HIGH-VOLTAGE FUSES – NEXT GENERATION WITH IMPROVED PERFORMANCE

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ABSTRACT

Within distribution networks, high-voltage (HV) fuses have been used for decades as an economical and extremely reliable protecting device standardized by IEC60282-1[1]both in functionality and dimensions. They fulfil both the disconnection and the consumer protection tasks. Hereby, the pure switching task is usually limited to switching the operating current and is taken over by medium-voltage switch and control. In the event of a fault occurring either on the grid or in one of the components, failure currents may arise which exceed the breaking capacity of the switching device so that it does not properly cut off those currents. This is where the "high-voltage high-breaking- capacity fuses" – or HV fuses for short – step in.
In parallel to the technical aspects of improved protection, the "Think Green" philosophy should also be taken more and more into consideration with these products.

This contribution will show that with an improved generation of HV fuses, both requirements can be fulfilled satisfactorily.

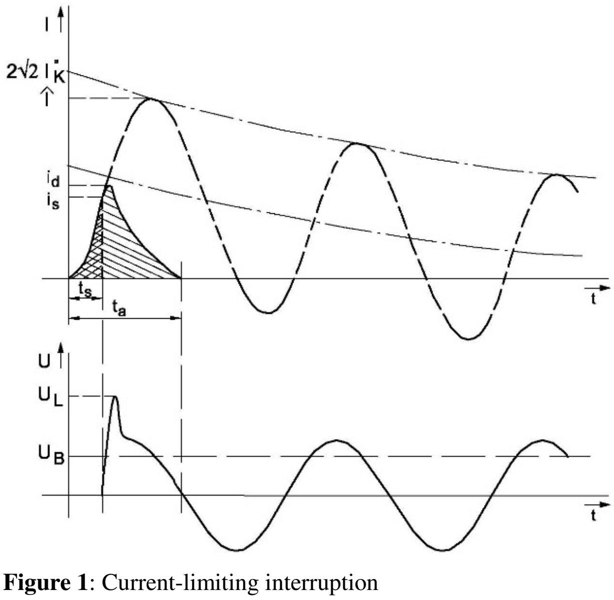

Figure 1: Current-limiting interruption

INTRODUCTION

Basically, high-voltage fuses offer the unique benefit of a switching device with the so-called "current – and energy limitation" property. It enables the customer to design network components at a greatly reduced financial investment. Figure 1 illustrates the fast current- and energy limiting interruption of a short-circuit failure current in the region of kilo-amps. HV fuses consist of an insulating tube, made of organic or non-organic material, with contact fittings at both ends. These components form the fuse housing and only after opening this housing, additional components become visible, such as the arc-quenching medium, the melting-element system including the carrier and an optional tripping mechanism or striker pin.

Figure 2: Construction of HV fuse-links acc. to DIN43625 [2]

Besides holding all the components together mechanically, the essential feature of the insulating tube is its resistance to the very high temperatures occurring in case of switching off high energy fault currents. Fuse bodies for high-voltage fuses are, therefore, mainly manufactured from ceramic materials in accordance with IEC 60672-1 [3]. For the contact fittings, a good electrical and thermal conductivity is essential. Therefore, they are typically manufactured from copper or brass. For anti-corrosion protection purposes, a corresponding silver plating protects these components.
For a proper failure current interruption, a precisely defined arc-quenching medium is needed. In most cases, quartz of a defined grain-size distribution is used. In delivery state, it has been washed and sieved to a pre-determined grading and is free of elements having a negative effect on the switching characteristics and it has a controlled residual moisture content. During fuse operation, the sand is responsible for the heat transfer from the fuse element to the environment. At the moment of disconnection, the current limiting interruption is due to the presence of this quartz. The heart of the fuse is a ceramic carrier with the fuse elements fixed to it. The fuse elements are mostly wound around the carrier helically and they are connected to its ends by means of contact caps. The contact cap itself is connected to the connecting fittings to be conductive. In order to achieve low contact resistances, these connections are preferably welded.

HV fuses are operated with permanently elevated temperatures depending on the intended use. Whilst there is no problem with using copper as fuse-element material for low-voltage (LV) fuses, the same may lead to surface oxidation with fatal consequences for breaking currents with high-voltage fuses. Therefore, the main material to be used for fuse elements is silver of the highest purity.

