Low voltage fuse with additional activation function

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***Abstract*—The article will present a low voltage fuse with an additional activation option which enables a rapid cut-off when the appropriate signal is given. The fuse has a classical passive time/current characteristic and a high switching capacity. The additional activation option makes it possible to change the characteristic, not only with nominal current or slight overcurrent, but even with medium short-circuit currents. FEM calculations demonstrate the functional principle and the passive and active characteristics of functional models will also be presented. The switching behaviour with different overcurrents in case of passive or active triggering will be discussed on the basis of the measuring results. The behaviour of such a fuse with high impulse currents will also be touched upon.**

***Keywords*--actor fuse, functional principle, low voltage fuse, smart fuse**

I. INTRODUCTION

The electrical fuse is the oldest existing overcurrent protective device. For more than a hundred years, the supposedly simple functional principle has been further developed for and adapted to the most diverse networks, consumers and protective objectives. The massive modification of the power supply networks which is currently underway also sets new requirements for fuses. As numerous power generators feed electricity into the grid at different points, the flow of power in the distribution network is no longer unidirectional, but frequently bidirectional. What is more, the source characteristics of numerous electricity generators and the new regulating mechanisms for controlling the power flow reduce the short-circuit currents in the grid. Both effects influence, among other things, the tripping conditions for overcurrent protective devices in the power grid. If one is to further uphold the protective requirements, not only the optimum configuration and selection of fuses is of interest, but also additional functions, for example active control.

Fuses have the advantage over switches of being smaller whilst possessing a very high short-circuit breaking capacity, and of strong current limitation as well as a correspondingly low total clearing integral. They are also inexpensive and do not blow out ionised gases. In case of undefined, changing and small overcurrents or short-circuit currents produced in the grid by the changes described, there is a danger that the tripping time will be either too long or undefined. The benefit of some complex switches is that the overcurrent characteristics are easily adjusted and can be remotely controlled. This controllability via additional monitoring devices makes relatively quick clearing possible, even in case of faults which do not immediately result in high short-circuit current and in networks with little difference between the operating and short-circuit current. However, in networks with active power control, the passive protective characteristic of overcurrent 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 single switching function in combination with external controllability is adequate.

For a long time now, measures have been available for fuses to accelerate the disconnection of small currents. These include exothermic masses which passively or actively heat the solders of fuse-elements or directly heat partial areas. Such procedures can significantly reduce the natural pre-arcing time but, unlike with switches, they cannot achieve disconnection within just a few 10 ms. Speeding up the disconnection of fuses by way of a short-circuit is also a well-known method of achieving rapid disconnection after the short-circuit [1]. However, this requires conventional networks with a high short-circuit rating. Bessei [2] provides a summary of different approaches.

The objectives of our own concept on a special fuse for low-voltage were:

- adequate time/current characteristic of a low-voltage fuse without additional activation
- high passive short-circuit switching capacity in line with that of a low-voltage fuse
- integration of remote activation with a disconnection time < 30 ms
- high impulse current carrying capacity, especially lightning impulse currents
- nominal current up to approx. 250 A and nominal voltage 230 V AC

FEM simulations were a helpful aid in realising the above-mentioned concept. These determined the geometries and materials later used in experiments. The time/current characteristic was also simulated in advance.

In order to realise the required adequate time/current characteristic of the “passive” low-voltage fuse in combination with a high impulse current withstand capability, transient electric-thermal coupled simulations were conducted using the finite element method ANSYS [3], [4]. Configuration and components of the solution approach examined.

The model solution was set up on the basis of the individual parts of a capsule fuse size 22x58. Although this fuse size is marginal in terms of the values strived for regarding the nominal current, the switching capacity and the nominal voltage, this basis allows a realistic assessment of the physical limits and the construction volume actually required for later realisation.

