and only provides a single protective layer to prevent e.g. oxidation. The rolling process is controlled so that the melting integral value is not reduced with regard to the theoretical material value. When integrating the fuse element into the fuse enclosure, it is ensured that the fuse element does not contact the enclosure wall, is not twisted and is surrounded on all sides by a silica sand mixture which is very coarse for the small size.

The cap for printed circuit board mounting ensures a low-impedance connection due to its flat contact lugs and a high mechanical strength of the combination. Due to this low terminal impedance, only small voltage drops occur in case of steep impulse currents so that the voltage protection level specified for the arrester is reliably maintained. A low inductive voltage drop across the fuse itself is achieved by using a special low-impedance fuse element designed as a strip. Despite the confined space, the contact lugs on both sides allow defined positioning, mounting and easy welding.

The impulse-current-resistant special fuse can either be used alone or in combination with a parallel indicator fuse indicating the status of the fuse. In case of the fuse shown in Figure 4, the status of the special fuse is indicated by means of the striker of the additional indicator fuse which activates the status indication of the lightning current arrester. Due to the small size of the special fuse, no additional indicator wire has to be used. If suitably rated, the indicator fuse also switches as soon as the special fuse trips and its striker is pushed out with the force of a coil spring (several N). The status of the special fuse can also be indicated electrically.

Individual elements of this combination fuse are additionally fitted with an insulating heat shrinkable sleeve e.g. to extend the isolating distances and thus to increase the dielectric strength of the fuse.

The requirements and the functional principle of the special fuse in lightning current arresters depend on the operating states of the surge protective device, the supply voltage, and the performance of all functional components of the complex arrester and will be described in detail.

3.1 Requirements during normal operation

The test procedures described in the IEC 61643-11 [5] standard serve as a reference for the quantity and intervals of the loads the entire lightning current arrester must be able to handle without restriction. These tests predominantly load the spark gap.

Under normal operating / mains conditions the trigger circuit of the surge protective device is disconnected from the power supply by means of the gas discharge tube and the special fuse is de-energised. It is only when the gas discharge tube is activated according to its dynamic spark over voltage that current flows through the special fuse on the trigger printed circuit board.

Dimensioning the special fuse for a characteristic fuse parameter, the rated current, is therefore not relevant for this application. If used as described above, the special fuse has an equivalent nominal current rating < 16 A.

The integrated trigger circuit assesses the energy of the interference and activates the spark gap at a defined limit value to relieve these components. For this reason, both impulse currents of waveform 8/20 µs and 10/350 µs with a low amplitude and cut-off impulse currents of these waveforms with a higher amplitude flow through the integrated fuse until the spark gap is activated. In addition, the integrated fuse may also be loaded by low-energy impulses with a higher current steepness, e.g. in case of burst impulses.

If lightning current arresters are adequately dimensioned, impulse currents with a peak value up to approximately 5 kA of waveform 8/20 µs can be discharged via the trigger circuit (printed circuit board current) without igniting the spark gap. This corresponds to a Joule integral of approximately 380 A²s.

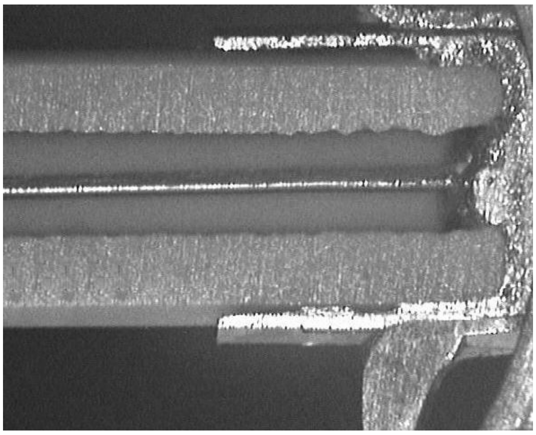

Fig. 5: Section of a fuse element after 30 x 5 kA 8/20 µs

Figure 5 shows a fuse element in an open fuse after 30 impulse currents of 8/20 µs waveform with 5 kA without visible signs of ageing.