Table 1: Technical data of silver for melting-elements

Material	σ	$T_{melting}$	$T_{boiling}$	ρ
	[S/m]	[°C]	[°C]	[g/cm³]
Silver (Ag) 99.99	$6.3*10^7$	962	1950	10.5

In spite of using material of such high electrical conductivity, the length of the melting element (which correlates with the rated voltage of the fuse-link), leads to a relatively high resistance level of HV fuse-links compared to the level of LV fuse-links. According to the relationship I^2*R, this also means a comparatively high power dissipation (power-loss) of these protective elements compared to corresponding low-voltage protective devices.

INNOVATION OF HV FUSE-DESIGN

If we focus on the protection of distribution transformers, the requirements placed on the HV fuses in the past were limited. Principally, the fuses had to fulfil the requirements for a proper transformer protection subject to the international standard IEC/TR 62655 "Tutorial and application guide for high-voltage fuses. [4]" Figure 3 reflects all parameters that have to be taken into consideration for a proper transformer protection by a HV – as well as LV fuse system.

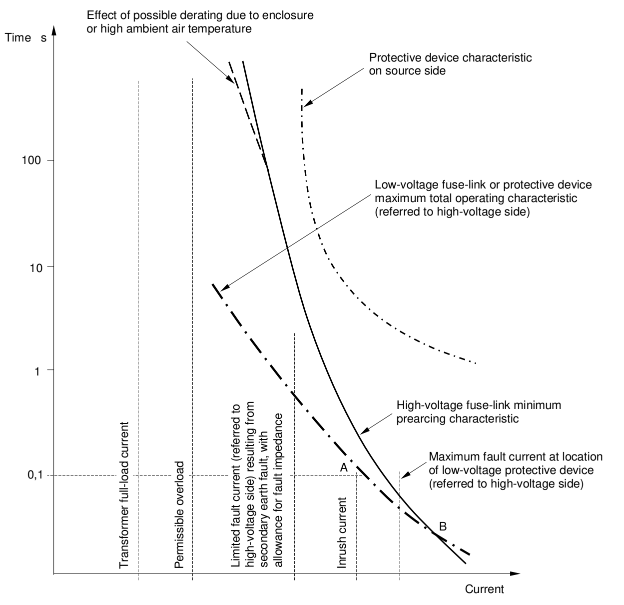

Figure 3: Transformer protection schema acc. to IEC TR 62655

Combine conflicting requirements

In some cases, additional requirements for a precise discrimination to additional up- and downstream protective devices had to be taken into consideration, as stipulated by DIN VDE 0670-402 [5]. The customer could choose between two main degrees of freedom, which generally contradict each other due to basic fuse physics. Either the fuse-link was able to offer a reduced power-loss, or provided a defined time-current characteristic for proper coordination inside the network and its components such as switch-fuse combinations.
However, some years ago SIBA, who had already started focusing on the "Think Green" philosophy, was able to offer an HV fuse, combining all the technical benefits of an economical switching device – including a significant reduction in power-loss – with the requirements of a non-hazardous and recyclable construction [6]. As well as this primary objective, additional requirements, stipulated by new standards, were also taken on board.

Evolution of standardisation: IEC 62271-105

With the official entry of IEC 62271-105 [7], additional requirements had to be taken into account. In parallel with the continuing demand for a proper transformer circuit protection, the requirements of the devices which the HV fuse-links are built into, (such as gas – or air insulated switchgears), became increasingly relevant. Switchgear parameters like the "rated transfer current", "maximum temperature-rise and power dissipation" had to be fulfilled by maintaining the proper transformer circuit protection in parallel. By means of improving the existing fuse design, both requirements - the well-known transformer circuit protection as well as the new switchgear restrictions - could be fulfilled by using this new HV fuse technology [8].

Eco-design: Reduced power-losses

Parallel to the requirements to keep the parameters such as the transfer and the minimum breaking current low, a well-controlled low temperature-rise and power-dissipation was desired, especially in case of higher transformer ratings in combination with gas-insulated switchgear. Here the new fuse technology was able to offer improved solutions, realized by new melting-element systems and improved winding technology at the same time as fulfilling the current global market philosophy by being a green network component in the existing distribution networks.

REDUCED LIFE-CYCLE COST BY REDUCED POWER-LOSSES

Current distribution networks are continuously expanding, but the main part has already existed for decades and needs a corresponding protection, as required by utility standards. These standards are often as old as the network structure. Here special requirements, like discrimination between up – and downstream protection devices, are needed and cannot be changed. By means of this fuse-innovation, these long-term existing requirements can still be fulfilled without making compromises. At the same time, the carbon footprint as well as cost saving can be improved by offering a reduction in power-losses of up to 30 %. Diagram 1 shows a comparison of the power-losses at rated fuse current between standard (blue) 24 kV HV fuse-links of different rated currents and the corresponding new innovative types (red).

