Triggered electrical fuse

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***Abstract*—The increasing number of applications with short circuit current indicates that there is a need to development of new technologies in the field of fuse-based overcurrent protective devices. Several ideas to trigger fuses are already known. This paper presents technological investigations of the direct triggering of fuses. The goal is to propose a relatively simple function mechanism which allows the triggering of a fuse with low amount of auxiliary energy. Moreover, the device or the system protected by the fuse should be energetically protected efficiently against overcurrent and short-circuit current. The current which leads to the melting of the fuse-element and the subsequent current, until the final quenching of the short-circuit current or overcurrent, the so-called clearing integral (let-through integral, Joule integral) of the fuse should not lead to any damage of equipment installed downstream. The system bases on an easy way to start a sustained electric arc directly at the fuse wire. This electric arc cuts the fuse element. For the artificial creation of this electric arc, two additional contacts are integrated at one side of the fuse. This paper shows that it is successfully possible to trigger a fuse even during fault currents close to the rated current of a fuse. For the creating of the fuse-link-cutting arc only a relatively small amount of auxiliary energy is needed. The amount of overcurrent flowing through downstream equipment is reduced by using a special auxiliary circuit.**

***Keywords*— triggered fuse, modified NH-fuse, clearing integral, let-through integral, PV application,**

I. Introduction

Since the very beginning of electrification, fuses are used for the protection against overloads and short-circuits and are continuously being further developed. The compact design combined with the high and safe cut-off capacity guarantee economical protection of electrical systems and devices. Thus, fuses have been continuously adapted and optimized to the requirements of various electrical systems. Their field of application ranges from the smallest currents in the low-voltage and signal range up to high-current and high-voltage applications. Accordingly, the designs are manifold.

The aim of continuous development is to precisely match the components of the fuse link between sufficient robustness in rated current operation against ageing and unwanted and reliable and predictable operation in the case of an electrical fault. Both rated operation and tripping are considerably influenced by the ambient conditions. The ambient temperature is one of the main influencing factors. High ambient temperatures can lead to early ageing. The soldering regions of the perforation of the fuse element are particularly affected. At high ambient temperatures in conjunction with operating currents close to the rated current of the fuse, the diffusion process can start. Those pre-aged fuse-elements can lead to unwanted blowing of a fuse. Conversely, very low temperatures lead to delayed tripping in the case of an overload current. The correct selection of the fuse is particularly critical if there are high fluctuations in the ambient temperature.

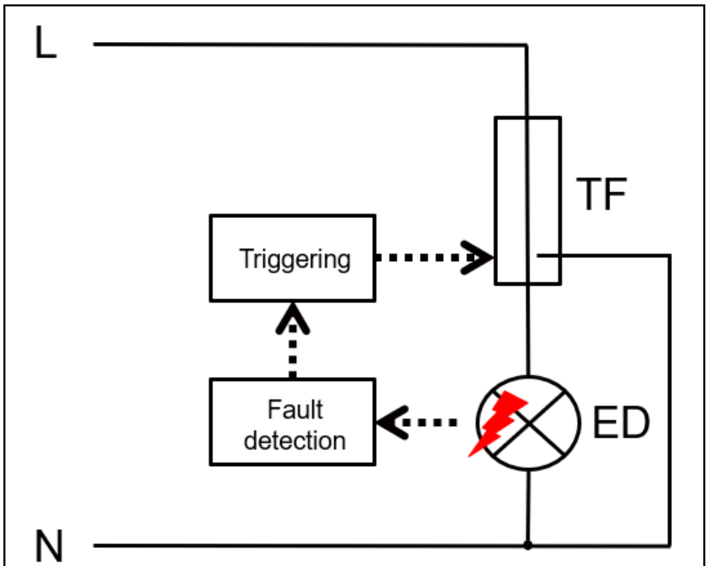

Fig. 1: Concept of protecting an Electrical Device (ED) against overload and short current including electrical relive by a Triggered Fuse (TF)

A very precise choice of the electrical parameters is necessary where systems have an undefined or strongly limited short-circuit current. For example, PV systems deliver short-circuit currents that are only approx. 10% higher than the current at the so-called "maximum power point". Many electronic power sources, in particular DC power supplies, are not able to produce overcurrent which are suitable for the reliable blowing of fuses.