The arc extinguishing medium selected was compressed silica sand whose grain size was normal for fuses of this size but which had a reduced fine-grain content. To achieve the desired high impulse current carrying capacity, two parallel copper fuse-elements with modulation were routed, as far as possible, in a straight line through the housing. The nominal current of the double fuse-element is in the range of 250 A. The fuse can carry lightning impulse currents with an amplitude of 25 kA (waveform 10/350 µs with $I^2t = 156\ kA^2s$). In this way, a configuration was chosen which lies at the upper limit for both the nominal current and impulse current and therefore meets the highest demands in terms of the breaking capacity. This ensures applicability for lower values in a construction of the same size or the same values in a larger construction.

The housing of the sample fuses was split into two cavities. In the first cavity, 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 divided 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 by several millimetres in axial direction within the housing by an internal electric match. When the piston moves, both fuse-elements break and separation points are formed in the fuse-elements which equals the stroke length of the piston. The areas of the fuse-elements moved by the piston are deformed in the cartridge.

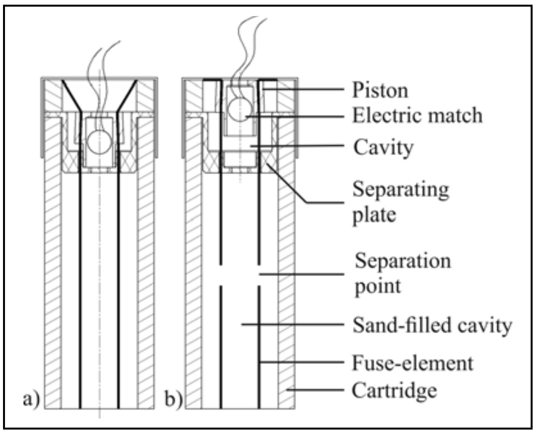

Figure 1. Principle design of the fuse-link; **a)** initial state; **b)** after breaking of the fuse-elements.

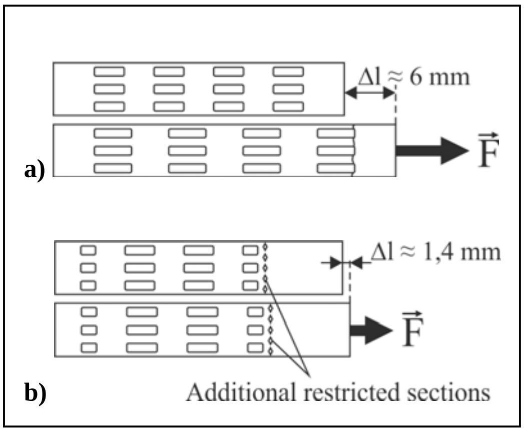

Figure 2. Calculated change in length up to elongation fracture **a)** without additional restricted section; **b)** with modified fuse-link and additional restricted section

Fig. 1a shows such a basic configuration in the conductive, or rather, initial state. Fig 1b shows the state after movement and breaking of the fuse-elements. Several measures are necessary to achieve a defined separation point and a defined isolating distance in minimal space. The isolating distance between the split fuse-element sections should be at least the stroke length and should meet the switching requirements and, where applicable, the required dielectric strength. As the tensile force impacts on the fuse-element as a whole and on all the restricted sections in the row, also taking the temperature rise of the fuse-elements with nominal and overcurrents into account, a considerable elongation of several millimetres occurs before the fuse-element is expected to break.

Fig. 2a shows the elongation calculated for one of the two fuse-elements with restricted sections without a temperature rise before breaking. Besides taking up a lot of space, this requisite elongation also leads to requirements relating to the force necessary and the time it takes to provide it. What is more, the break can occur at almost any of the restricted sections of the fuse-element. To combat these disadvantages, a further restricted section is introduced in the fuse-elements in the cavity filled with silica sand. 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.

Fig. 2b demonstrates the elongation on an appropriately modified fuse-element. Due to the short execution of the additional restricted section, the rise in temperature in this restricted section in case of nominal current, short-circuit current and even impulse current of waveform 10/350 µs is lower than that in the other restricted sections. The additional restricted section, therefore, has little influence on the time/current characteristic of the fuse. The additional restricted section also barely changes the switching behaviour.