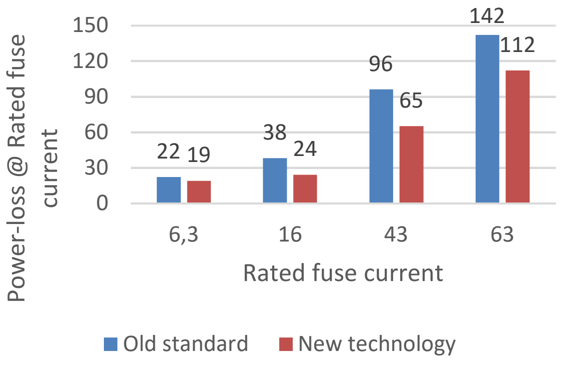

Diagram 1: Power-loss comparison "old" vs. "new"

Several major customers have already implemented this innovative solution and have been able to achieve remarkable positive results within a period much shorter than usual within a standard life cycle budget.

Financial view

Based on a dynamic capital budgeting calculation, let us have a look at what such a reduction in practical application means. There is a defined purchase price for the different types "old standard" and "new technology". Both types have individually different values of power-losses, which must be valued in monetary terms by the grid operator. If we take into account, the following additional parameters [9] such as:

- Cost of power-generation = 0.07 €/kWh
- Period of consideration = 30 years
- Average transformer load = 40 - 50 %
- Capital return = 6 %

the remuneration values are in the range of 1.5 € – 2.2 € Euro per watt saved.

Carbon footprint view

HV fuses commonly used in utility grids show power-loss values at its rated current in the range of P~100 W. According to realistic assumption, they are loaded with 50 % of its rated current on average. This results in practical power dissipation of P=25 W.
Power generation which burns fossil fuel like coal and gas releases 600 – 1000 g of CO_2 into the atmosphere in order to generate one kilowatt hour (1 kWh) [10]. This means, if only ten of these fuses run over a short period of only four hours, 600 – 1000 g CO_2 are produced by the power station. As described above, the new fuse technology is able to offer a reduction in power-dissipation of up to 30 %. The following calculation will emphasise the enormous saving and positive influence in avoiding CO_2 emission even in using a protective device like a HV fuse-link.

If we consider the following parameters for the German market

- Installed distribution transformers = 600 000
- Share protected by HV fuses = 400 000 @ 3 fuses
- Average installed power = 400 kVA
- Average load = 50 %
- Rated fuse current = 31.5 A
- Considered power dissipation @ Ir = 65 W
- Operating voltage level = 10 kV and 20 kV (1:1)

this will lead to a reduction in power consumption from 42 GWh/year down to 29 GWh/year and consequently to a saving of up to 10 000 t CO_2 depending on the kind of power generation.

HIGHER RATINGS FOR INCREASING NETWORK REQUIREMENTS

The power of network components is continuously increasing. Being able to keep the advantage of the "fault current and energy limitation" by using HV fuse-links, fuses of higher ratings in existing dimensions are needed. The development of improved component materials and production methods within the last few years has enabled us to offer this new fuse technology for electrical performance ranges requiring higher fuse ratings as well. The new fuse-ranges can be applied where only much more expensive solutions had to be chosen in the past, which were also not able to offer the benefits of any current limitation. Especially in the region of such high power-classes, a defined percentage of loss reduction results in high benefits with regard to the carbon footprint and economical savings.
Therefore, over the last decade many empirical tests, carried out under realistic high power conditions, have led to the realization of higher rated HV fuses being able to offer this new power saving technology. Today HV fuse-links in this so-called "Low-loss" technology can be offered from 3.6 kV – 500 A up to 40.5 kV – 100 A in different dimensions.

CONCLUSION

The development of the new SIBA fuse technology enables us to extend the application of the well-known advantages of HV fuse-links for the protection of network components in medium–voltage distribution systems towards higher performances. The technology is able to fulfil the contradicting requirements for a proper transformer protection in combination with the (in some extent) limited switchgear parameters by offering a significant reduction in power-loss. These opportunities are able to generate a notable positive contribution in terms of the "Think Green" philosophy as well as the financial cost situation.

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