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Funtional Charcateristics of a Surge Arrester at Lightning Impulses and Mains Follow Currents

ABSTRACT

Spark gaps are surge arresters with a high lightning current discharge capability. Modern spark gaps are encapsulated and have a low voltage protection level with a high follow current extinguishing capability. The special performance and the pressure loading of a spark gap at lightning impulse currents and mains follow currents will be described.

1. INTRODUCTION

Powerful spark-gap based surge arresters are used within the scope of lightning equipotential bonding directly at the service entrances of buildings or industrial plants between the conductors of the three-phase current system and the PE or PEN conductor, which is connected with the equipotential bonding system or the earthing system. A lightning stroke into the external lightning protection system of a building is only partly discharged by the earthing system. Considerable partial lightning currents are discharged by the metal pipes or also by electrical conductors which are interconnected within the lightning equipotential bonding. The surge arresters installed into the system shall therefore be capable of discharging high-energy partial lightning currents safely. The increasing use of electronic and sensitive devices in many fields as well as the tendency to compact systems is, in addition to the lightning current carrying capacity, a further requirement on modern surge arresters. Using lightning current arresters in compact systems and in direct vicinity of sensitive terminal equipment, no longer allows the application of the approved structure of a multistage protection concept with the usual decoupling coils between the cascaded surge arresters.

The lightning current arrester shall therefore be capable of protecting a terminal equipment directly. With the low voltage protection level, however, also the sensitivity of the lightning current arresters increases with regard to low-energy surge impulses and mains surges. This can lead to an increasing rate of response of the lightning current arresters with the consequence of a mains follow current on the arrester circuit and a tripping of overcurrent protective devices. Thus, the availability of the system can be endangered. There are two possibilities to avoid this disadvantage. To realise the voltage protection level, firstly a trigger unit can be used, which takes over the tasks of surge protection from low-energy interferences and activates the spark gap with lightning current carrying capacity only at high-energy impulses. As an alternative, the spark gap shall be capable of strongly limiting the arising follow currents. The first measure increases the system availability as well as the service life of the lightning current arrester considerably. In order to ensure the system availability also in case of more powerful impulses, it is sensible to use spark gaps capable of extinguishing and limiting mains follow currents in the mains short circuit current range of the system. The let-through I^2t – value (current square impulse) of the lightning current arrester shall be less than the tripping value of the overcurrent protective device. Additionally, the voltage reduction during discharge should be as low as possible. Further details on this matter have been introduced in [1, 2, 3].

In [3] a lightning current arrester has been introduced which, due to its high short circuit withstand capability of 50 kA_{rms} and its high current limitation, is comparable to a circuit breaker. This arrester with very high lightning current carrying capacity is based on the “Radax-Flow-Quenching Principle“ and is a non-exhausting type.

This principle, which is very efficient and approved for spark gaps, however, is not suitable for compact systems in direct vicinity of electrical installations and IT equipment. The necessary space for additional protection measures against emitted ionising gases can reduce the possibilities of installation. For using the reliable ”Radax-Flow-Quenching Principle“ in compact systems, a space-saving encapsulation of the spark gap is necessary.