Other electric devices have a limited ability to withstand overcurrents or short-circuit currents. Power semiconductors are highly utilized for economic reasons and operate in the range of the limit load. Such devices are usually not able to carry the let-through current of a fuse without destruction. The technology presented here may help to switch off an electrical fault early and to relieve the device located behind the fuse from passing through the fuse. Alternative energy production leads to electric storage systems which become more and more powerful. This also increases the demand for devices that switch off these sources quickly and safely in the event of an electrical fault or damage. Particularly in the field of e-mobility, high-performance and compact safety facilities are necessary.

From a technical point of view in some cases the alternative is to use molded-case circuit breakers (MCCBs) with adjustable tripping characteristic - instead of fuses. Adjustable MCCBs are capable to detect reliably overcurrents which exceed the rated current slightly. However, MCCBs are more expensive – in comparison to fuses und they need more space.

For the reasons mentioned above, it is frequently considered to find mechanisms which use the favorable operation characteristics of fuses, and to eliminates the disadvantages in certain applications. Many proposals have already been made and corresponding industrial property rights have been registered. Some are quite old as US 3256408 A, June 14, 1966, "Fuse having an auxiliary Arc-Transfer Electrode," [1] and US 2,400,408, May 14, 1946 “Electrical Circuit Breaking Fuse of the Controlled Operation Type,” [2]. Other current registrations are only a few years old, like DE 2012 000 339 U1, „Elektrische Abtrennvorrichtung, 2012-03-11 [3], and “Schmelzsicherungen für Niederspannungsanlagen,“ DE 10 2017 126 419 A1, 2017-11-10 [4].

A distinction can be made between purely mechanical solutions, pyrotechnic solutions, electrical heating systems and electrical short-circuiting systems which trigger the fuse by an active short-circuit current. A conclusion of several of those solutions are presented on ICEFA-Conference 2015. Herbert Bessei, Felix Glika "Smart Fuses for Smart Grids" [1].

The function principle presented in the paper is based on the generation of an active short circuit, as described in by Mitja Koprivšek, ICEFA-Conference 2015, "Triggered Fuse," for example. In contrast that triggered fuse by Mitja Koprivšek, the switching mechanism for generating the short circuit is very compact within the fuse and is based on the generation of an electric arc between an additional copper electrode and the fuse element itself. Only very low energy is required for initialize the electric arc. The internal structure of the fuse remains mostly unchanged, so that the properties are retained in comparison to an unmodified fuse. During the course of development, it has also been shown that a suitably designed short-circuit mechanism can "actuate" the fuse at overload currents in the range of the rated current of the fuse.

II. STRUCTURE OF THE TEST DEVICE

A standard NH fuse-link from Siemens 3NA3 132, NH1-gL/gG, 125 A was used for the testing. The fuse is first opened and disassembled avoiding changes to any parts. The installation of the additional parts increases the distance between the contacts blades. However, the increase in length is so little that the fuse element itself don´t have to be extended additionally for the tests. The fuse is subsequently refilled with sand and screwed together (Fig. 2).

According to the design, the fuse link now got two additional electrical contacts. A short-circuit current carrying copper plate (I) and an additional connection (H) made of a copper-coated substrate for printed circuit boards. Further insulation parts are used for internal insulation of the short-circuit current carrying copper sheet and for mechanical fixing of the construction. The unmodified side of the fuse is used to supply the operating voltage from the mains. The second connection on the modified side contacts the device or system to be protected. The first additional contact is the copper plate. In the tests it is connected to the neutral conductor