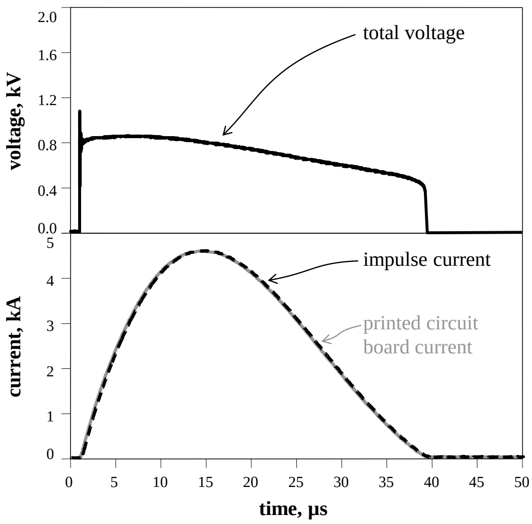

Fig. 6: Protection level of the arrester without ignition of the spark gap at 5 kA 8/20 µs

The corresponding current and voltage curves can be found in Figure 6. The residual voltage of the entire arrester is considerably lower than the required 1.5 kV, the voltage drop directly across the fuse being some 10 V.

The special fuse must not be subject to ageing during these adiabatic loads. The fuse element is dynamically loaded within a matter of some µs by extremely high current forces in particular in case of the “cut-off“ impulse currents with a high amplitude.

Figure 7 shows the current and voltage characteristics across the lightning current arrester during the ignition of the spark gap at a load of approximately 9 kA 8/20 µs.

An impulse current of waveform 8/20 µs flowing through the trigger circuit is cut off as soon as the spark gap ignites as shown in Figure 7 (printed circuit board current). This happens under consideration of all tolerances of the trigger circuit and the spark gap if the current is greater than approximately 5 kA. This can be referred to as a cut-off 8/20 µs wave that loads the fuse. For safety reasons, the special fuse is dimensioned so that impulse currents of waveform 8/20 µs with values of Joule integral of more than 500 A²s are discharged several times without damage.

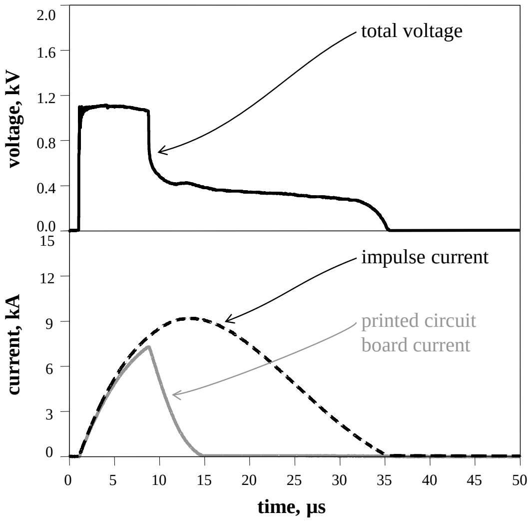

Fig. 7: Protection level of the arrester with ignition of the spark gap at 9 kA 8/20 µs

The lightning current arrester is rated for impulse currents of waveform 10/350 µs up to e.g. 25 kA. In case of such loads the trigger circuit already ignites the spark gap within the rise time of the current impulse. Therefore the behaviour of the trigger circuit and the load on the special fuse do not fundamentally differ for impulse currents of waveform 8/20 µs and 10/350 µs since both impulses have roughly the same front time.

In case of an impulse current of waveform 8/20 µs of e.g. 25 kA only a peak current value smaller than 8 kA occurs across the fuse (Fig. 8).

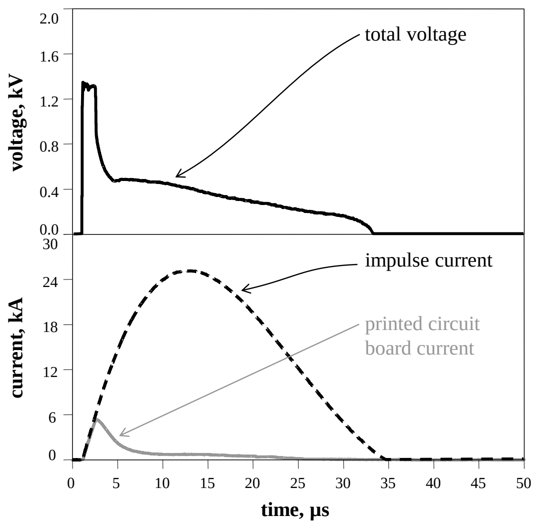

Fig. 8: Protection level of the arrester when loaded with 25 kA 8/20 µs and the spark gap ignites in the impulse front

With less than 200 A²s, the adiabatic load on the fuse is frequently smaller than in case of a full wave of 5 kA 8/20 µs without ignition of the spark gap (see Fig. 6).

3.2 Requirements in case of overload and ageing

The surge protective device can be heavily loaded by little load e.g. in case of incorrect installation. Similarly, frequent loads on the surge protective device can cause ageing of the individual components. In both cases, the special fuse should put the trigger circuit into a safe state, which is disconnected from the power supply, and the relevant status should be indicated.