2. “RADAX-FLOW-QUENCHING PRINCIPLE“ FOR ENCAPSULATED SPD’S

The “Radax-Flow-Quenching Principle” of an exhausting lightning current arrester for low-voltage systems is described in [3, 4]. The quenching principle of the arrester is based on the pinch, the cooling with hart gas and the extension of the arc by radial and axial blowing. The arrester has a tubular discharge area between two electrodes. One of them is a hollow electrode, open at both ends through which the hot gas is blown out (Fig. 1). The arc is blown radially by hard gas between both electrodes, which is generated by the thermal decomposition of the polymer under the influence of the arc. An overpressure is produced from the gas emission and the arc in the discharge area. This pressure induces a directional axial flow from the discharge area through the hollow electrode into the outer area. This flow leads to an extension of the arc and the base point at the hollow electrode can be shifted up into the outer area of the arrester. Especially the radial blowing of the arc between the two electrodes produces an intensively cooled, wall-stabled arc with a high electric field strength. The electric field strength of the arc is lower in the area of the hollow electrode because of the less efficient cooling. But the voltage drop is considerable, anyhow, because of the great extension of the arc in the area of the hollow electrode. The consequently high arc voltage is used for follow current limitation. An energy balance of the arc for this exhausting spark gap is shown in [4]. The records show that only approximately 10 % of energy in the arc is absorbed by the material of the spark gaps. The biggest part of the energy is emitted to the environment by the blown-out gases. Encapsulating a spark gap with the “Radax-Flow-Quenching Principle“ meant that several problems had to be solved. Almost 100 % of the power input in the spark gap has to be absorbed by the material of the components of the spark gap. To avoid reignition, the hot gases have to be deionised quickly. The high dynamic pressures arising due to the hard gas emission and the avoiding of blow – outs have to be controlled mechanically.

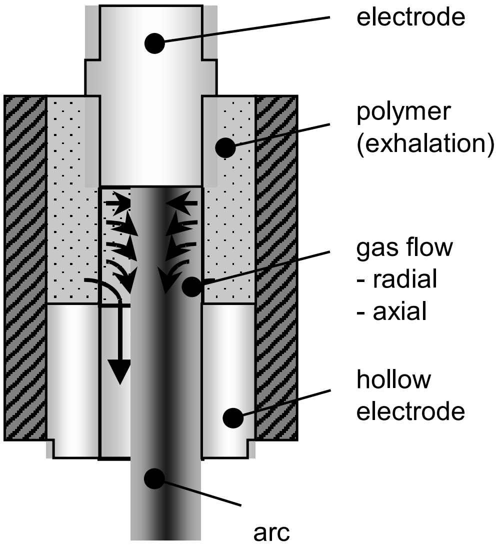

Fig. 1 - Exhausting lightning current arrester

The directed flow which is used for the arc extension in the hollow electrode should be kept within the spark gap. This is especially necessary for limiting the mains follow currents. In case of lightning current loading, however, the arc length should rather be kept low for reducing the power input. Thus an extension in the hollow electrode should be renounced. Controlling the power input, the flashing and the pressure in the spark gap are mainly “just” requirements with regard to the geometrical shape and the selection of material for the encapsulation of the spark gap. Maintenance of a directed flow is absolutely necessary for successful realisation of the “Radax-Flow-Quenching Principle”, especially in case of follow current loads within the spark gap.

The flow rate of exhausting spark gaps can reach values in the range of sound velocity, even without special shaping of the exhausting outlet. If the spark gap is encapsulated, similar permanent rates can only be achieved for relatively great volumes downstream of the spark gap. For using a spark gap, however, it is necessary that the volume of the encapsulated spark gap and that of the exhausting spark gap are almost equal. This means, there is only a small volume into which the hot gas can flow. The pressure in this volume, which can be called pressure equalisation volume, increases almost simultaneously to the pressure in the arc chamber. The pressure difference between the arc chamber and the pressure equalisation volume reduces the flow rate of the hot gas and thus also the efficiency of the arc extension in the hollow electrode. If there is no flow in the spark gap or if it is too slow, the arc extension is interfered or a stochastic abrupt shortening of the arc length and thus of the arc voltage will be caused. This finally impairs the achievable follow current limitation of the spark gap. Examination and influencing of the pressure in the arc chamber and in the pressure equalisation volume is the basis for application of the “Radax-Flow-Quenching Principle“ for encapsulated spark gaps.

3. PRESSURE MEASUREMENTS AND MATERIAL TESTING ON ENCAPSULATED SPARK GAPS

The basic pressure measurements were carried out at encapsulated spark gaps without trigger unit. Fig. 2 shows such a spark gap. The used pressure sensors [5] were coupled to the pressure equalisation volume or to the arc chamber without important volume extension.

Attention was paid to avoid pressure reflections and arc thermal influence in the spark gap. The pressure sensors were protected against the optical and thermal effect of the arc. The geometry and the material in the arc chamber can only be varied to a certain extent because of the intended performance parameters.