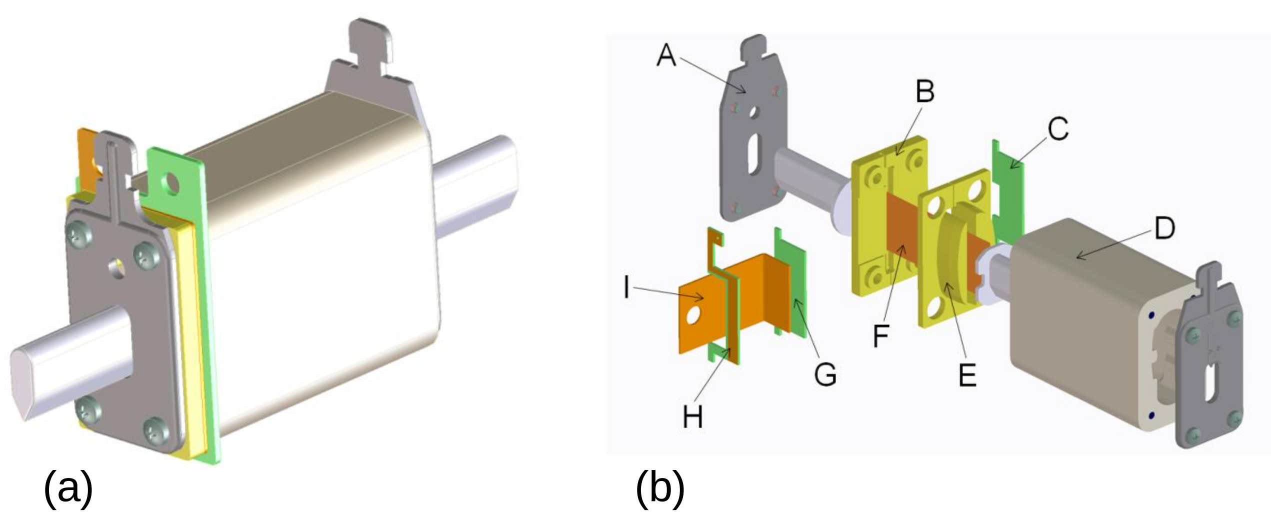

Fig. 2: Structure of the test device. (a) A common NH fuse link is modified with two additional connections. (b) The exploded view shows all single components and their assembly. A housing cover, B POM isolation, C and G FR4 isolation, D ceramic housing, E POM isolation, F fuse element, H ignition, I neutral potential connector

parallel to the device to be protected. The second contact is the ignition contact. The trigger signal is supplied via this connection. Pulse currents or currents from the mains can be used as trigger signals.

The trigger signal applied to the contact H generates an arc between the fuse element F and the copper plate I. The then flowing unlimited short-circuit current feeds the arc and blows the fuse. In the case of currents in the overload range of the fuse two effects overlap. On the one hand, the fuse element is heated by the current as it's heated up during an ordinary overload event. The soldering point diffuses in and leads to the well-known disconnection. On the other hand, the electric arc between the fusible conductor and the copper sheet creates additional heat. At the same time the arc burns off the fusible conductor. This effect of burning off the fusible conductor due to the arc can also be used with currents that are considerably lower than nearly unlimited short-circuit currents. The tests show that prospective short-currents in the range of the rated current of the main fuse (5) still lead to an interruption of the fusible conductor of the main fuse (5).

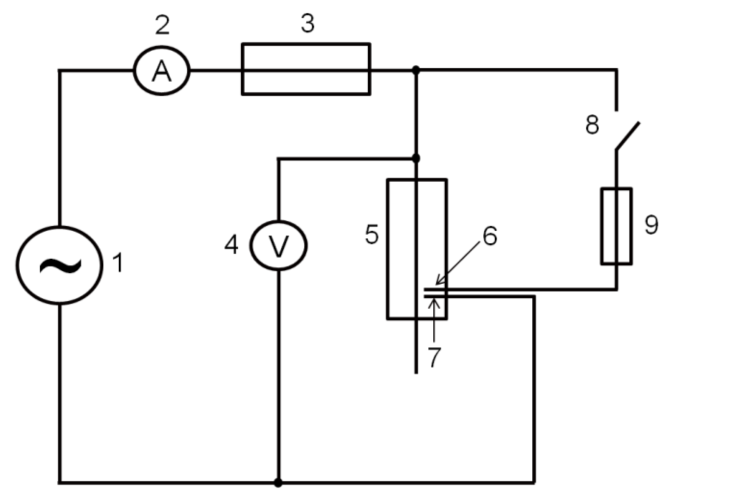

Fig. 3: Circuit diagram of the test setup with generating the trigger from the net energy. 1 mains power net, 2 current measurement, 3 backup fuse, voltage measurement, 5 DUT, 6 ignition plate, 7 copper bypass, 8 opening switch, 9 micro fuse

III. MEASUREMENTS

The test setup is shown in Fig. 3. The voltage source (1) supplies a voltage of 440 V AC to a low-impedance network. The prospective short-circuit current is 50 kA, the cosPhi 0.25. The current is measured using Pearson Coils (2), the voltage (4) with probes connected to a Bitgate Measuring System. In case of an electrical failure of the device under test, there is an additional NH fuse (3), with a current rating of 400 A, in the test circuit as a back-up fuse.

