Ehrhardt, Arnd; Wolfram, Sven:

Switchgear combination of pyrotechnic switch and fuse

DOI: 10.22032/dbt.51521

URN: urn:nbn:de:gbv:ilm1-2022200070

Original published in: 30th International Conference on Electrical Contacts : 7-11 Juni 2021, Online, Switzerland : proceedings / Weichert, Hans (ed.). - Fehraltorf : Electrosuisse, 2021. – S. 157-161.
(International Conference on Electrical Contacts (ICEC) ; 30 (Online) : 2021.06.07-11)

Original published: 2021-06-09
ISBN: 978-3-907255-11-7
DOI (Proceedings): 10.5281/zenodo.4917120
[*Visited:* 2022-02-16]

Switchgear Combination of Pyrotechnic Switch and Fuse

Arnd Ehrhardt, DEHN SE + Co KG, Hans-Dehn-Straße 1, 92318 Neumarkt, Germany, arnd.ehrhardt@dehn.de

Sven Wolfram, Technische Universität Ilmenau, Gustav-Kirchhoff-Str. 1, 98693 Ilmenau, Germany, s.wolfram@tu-ilmenau.de

Abstract

The article presents the combination of a low-voltage fuse with a pyrotechnic switch in a compact design. Different circuit concepts will be discussed, and their scope of application demonstrated with the aid of simulations and experiments based on two sample arrangements. Besides having a passive over-current protective characteristic, both arrangements allow active triggering and fast disconnection. The protective behaviour of both variants from the over-current to the short-circuit range is described for purely passive behaviour and especially for active triggering.

1 Introduction

The massive modification of power supply networks, which is currently underway among other places new demands on over-current protective devices. As numerous power generators feed electricity into the grid, the flow of power in the distribution network is no longer just unidirectional, but frequently bidirectional. The source characteristics of numerous electricity generators and new regulating mechanisms for controlling power flow reduce short-circuit currents in the grid. Both effects influence the tripping conditions for over-current protective devices in the power grid.

Fuses have the advantage over switches of being smaller whilst possessing a very high short-circuit breaking capacity, strong current limitation as well as a corresponding-low total clearing integral. Both, ambient temperature and the installation conditions are impacting the tripping behaviour of fuses, especially under small over-currents. This effect may yield to critical clearing times in modern networks with high content of renewables producing low short circuit currents. Koprivsek [1] proposed a short circuiter integral to the fuse to enhance the maximum fault current. However, this requires conventional networks with a high short-circuit power. A summary of different approaches is provided in [2].

Switches, on the other hand, generally have the advantage that the over-current characteristics are easily adjusted and can be remotely controlled. However, in networks with active power control, the passive protective characteristic of over-current protective devices often only plays a role when this control function fails. This means that in such cases, similar to with high short-circuit currents, the one-off switching function in combination with external controllability is adequate.

The design targets for our own concept of a simple "one-off switching device" for low-voltage applications (nominal voltage 230 V AC) were:

a) high passive short-circuit breaking capacity
b) full-fledged time/current characteristic of an over-current protective device
c) additional external triggering feature with a disconnection time less than 30 ms
d) high dielectric strength after disconnection
e) high capacity to carry impulse current, especially lightning currents (25 kA 10/350 µs)
f) nominal current up to approx. 250 A

A simple series connection of a fuse and a switch was selected for the test arrangement. The switch is integrated into the fuse.

In the first experiments, this basic concept is examined in detail in two different test arrangements. The two test arrangements differ, especially with regard to the function and arrangement of the switches.

2 Configuration and components of the test arrangements examined

Both test arrangements were set up on the basis of the individual parts of a capsule fuse size 22 x 58. The arc quenching medium selected was conventional compacted silica sand. To achieve the desired high impulse current resistance, two parallel copper fuse elements with modulation were routed, as far as possible, straight through the housing. The nominal current of the double fuse element is 250 A. The fuse can carry lightning impulse currents with an amplitude of 25 kA (impulse shape 10/350 µs with I^2t = 156 kA^2s). Thus, a configuration was selected by which the nominal current and impulse current are at the upper limit, resulting in maximum requirements on the switching capacity. Realisation of the active switching function was achieved by integrating a very simple pyrotechnic switch in a fuse filled with silica sand.