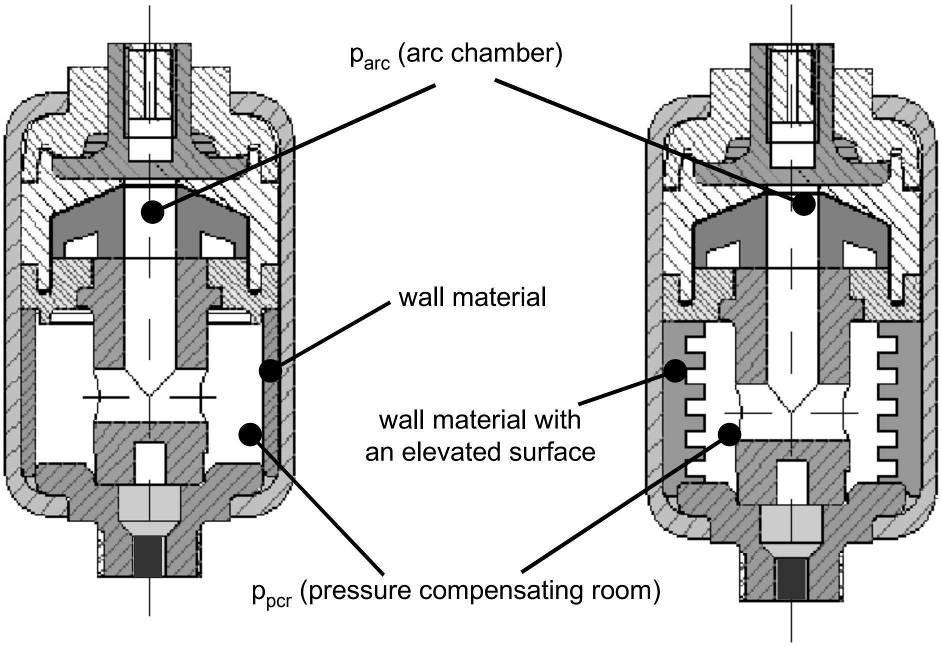

Fig. 2 – Encapsulated spark gaps

Influencing possibilities of the flow are therefore restricted to the shaping of the hollow cylinder electrode and the pressure equalisation volume. In addition to usual parameters concerning the flow, such as the cross-sectional area and the injector shape of the hollow cylinder electrode as well as the volume of the pressure equalisation volume, especially the influence of the wall materials in the pressure equalisation volume were examined. Fig. 3 shows the pressure, current, and voltage characteristics of the spark gap being loaded by a mains follow current in connection with different materials of the wall and one combination with an elevated surface. Fig. 4 shows the characteristics in case of lightning current loads in connection with the same materials. It is apparent that even at a short loading period (< 1 ms) there is a clear influence of the wall material on the pressure and thus also on the flow. The selection of the material and the relation of the surface to the volume in the pressure equalisation volume can be used to optimise the flow conditions in the spark gap. From Fig. 3 it can be taken that a high pressure in the pressure equalisation volume increases the electric field strength of the arc so that a better current limitation can be achieved. The arc voltage, however, decreases in case of lightning current loads in spite of a clearly higher pressure.

This effect is already caused by a reduced flow so that the arc in the hollow cylinder electrode can hardly be extended, at least not constantly.