In the first experiments the trigger is started by a high voltage pulse 8/20 µs which can be variably synchronized to the 50 Hz AC -Voltage. This impulse trigger source is placed instead of the elements 8 and 9. For further experiments the circuit according to Fig. 3 is used to trigger the fuse. The ignition circuit from elements 8 and 9 applies the operating voltage to the ignition electrode at the time to trigger. The arcing process starts immediately, and the ignition current is fast interrupted by the micro fuse of 2 A (9).

Fig 4 shows the time-dependent current and

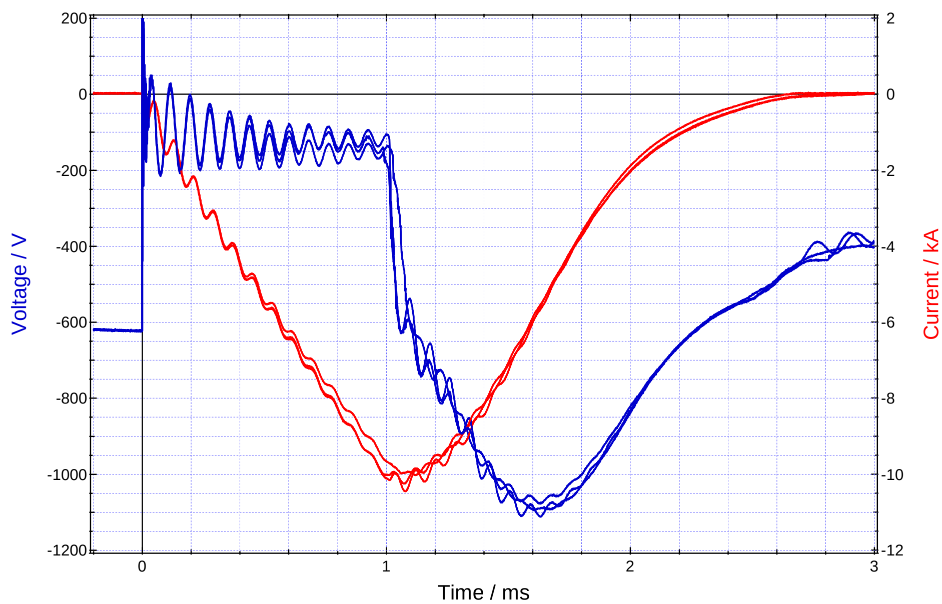

Fig. 4: Voltage and current data from three DUTs while blowing the fuse. The system parameters are U = 440 V and Ip = 25 kA (cosPhi = 0.25). The DUTs are triggered at 0 ms at the maximum negative voltage. After approx. 3 ms the current returns to zero and isolation has achieved.

voltage values during the triggered switching-off of three identical DUTs. At a time of 0 milliseconds, the triggering is started by the high-voltage pulse at the maximum voltage of the negative half-wave. Due to the very short duration of the pulse, it can only be recognized as a line in the positive direction. Immediately after ignition at 270°, the voltage collapses. The residual voltage consists of the arc voltage and the voltage drop across the fuse element. After approximately one millisecond, the melting integral of the fuse element is reached, and the voltage then returns with a corresponding overshoot. At the same time, the current drops to zero and the voltage returns to the sinusoidal voltage. The figure shows that the three test specimens behave identically.

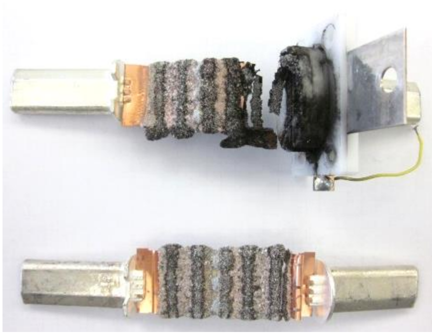

Fig. 5: Comparison of the tripped fuse elements of a triggered fuse link (up) and a fuse element of an unmodified fuse link (down)

The three DUT´s of modified fuse links were mechanical stabile under test conditions and show no abnormal behavior. To analyze the difference of the inner mechanism of the provided technology of these triggered fuses and the normal blowing of that fuse at unlimited short current, the three DUTs got opened. Fig. 5 shows the separated fuse element of the triggered fuse in comparison to the separated fuse element of an unmodified fuse of the same model (Siemens 3NA3 132, NH1-gL/gG, 125 A). The unmodified fuse link has been tripped under equal conditions regarding the mains power source. The comparison show that triggered fuse element also interrupts at the restrictions. Only there the cupper plate at neutral potential is located to the fuse element, the triggered arc destroyed the fuse element totally.