2.1 Structure and description of the test samples according to test arrangement 1

Figure 1 shows the principle structure of a test sample according to test arrangement 1. The pyrotechnic switch for radially cutting the fuse element with the aid of an insulated cutting blade is located in the middle of the fuse. The sand-filled part of the fuse link (fuse part) is split into two sections. Each of the two fuse parts holds half the restricted sections of the fuse element required to disconnect the short-circuit current.

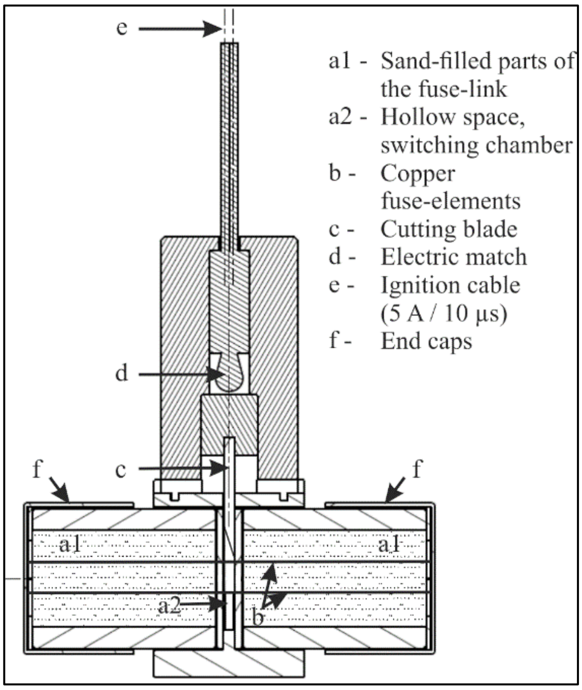

Fig. 1 Test sample according to test arrangement 1

Between the fuse parts a1 is a hollow space a2 through which the fuse elements b are guided. In this chamber, the fuse elements have an additional restricted section, which is dimensioned in such a way that it does not trigger at the usual total clearing integral of the fuse when short-circuit currents are interrupted. A single fuse element with such a restricted section in the centre is shown in **Figure 2a**. This special restricted section does not melt in the entire time/current range with the usual passive function of the fuse. It merely reduces the power required for cutting.

The time/current behaviour of the sample arrangement was simulated with FEM calculations of transient impulse current loads up to 1 h current. **Figure 2b** shows the temperature rise of the fuse element when impulse current flows through it [3]. A simple simulation model for optimising the cutting blade, the force required and the stroke path is shown in **Figure 2c**. To determine the separation distance, the model is supplemented with the walls of the hollow space a2 in addition to the blade and the fuse element.

An insulated cutting blade is guided in the hollow space between the two fuse parts and cuts through the special restricted section when the electric match is actuated. The fuse parts with silica sand filling are separated from the hollow space by a wall thinner than 1 mm in such a way that no quenching agent can penetrate the hollow space. This ensures that the force required to operate the cutting blade is low. The total width of the hollow space is narrower than 5 mm. When the cutting device is actuated, the severed fuse elements are crushed between the insulated blade and the walls made of insulating material which separate the fuse parts. This results in the arrangement of an isolating gap switch for the arc that may arise. If the intrinsic switching capacity of the pyrotechnic switch is exceeded, an arising arc can extend along the fuse element to the fuse parts filled with silica sand. In this case, the arc is also safely quenched.