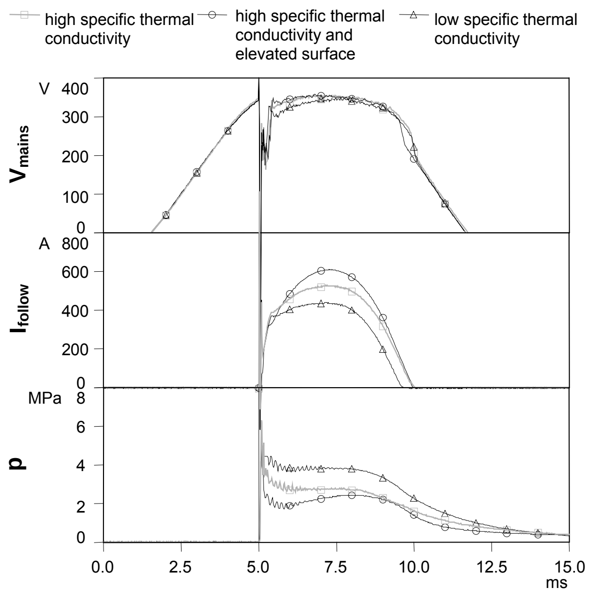

Fig. 3 – Behaviour by a mains follow current

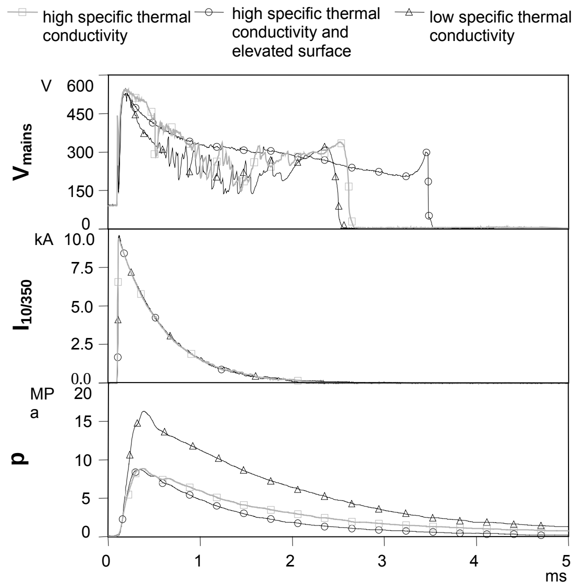

Fig. 4 – Behaviour by a lightning current

In case of lightning impulses, this effect limits the power input and the flashing in the spark gaps. For mains follow currents, however, it should be avoided. Fig. 5 shows pressure measurements in the arc chamber and in the pressure equalisation volume loaded with follow currents (5a) and lightning currents (5b), carried out synchronously. A type of stainless steel (mean specific values of thermal conductivity and thermal capacitance) was used as wall material. It can be clearly seen that there is a drop of pressure of several bar between the arc chamber and the pressure equalisation volume in both cases (Fig. 5a, b).