The measurement of the isolation resistance with 440 V DC at the triggered and tripped fuse-links proofs sufficient isolation resistance greater 20 MOhm.

In further tests, the short-circuit current is strongly limited. Tests with 1000 A, 500 A, 200 A, and 100 A show that significantly longer current flow occurs with decreasing rated short-circuit current before the current is interrupted by the modified fuse. Remarkable is that even at 100 A it was possible to blow the fuse link that had a nominal current of 125 A. Fig. 6 shows the time-dependent current and voltage values during

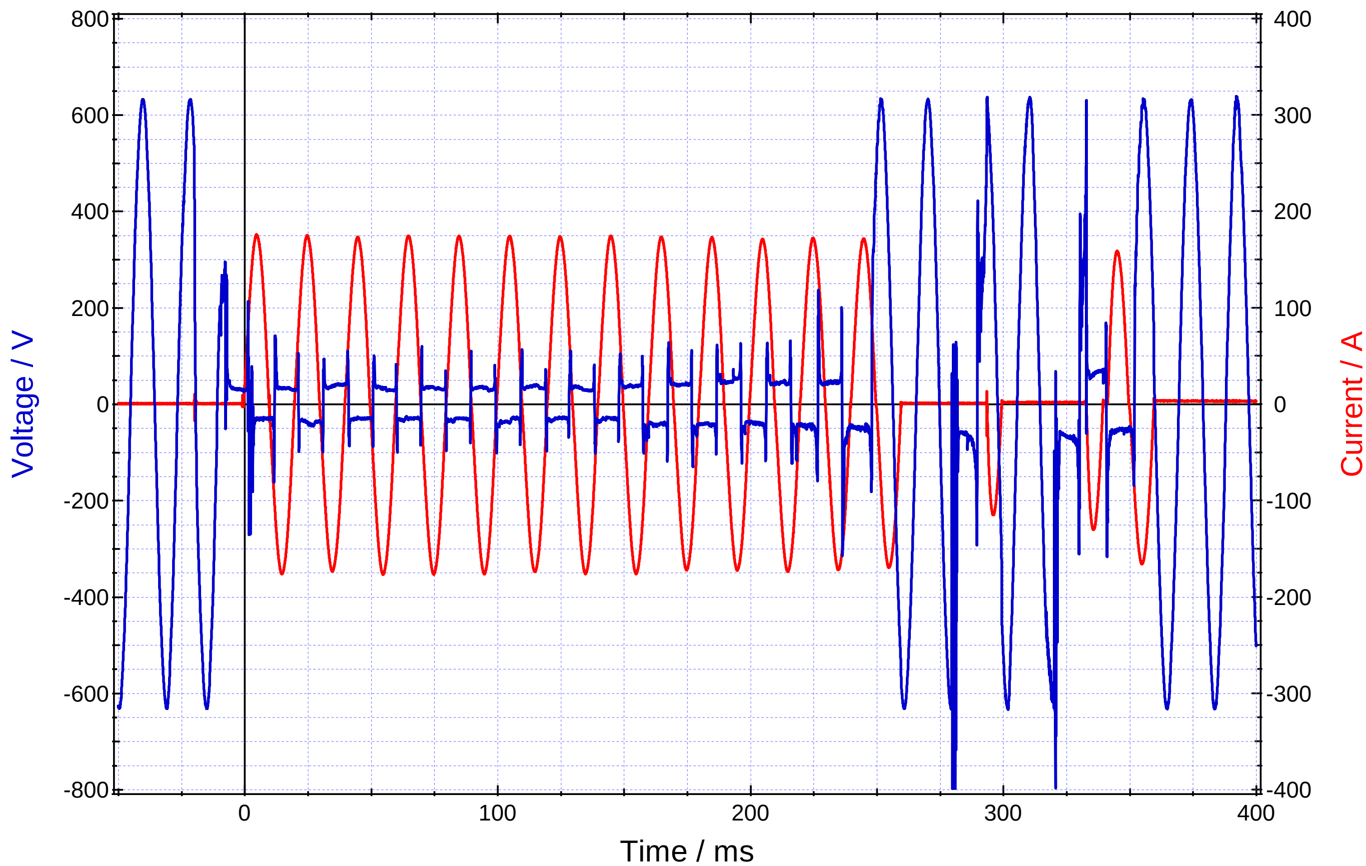

Fig. 6: Voltage and current data from a test with Ip = 100 A and V = 440 V. At the time 0 ms the fuse is triggered, and the current starts to flow. After 350 ms the current is interrupted.

the triggered switch-off. After triggering, it takes about 350 ms until the fuse is finally cleared. After approx. 270 ms, the current is zero ampere for the first time. Subsequently two re-ignitions appear. After that, the fuse remains permanently isolating, even after the period shown in Fig 6.