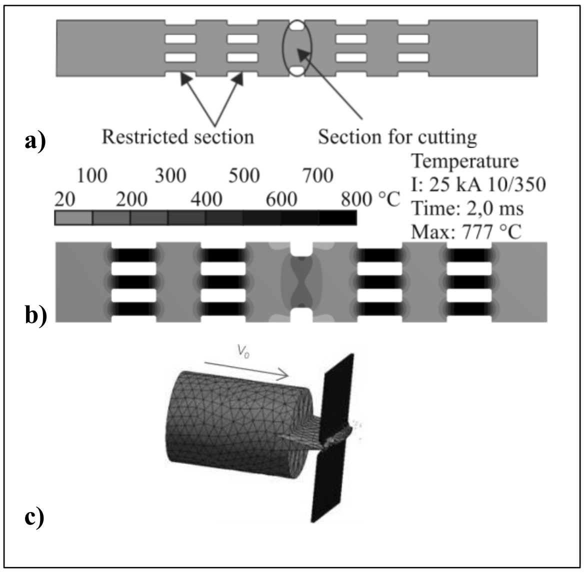

Fig. 2 **a)** Fuse element with additional restricted section
b) Calculated maximum temperature at 25 kA, pulse shape 10/350 µs
c) Simulation model of the cutting process

2.2 Structure and description of the test samples according to test arrangement 2

The housing of the sample fuses was split into two cavities. In the first cavity of the switching chamber, the fuse elements are surrounded by silica sand. All the restricted sections of the fuse elements can also be found in this cavity. There is no silica sand in the second cavity and the cross-section of the fuse elements there is undiminished. The two cavities are separated by a plate through which the fuse elements are loosely routed. In the cavity with no silica sand, the fuse elements are fixed to a moving piston. The piston can be moved axially by several millimetres within the housing by an internal electric match. When the piston moves, both fuse elements break, and a separation point is formed in the fuse element within the switching chamber which equals the stroke length of the piston and is surrounded by silica sand. The parts of the fuse elements moved by the piston are deformed in the cartridge without silica sand.

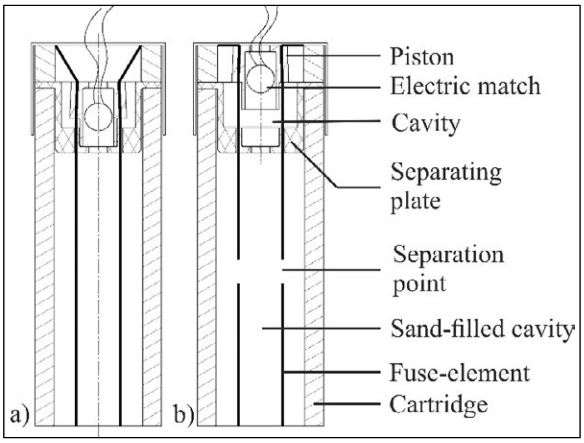

Fig. 3 Sample fuse according to test arrangement 2
a) in normal state
b) after active disconnection

The arrangement in the cavity without silica sand thus corresponds to a switching mechanism. The fuse and the interruption section of the "one-off switch" are both located in the cavity filled with silica sand. **Figure 3a** shows such a basic arrangement in the conductive, or rather, normal state. **Figure 3b** shows the state after movement and breaking of the fuse elements following an active actuation of the electric match. Several measures are necessary to achieve a defined separation point and a defined isolating distance in minimal space. The tensile force acts on all restricted sections of the entire fuse element. Taking into account the heating up of the fuse element at nominal current and overcurrent, there is a considerable expansion in the order of several millimetres before the fuse element interrupts. The interruption takes place at one of the defined restricted sections of the fuse element. **Figure 4a** shows the elongation (> 6 mm) calculated for one of the two fuse elements with restricted sections without a temperature rise before breaking. If, for example, an isolating distance of 6 mm is to be reliably achieved in addition to tearing, a linear stroke of more than 12 mm is required. To combat these disadvantages, a further restricted section is introduced in the fuse elements, see **Figure 4b**. This additional restricted section has a much lower residual cross-section than the other restricted sections. It is, however, very short. This design means that the elongation required to break the fuse element under force is very small and is almost entirely limited to the additional restricted section. The stroke of the piston is, therefore, almost identical with the minimum isolating distance.

The force required to break the restricted section can be reduced by more than a third. The influence of the additional restricted section on the time/current characteristic and the switching behaviour of the fuse is therefore imperceptible.