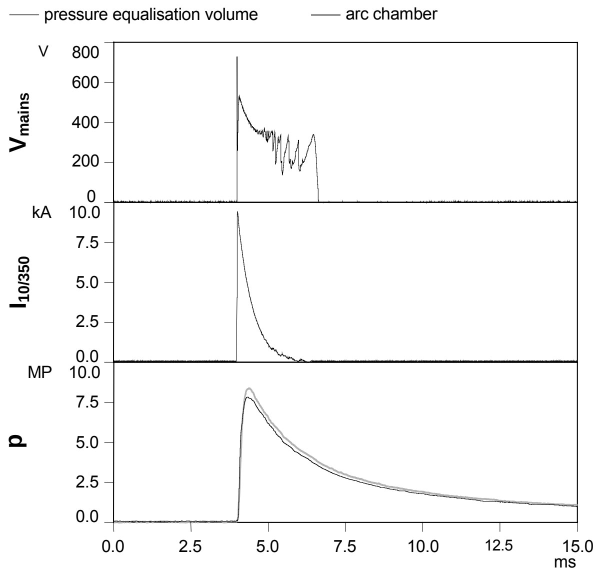

Fig. 5a – Pressure measurements by a mains follow current

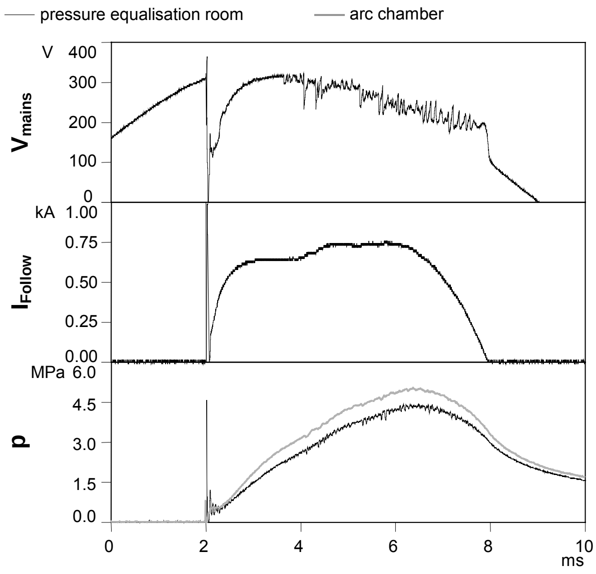

Fig. 5b – Pressure measurements by a lightning current

4. POTENTIAL OF THE OPTIMISED SPARK GAP

Fig. 6 shows the optimised encapsulated spark gap with trigger unit regarding material and costs. The trigger unit of the spark gap controls the size of the overvoltage and the energy content of the resulting surge current. The trigger unit ignites the spark gap only if the specific energy of the surge current is higher than a selected value, for example W/R = 16 A²s. This value corresponds to a 8/20 µs surge current with 1 kA or a 10/350 µs impulse current with 240 A. The trigger unit assured the low protection level for currents with a lower energy content and overvoltages with a duration belows 1 µs for example by burst impulses. The surge arrester works in these cases without follow currents.

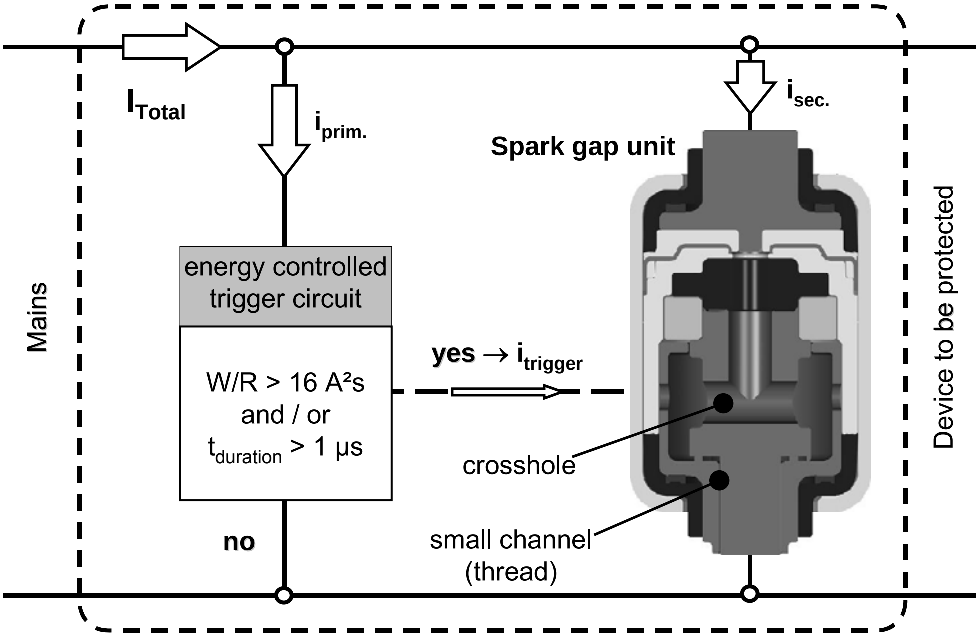

Fig. 6 – Encapsulated spark gap with trigger unit

A arc-resistant material with high specific thermal conductivity and thermal capacitance has been chosen as wall material of the pressure equalisation volume. Controlled emission of cooled gas through a small channel and cooling is the means to maintain the pressure difference between arc chamber and pressure equalisation. This gas emission is also necessary to avoid a permanent increase of pressure in the spark gap due to the emission of hard gas. By the shaping of the cross-hole, a flow constriction has been created which impairs the flow and thus the extension of the arc in the spark gap only at high lightning current impulses.

This reduces the power input up to the 20 % in the spark gap. Fig. 7 illustrates the current and the voltage characteristics as well as the potential input into the spark gap at their nominal power parameters in case of mains follow currents (50 kA_{rms}) and lightning impulse currents (25 kA 10/350 µs). The pressure loading of the optimised spark gap at lightning impulse currents is presently approx. 30 MPa and < 10 MPa at mains follow currents.