The following Fig. 8 shows one of the fuse elements after it is blown up at 100 A in the test after approx. 350 ms. Obviously, at the fuse-element and its restrictions there are no mechanical or thermal changes visible. Even the restriction with soldered points is not activated, as it is expectable at 100 A. Just the region where the triggered arc works the fuse-element is destroyed and disconnected.

Further measurements of the isolation resistance were done at 440 V DC. The resistance of the modified fuse-links after they blow up differs in a wide range. Fig. 8 shows the wide variance. Just for orientation the average of 190 kΩ is marked in the diagram.

The large variance of the measured values is unsatisfactory. Even if it has not got tested, these samples would probably not pass the testing according DIN EN 60269-1. The reason for the poor insulation values after triggering can be decomposition products of the materials used.

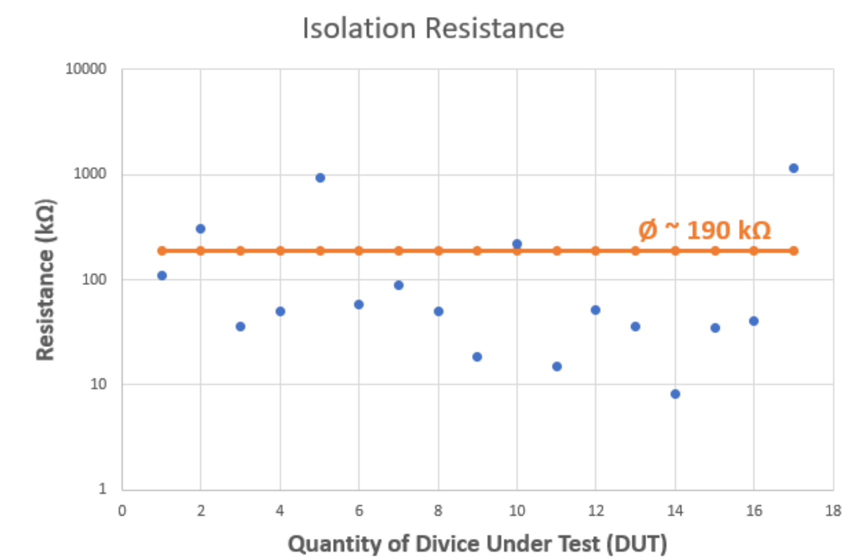

Fig. 8: Variance of isolation resistance of blown triggered fuses measured at 440 V DC

Fig. 8 shows the arc-separated portion of the fusible conductor. The fusible conductor no longer has any metallic connection. The area of the separation point has a fouling of carbon, which is due to degradation products of insulation materials. The carbon probably leads to the resistive conductivity.

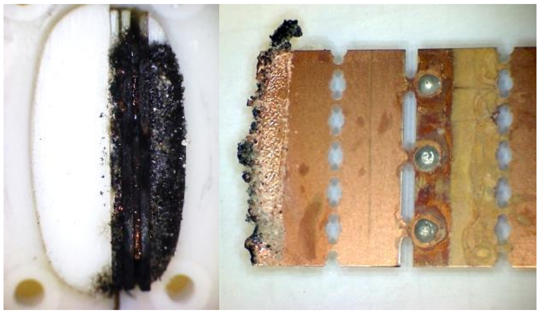

Fig. 7: Breaking area of a tripped fuse elements of a triggered fuse link at a current of 100 A after approx. 350 ms

IV. Conclusion

The presented technology offers the possibility of triggering fuses with comparatively low energies and blows them reliably. On powerful networks, the modified DUTs behave like normal fuses. The function is maintained even with currents in the overload range. With very limited currents, the tripping is successful even below the rated fuse current value. Further investigations are necessary, as in particular to improve the insulation resistance values. The aim should be to pass testing based on DIN EN 60269-1.

Patents:

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