Figure 9 shows a current and voltage curve of a significantly aged spark gap with a high ignition delay time. The adiabatic load on the fuse is already approximately 400 A²s to 500 A²s. The special fuse can handle such cut-off impulse currents with high amplitudes up to approximately 10 kA at a later ageing stage of the spark gap for a limited number of loads.

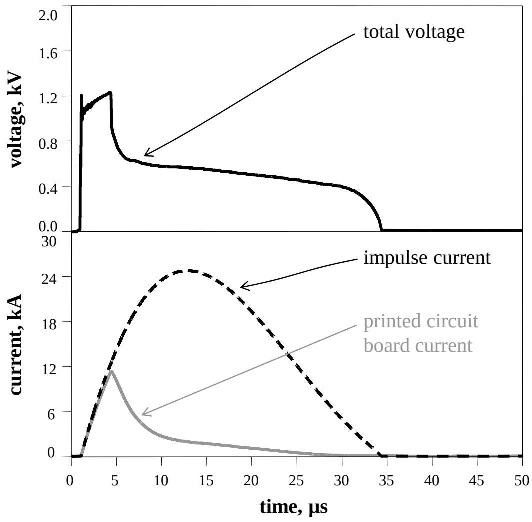

Fig. 9: Protection level of the arrester when loaded with 25 kA 8/20 µs and an aged spark gap ignites in the impulse front

Nevertheless, after several loads of this kind, the fuse element shows clear signs of ageing such as diffusion of the surface coating and diffusion on the solder contact as well as partial signs of melting at the surface of the fuse element. Figure 10 shows examples of fuse elements with such signs of ageing.

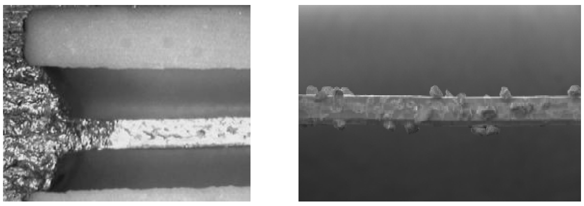

Fig. 10: Diffusion on the solder contact, diffusion and signs of melting at the surface of fuse element

If the load limit of the special fuse and/or the other elements of the trigger circuit is reached, the trigger circuit of the lightning current arrester is safely disconnected from the power supply. This is directly indicated by the status indication / transferred to a monitoring unit via a remote signalling contact.

Not only the spark gap is subject to ageing due to a high number of loads, but also the components of the trigger circuit. Both the gas discharge tube and the varistors can handle the loads individually, however, ageing cannot be entirely ruled out.

If the varistors fail due to ageing, a limited short-circuit might flow through the trigger circuit. The special fuse must safely handle this power-frequency fault current. Owing to the current-limiting disconnection of the power-frequency fault current by means of the fuse, the trigger circuit of the arrester is disconnected from the power supply. This is indicated by means of the indicator fuse.

3.3 Additional requirements

In case of very high impulse current loads on the arrester and/or extremely aged spark gaps, the load on the trigger circuit is significantly increased by the amplitude of the cut-off impulse current. If the fuse is loaded with a peak current value of approximately > 10 kA according to Figure 11, the fuse may already trip during the rise of the impulse current.

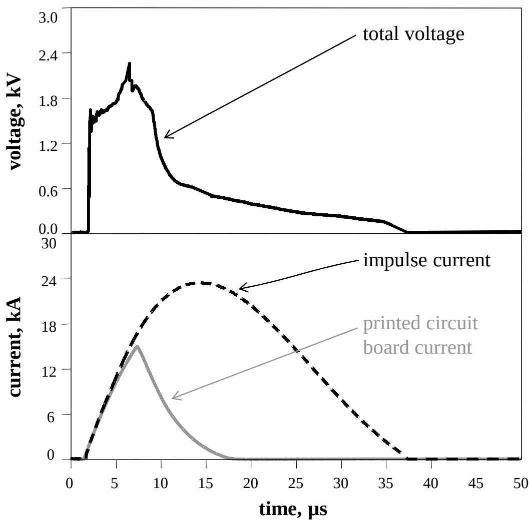

Fig. 11: Behaviour for a tripping fuse in case of an extremely aged spark gap

If in such cases the spark gap is not activated by the trigger circuit in due time, the spark gap is safely ignited by the switching voltage which occurs across the fuse during the disconnection process and which can reach high values of more than 2 kV. This is intended and is an "emergency operation function" for the arrester. The formation of a high switching voltage by means of the fuse in this case serves for the passive ignition of the spark gap which, as a consequence, safely discharges the impulse current.