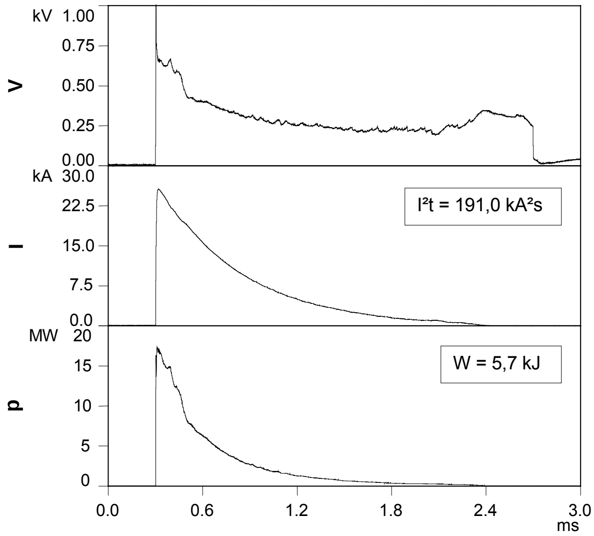

Fig. 7a - Characteristic of the power during a lightning current

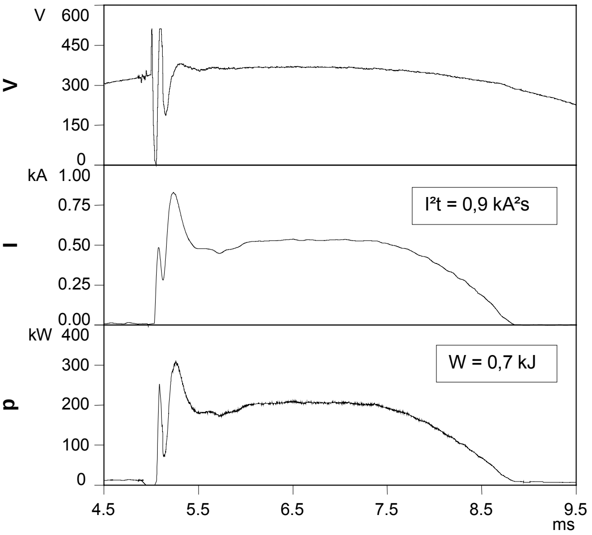

Fig. 7b - Characteristic of the power during a follow current

The current limiting effect of the encapsulated spark gap is exemplified in Fig. 8. The diagram shows the unimportant voltage reduction during the discharge and the time of follow current.

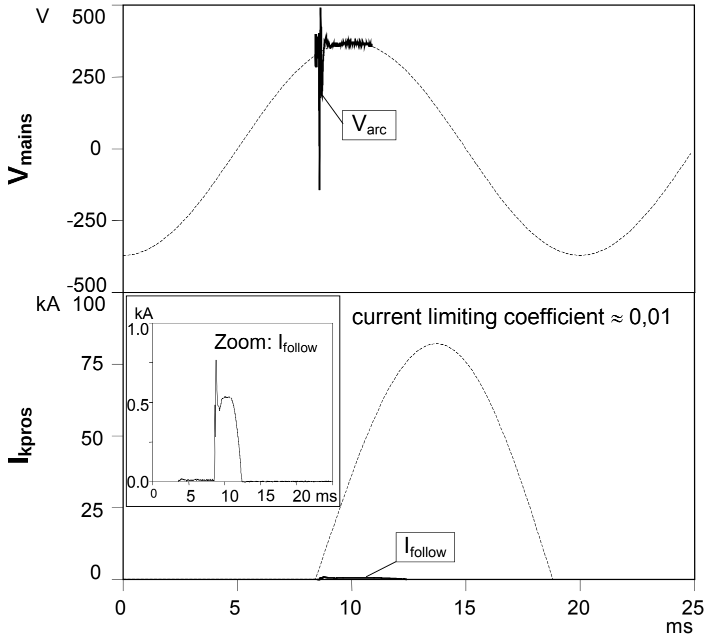

Fig. 8 – Follow current limiting capacity

The diagram in Fig. 9 shows the let through values of the blow out spark gap and of the encapsulated spark gap. The follow current limitation of the encapsulated spark gap is higher and so the let through value is smaller than the prearcing value of a NH 00 32 A gG fuse until prospective short – circuit currents of 50 kA_{eff}.