Fig. 3 shows the rise in temperature in the additional restricted section (Fig. 3 point B) when loaded with impulse current in comparison to one of the other restricted sections (Fig. 3 point A). This characteristic allows the additional restricted section to be positioned at almost any location 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. The model configuration was subjected to impulse current loads following the sequence laid down in the normative requirements for type 1 surge protective devices (SPD) [5]. The behaviour of such a model configuration with an impulse current load of 25 kA 10/350 µs was also tested. No signs of ageing were observed either during or after the loads. Fig. 3b shows how the restricted sections of a fuse-element look after the impulse sequence. The restricted sections have not been deformed by the force of the current in areas with high current density, they have not partly melted or been heated to such an extent that sand grains adhere to them. This uncritical behaviour corresponds with the results of the FEM calculation.

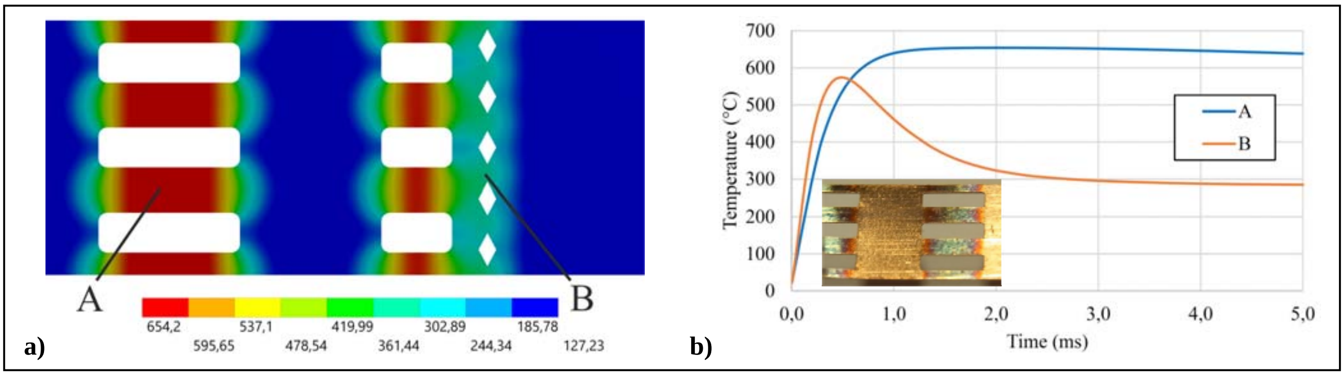

Figure 3. **a)** Calculated temperature distribution (°C) at the fuse-element after 2 ms at 25 kA 10/350 µs pulse; **b)** Calculated temperature/time curve for points A and B and restricted sections after current impulse

II. MODE OF OPERATION

A. Passive Operation

The time/current characteristic of the model configuration was simulated with FEM calculations of transient impulse current loads of up to 1h current and compared with a conventional fuse with no division of the switch chamber. Fig. 4 shows the temperature rise of the fuse-element with the additional restricted section in case of an overload current with a pre-arcing time of approx. 30 ms.

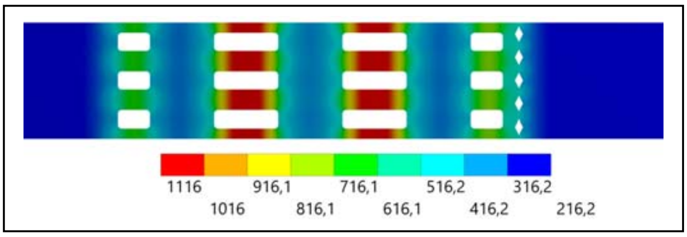

Figure 4. Calculated temperature rise (°C) after 30 ms at prospective alternating current I_P = 3 kA.