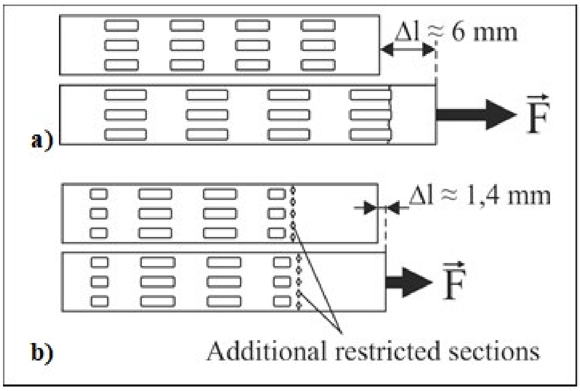

Fig. 4 **a)** Calculated change in length up to elongation fracture
b) Calculated change in length up to elongation fracture with additional restricted sections

Figure 5a, 5b show the rise in temperature in the restricted section when loaded with impulse current in comparison to one of the other restricted sections. The characteristic allows this restricted section to be positioned almost anywhere in the fuse elements. However, the additional restricted section should be far enough away from the plate separating the cavities with and without silica sand to ensure that, when activated, the safe interruption of overload currents is possible in a single break.

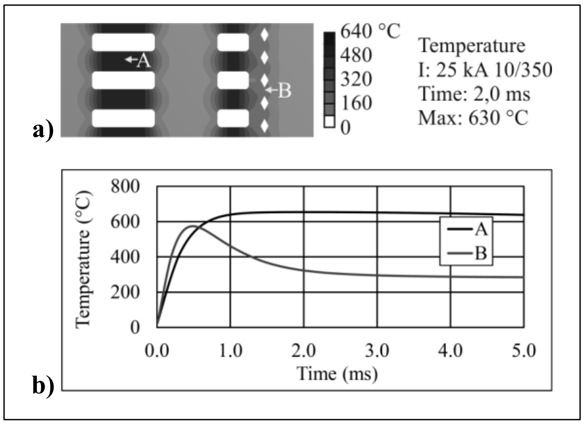

Fig. 5 **a)** Calculated temperature distribution (°C) at the fuse-element after 2 ms at 25 kA, pulse shape 10/350 µs
b) Calculated temperature/time curve for points A and B

3 Mode of operation

3.1 Passive operation

The time/current characteristic of the model configuration according to test arrangements 1 and 2 was simulated with FEM calculations of transient impulse current loads of up to 1h current. **Figure 6** shows the temperature rise of the fuse element with the additional restricted section as per test arrangement 2 in case of an overload current with a pre-arcing time of approx. 30 ms.

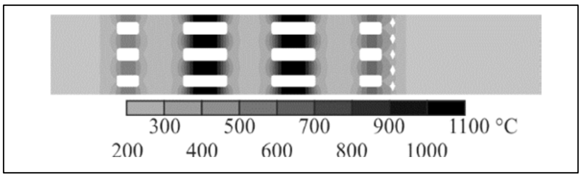

Fig. 6 Calculated temperature rise (°C) after 30 ms at I_P = 3 kA

Figure 7 compares the calculated and experimentally determined time/current characteristic in the current range from approx. 600 A to 50 kA. The curves of time/current behaviour are almost identical for both test arrangements. Figure 7 also shows the time/current characteristic of a conventional NH fuse.

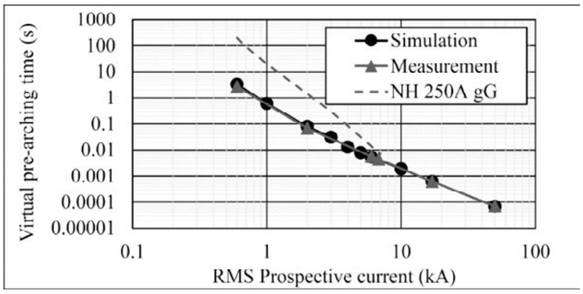

Fig. 7 Comparison of the measured with the calculated passive time/current characteristic