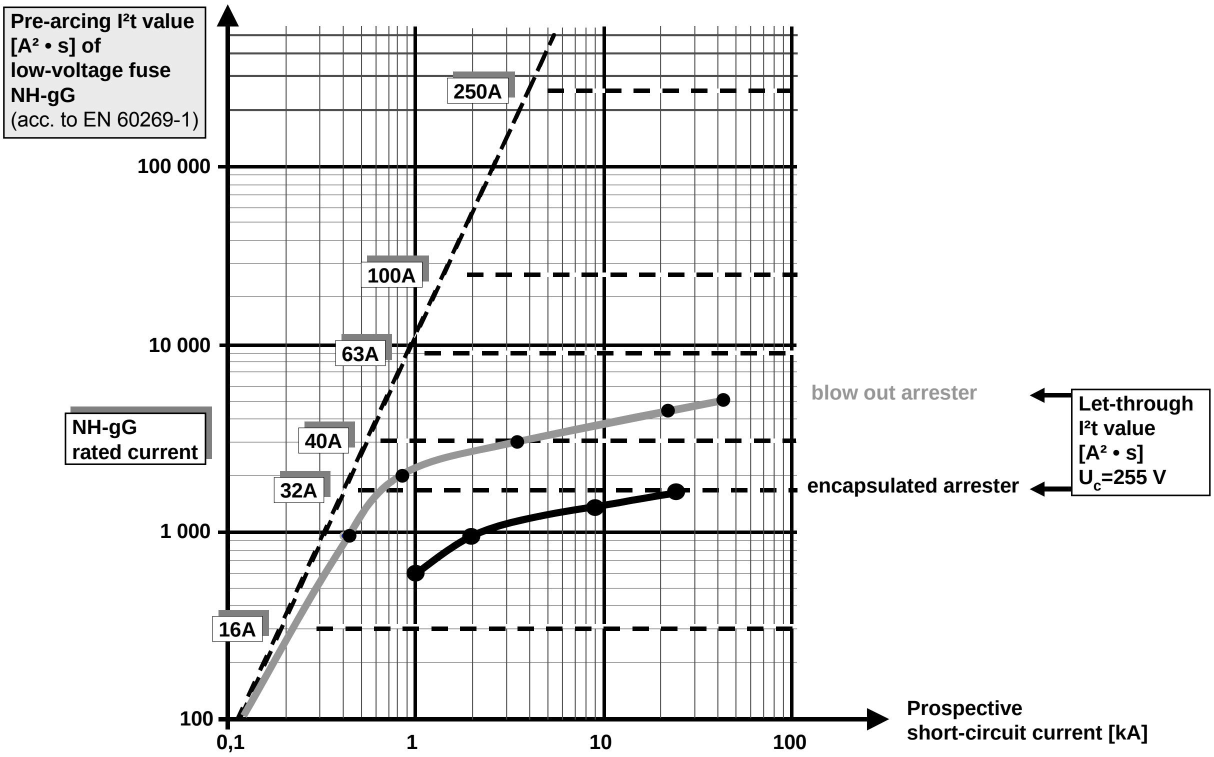

Fig. 9 – Selectivity between fuses and spark gaps at follow currents

5. SUMMARY

After systematic examinations we succeeded in transferring the basic performance of an exhausting spark gap according to the “Radax-Flow-Quenching Principle”, which is mainly based on the flow of gas to a pressure-proof encapsulated spark gap of equal size in the low voltage range. Additional possibilities have been determined to control the flow and the loading of the spark gap at lightning impulse and mains follow currents which opens perspectives for further optimisation of the performance.

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