The time/current characteristics calculated were compared with real loads in the current range from approx. 600 A to 50 kA. However, in order to assess the capacity, the loads were applied at a phase to phase grid voltage, i.e. at 440 V. The characteristics are shown in Fig. 5. The concordance was adequately good.

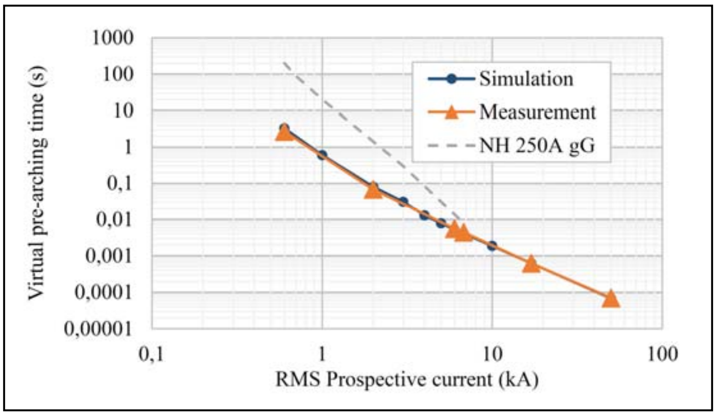

Figure 5. Comparison of the measured with the calculated passive time/current characteristic.

In Fig. 6a we see the current and voltage curve under a load of 3 kA and in Fig. 6b at 50 kA.

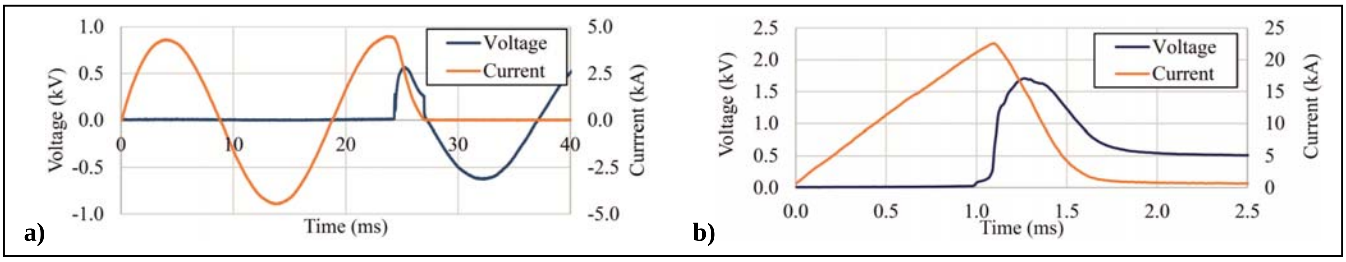

Figure 6. Measured voltage/current curve at **a)** I_P = 3 kA (U_C = 440 V; cosφ = 0.87); **b)** I_P = 50 kA (U_C = 440 V; cosφ = 0.87).

B. *Active Operation*

In addition to the passive operation, the operation in case of active triggering of the electric match was tested without a load and with overload currents. Here, the triggering time and the time until both fuse-elements break are relevant. If the passive melting time is less than the delay resulting from detection, triggering and actuation, the fuse switches in a purely passive manner. In this way, the minimum time delay determines the maximum current load to be mastered by active triggering. As it is neither necessary nor sensible to aid or accelerate the disconnection in case of overcurrents or short-circuit currents which trigger one or more of the restricted sections, there is no need for the delay time to be under 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. As a basic principle, short-circuit currents over 3 kA are only switched passively in the given model configuration. The configuration had already been modified to allow accelerated operation for the test shown in Fig. 7a. The test current in Fig. 7b and the switching capacity achieved with it in the model fuse therefore exceed the maximum capacity required. The already high switching capacity as a result of the high pull rate, as well as the separation distance when activating the electric match and the combination with the passive protective characteristics of the fuse, enable the safe and consistent operation of the model fuse in both active and passive modes of operation.