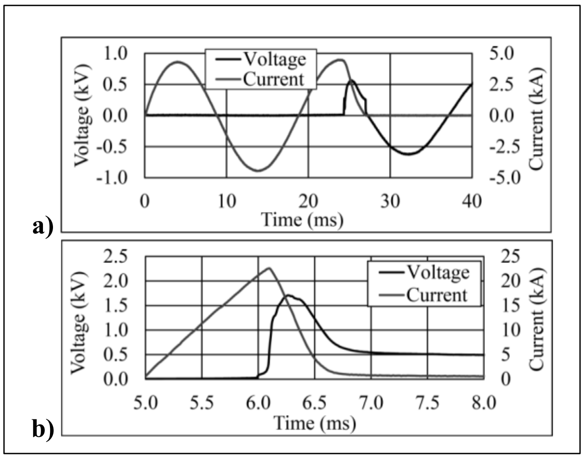

Fig. 8 Measured voltage/current curve at:
a) I_P = 3 kA (U_C = 440 V; $\cos\varphi$ = 0.87)
b) I_P = 50 kA (U_C = 440 V; $\cos\varphi$ = 0.23)

There is a sufficiently good congruence between simulation and measurement in both test arrangements. The passive switching behaviour with test samples of test arrangements 1 and 2 was examined at 440 V in the current range of 600 A to 50 kA. **Figure 8a** shows the current and voltage curves at a prospective load of 3 kA and **Figure 8b** at 50 kA for test samples of test arrangement 2. With regard to the passive switching behaviour, the two examined test arrangements 1 and 2 hardly differ, so that a separate representation has been omitted.

3.2 Active operation

In addition to the passive operation, the operation of functional samples of test arrangements 1 and 2 with active control of the pyrotechnic switch in the event of overload currents was also investigated. Here, the triggering time T_{Delay} and the time until both fuse elements break T_{PreArc} are relevant. The sum of both times is the whole time delay T_V. This time determines the maximum current load that must be mastered with active triggering. If the passive melting time is shorter than the delay time, the fuse switches purely passive. In the event of short-circuit currents, several or all restricted sections of the fuse elements respond. In this case, an active shutdown is not necessary and also not sensible. The triggering time must therefore not be less than 20-30 ms. At the same time, this enables safe fault detection and evaluation with a low error ratio and is fast enough for many applications.

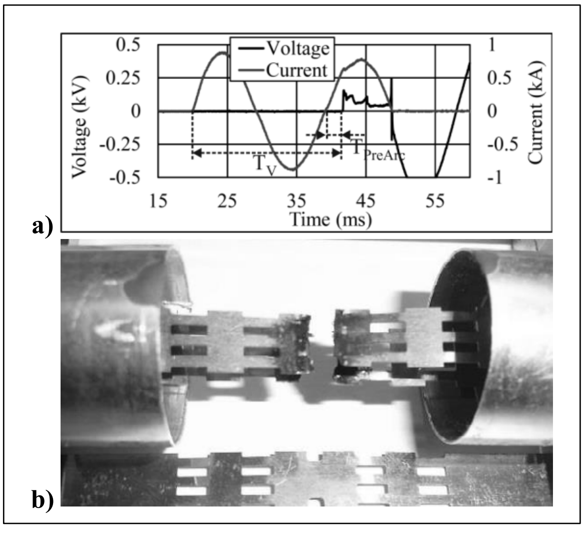

Fig. 9 **a)** Measured voltage/current curve at I_P = 600 A (U_C = 440 V; $\cos\varphi$ = 0.92)
b) Burn-off area after disconnection

Figure 9a shows the disconnection of a current of 600 A for a sample of test arrangement 1. The current load of 600 A is switched off by the switch itself as a result of the current zero. In **Figure 9b** the burn-off area is small and without silica sand residue. **Figure 10a** shows the disconnection of a current of approx. 3 kA for a sample of test arrangement 2.