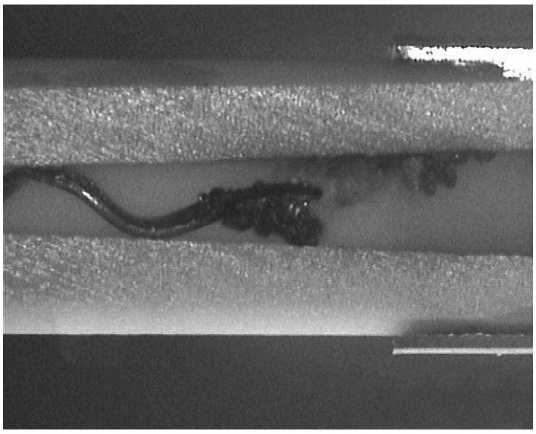

Fig. 12: Wave-shaped deformation of a fuse element after a high dynamic load with an amplitude of > 10 kA

If the fuse is loaded with these high current amplitudes, the fuse element does not melt any more due to an adiabatic current load, but it is mechanically broken due to the high dynamic force of the flowing impulse current. This is due to a repeated wave-shaped deformation of the fuse element (Figure 12). Where necessary, the exact breaking point can be influenced by means of an adequate design (predetermined breaking point) of the fuse element.

If the breaking point is not predetermined, the fuse element mostly breaks at the end where it is welded to the end caps and is already slightly bent due to the manufacturing process. During manufacture, the fuse element is mechanically processed (rolled) so that it is considerably reduced as soon as it breaks due to automatic twisting (like a corkscrew).

Very quick overload and ageing of the varistors in the trigger circuit might be caused e.g. by incorrect installation. In this process, the lightning current arrester is permanently exposed to extremely high power-frequency voltages. The components of the trigger circuit, however, are not designed for this values. In such a case the integrated fuse must safely disconnect the trigger circuit. Figure 13 shows the disconnection of the fuse for example in case of quick overload of the varistors.

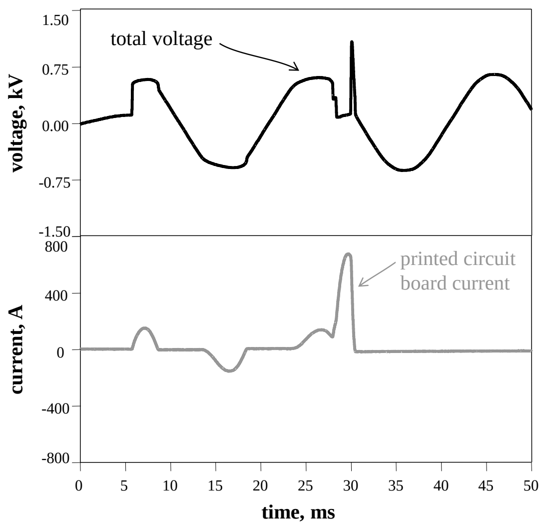

Fig. 13: Behaviour of the fuse in case of overloaded components

The passive spark gap is dimensioned so that surge protection is ensured with an increased voltage protection level (< 4 kV) even after the trigger circuit failed.

4. Summary

The trigger circuits used in spark-gap-based lightning current arresters are to be protected by means of a fuse. This special fuse has to fulfil special requirements due to the functional principle of the arrester. The fuse is supposed to show a defined behaviour both under normal mains conditions and in case of interference, overload e.g. due to incorrect installation and ageing of the individual arrester elements.

The parameters of the lightning current arrester such as lightning and impulse current carrying capability and voltage protection level must not be negatively affected by the fuse. Thus the special fuse must be able to carry small impulse currents several times and must be resistant to ageing at the same time. Furthermore, the fuse can safely handle high power-frequency currents also in case of an increased supply voltage.

For this reason, not only high values of the Joule integral and a high switching performance, but also a low-impedance and dynamically solid design were required. A solely mechanical status indication of the special fuse can be achieved by a parallel indicator fuse with spring-loaded striker.

To fulfil the high requirements, the fuse is provided with mechanical and insulating components. In addition, the special fuse was designed so that the switching voltage during the disconnection of the fuse is sufficiently high for a passive ignition of the spark gap in the arrester under certain fault conditions.

A specifically designed special fuse of type 5 x 20 mm with a slow-acting partial range characteristic meets these requirements.

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