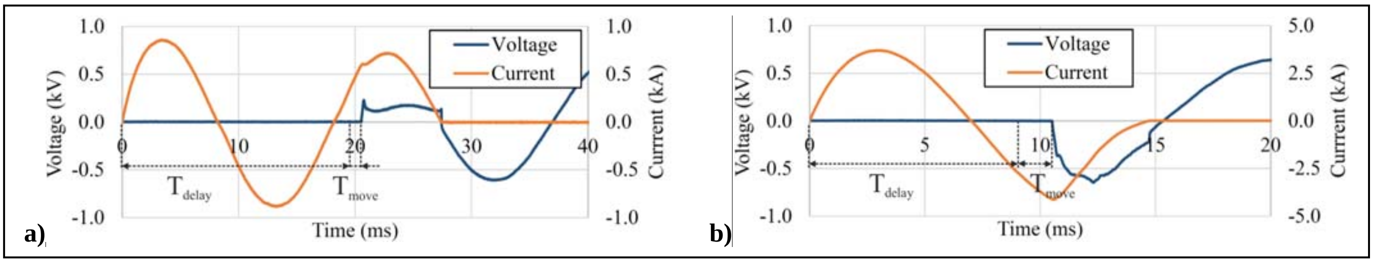

Figure 7. Measured voltage/current curve at **a)** I_P = 0.6 kA (U_C = 440 V, cosφ = 0,87); **b)** I_P = 3 kA (U_C = 440 V, cosφ = 0,87).

In Fig. 8 one can see the realistic active curve of the model fuse alongside the passive time/current characteristic. This diagram clearly shows that safe disconnection is possible within a total current range < 30 ms using the configuration examined. In case of a longer tripping delay or lack of activation, the configuration has the time/current behaviour of a fuse with corresponding characteristic.

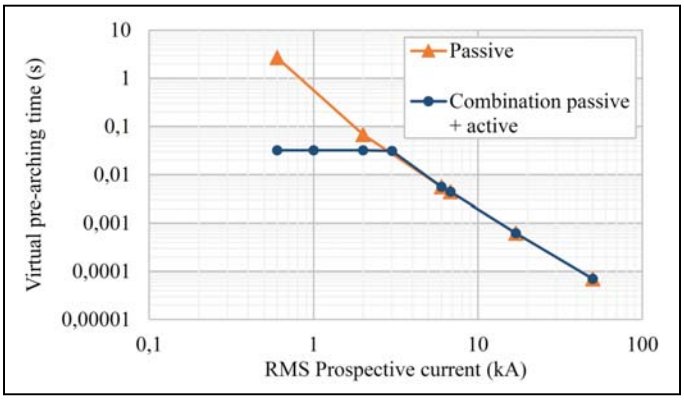

Figure 8. Time/Current characteristic of the low voltage fuse with additional activation function.

III. Condition after loading

After the switching loads which were mastered by active and passive functions, the impulse voltage withstand was tested by determining the sparkover voltage for the model configuration. This revealed that in case of active tripping the sparkover voltage was always > 6 kV, regardless of the current load. This also coincides with the values for the passive functional mode in case of short-circuit currents. However, without an active function, passive switching of currents with melting times in the seconds range (interruption of only one restricted section per fuse-element) only results in voltage withstand values of, in part, less than 2 kV.

IV. SUMMARY

The fuse model presented is a space-saving and reasonably priced compromise for networks, systems and equipment which only require a one-off switching function. It has been demonstrated that higher switching capacities and lower clearing integrals, similar to fuses of comparable size, can be achieved via the additional "activation" function. The disconnection time when controlled externally is comparable with that of remotely operated switching devices. In case of failure of the activation function, the fuse still, at least, fulfils the standard protective function of a normal passive fuse against overcurrent and short-circuits. In addition, the model fuse can conduct high transient impulse current. 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 model configuration is capable of carrying multiple high impulse current loads without incurring damage.

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