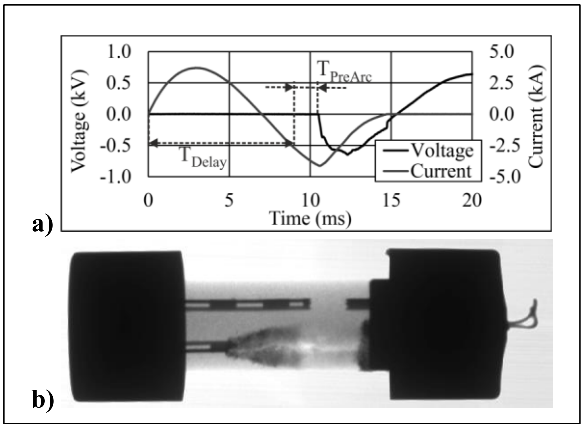

Fig. 10 **a)** Measured voltage/current curve at I_P = 3 kA (U_C = 440 V; cosφ = 0.86)
b) X-ray photograph after disconnection

As a basic principle, short-circuit currents of about 3 kA and higher are only switched passively in the given test configuration. For the test in Figure 10a, the arrangement had already been modified to allow accelerated operation. The test current in Figure 10a and the switching capacity achieved for the sample fuse therefore exceed the maximum capacity required. The X-ray photograph in **Figure 10b** show the basic behaviour of the fuses in test arrangement 2. Due to the rapid pulling movement, an arc is only generated in the fuse element which disconnects last. This arc is also rapidly extended by the movement, whereby the fulgurite contains few electrically conductive particles (bright).

4 Discussion of the results

In **Figure 11** the realistic active curve of the model fuse alongside the passive time/current characteristic for both test arrangements is shown. This diagram clearly shows that safe disconnection is possible within a total current range more than 30 ms using the configuration examined. In case of a longer tripping delay or lack of activation / high short-circuit currents, the configuration has the time/current behaviour of the fuse.

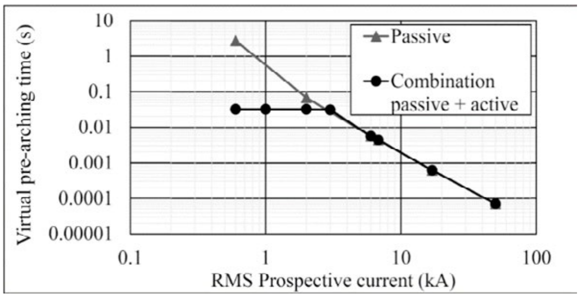

Fig. 11 Time/current characteristic of the switch gear combination

The switching capacity of the simple pyrotechnic switch and combination with the passive protective characteristic of the fuse thus allow safe and uninterrupted operation of the series connection in both active and passive mode of operation in both arrangements.

After the switching loads which were mastered by active and passive functions, the rated impulse withstand voltage was tested for the model configuration [4]. This revealed that in case of active tripping the impulse withstand voltage was always more than 6 kV, regardless of the current load. The tested sample arrangement thus reliably prevents a renewed current flow through the fuse even at higher voltages after disconnection.

A sufficiently precise simulation of the time/current characteristic of the fuse element could be achieved for both test arrangements examined. The mechanical interruption at the additional narrow point of the fuse element by cutting (arrangement 1) and pulling (arrangement 2) can be optimized through simulation. The two test arrangements examined offer the opportunity to achieve the self-defined objectives a) to e) such as listed in section one (introduction).

5 Summary

It has been demonstrated that higher switching capacities and lower clearing integrals, similar to fuses of comparable size, can be achieved via the additional “triggering” function. The disconnection time when controlled externally is comparable with that of remotely operated switching devices. In case of failure of the triggering function, the fuse still at least fulfils the standard protective function of a normal passive fuse against over-current and short-circuits. In addition, the test arrangements can conduct high transient impulse current without interruption. Safe, active disconnection is independent of the current load, i.e. from zero current up to the short-circuit current range, whereupon a higher and more defined withstand voltage is achieved than with passive fuses. The active triggering function can be implemented using simple monitoring devices and without an additional power supply.

6 Literature

[1] Koprivsek, M.: Triggered fuse. In 10th ICEFA, Sept. 2015, pp 69–78

[2] Bessei, H.: Smart fuses for smart grids: Considerations about the need, potential product features and feasibility. In 10th ICEFA, Sept. 2015 pp. 79–86

[3] Rochette, D.: Modelling of the pre-arcing period in hbc fuses including solid-liquid-vapour phase changes of the fuse element. In 64th IEEE Holm Conference on Electrical Contacts, September 2007, pp. 87-93

[4] IEC 60664-1 Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests, 2007