

Protection of low power mains against pulse power of natural lightning using spark gap arresters.

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Abstract

The present state of lightning arresters with spark gaps for protection of low voltage installations will be analysed. Requirements for such devices must follow the actual knowledge of lightning physics, especially the lightning parameters.

1 Introduction

Lightning arresters are used for transient potential equalisation in low voltage networks to protect the equipment from over voltages [1]. They are designed to handle large currents, which occur in case of a lightning stroke into the external lightning protection equipment. Different solutions are already on the market, e.g. [2,3]. Lightning current arresters are designed for impulse currents up to some 50 kA with a wave shape of 10/350µs. Metal oxide arresters, designed for the same values would require a large volume. Therefore the volume of metal oxide would be extreme compared to the volume of a gap arrester. This results from the higher residual voltage of a metal oxide arrester compared to a gap arrester. However, in some cases metal oxide arresters of compact design are used as lightning arrester but only for impulse currents up to some kA with 10/350µs wave shape. Lightning current arresters for highest currents are therefore still gap arresters. There are many solutions on the market which use the arc of an open gap for follow current interruption. In this paper a new carbon technology will be shown. The application of carbon technology avoids some disadvantages of the existing gaps and shows therefore a better performance. A key for success is the application of new materials and arc interruption principles. The paper summarises the impact of lightning parameters and follow currents on a spark gap and describes a new technology. The following parameters have to be taken into consideration:

- Lightning parameters
- Current distribution into the low voltage installation in case of lightning flash to a building
- Electrical spark-over characteristics of the gap, even under multiple lightning currents.
- Pressure in a spark gap due to the arc energy
- Erosion of electrode material
- Interruption of follow current
- Transient overvoltages
- Testing of spark-over voltage during service

All the above-mentioned parameters were used as the basic engineering parameters for a new technology for lightning arresters with spark gap.

2 Behaviour of a conventional spark gap arrester

Fig. 1 shows a group of lightning current arresters in a TT-Net. Fig. 2 shows a model to simulate the behaviour. The new lightning current arrester MC 50-B is represented using a macro model. Fig.3 shows the network behaviour. The gap triggers at 2 kV. The lightning

current of 50 kA with a shape of 10/350 μ s follows but contains a power frequency follow current. Due to the properties of the lightning current arrester the arcing voltage reduces the current. The prospective current would appear if a short replaces the arrester. It is the property of the lightning current arrester to reduce the prospective current due to the development of an arc in the gap. In conventional gap arresters the plasma of the arc is blown out e.g. [2]. Others use closed chambers but there is a limited follow current interruption capability [3]. Fig. 4 shows the performance of an open gap arrester. It is a disadvantage to blow out hot plasma and such solutions require special housings with pressure release.

3. New solutions with a closed gap arrester

To avoid the disadvantages of existing solutions, the main focus was concentrated on a closed gap with reduced aging and high follow current interruption capability. Fig. 5 shows a principal cross section drawing of a multiple gap arrester. The arcing voltage U_{arc} is generated using the anode- and cathode drop in each closed pressure chamber. The total arcing voltage is therefore given by $U_{arc} = n \cdot [U_{Anode} + U_{Cathode}]$ (1). The length of an arc in each chamber is negligible and therefore there is low energy dissipation. Fig. 6 shows the active parts of a phase arrester for 50 kA and fig. 7 shows an N-PE arrester for 125 kA both 10/350 μ s. Fig. 8 shows a complete phase arrester. The material of the electrodes defines the anode- and cathode drop. All metals vaporise at the footing points of arcs and result in a deviation of the spark-over voltage with the cumulative charge. To realise a constant spark-over voltage of each gap a solution without metal electrodes had to be found. Graphite as electrode material provides excellent properties for anode- and cathode drop, heat conduction and vaporisation behaviour. Experiences from application of graphite for electrodes in high power spark gaps have shown excellent results [7]. The surface of graphite electrodes remains smooth even after some 10000 shots of 100 kA 10/350 μ s in crow bar generator spark gaps [4]. Therefore graphite electrodes can handle large lightning impulse currents.

3.1 Performance under combined stress

As shown in fig.3, the power supply voltage drives follow current after the lightning current has passed the gap. The gap has to extinguish the follow current. The arcing voltage acts as a counter voltage and therefore the actual follow current in the gap is less than the prospective current. The behaviour of the multiple gaps under follow current was tested according to fig.9 [5] and the results are shown in fig. 10. In this test the gap was triggered using an 8/20 μ s surge current of 10 kA at a defined phase angle of 30 degrees of the power supply voltage. At this angle the voltage at the gap remains nearly constant at 285 Volt. When the arcing voltage is equal to the actual value of the power supply voltage, the gap extinguishes and does not reignite. Under test conditions of 25 kA prospective peak current [5] the actual follow current in the gap is only 6,3 kA peak. During the tests no plasma was visible from outside. From this test one can conclude that the arcing voltage in a multiple gap is sufficient to reduce the follow current and to extinguish the plasma in the chambers.

3.2 V-t curves of lightning arresters

The series connection of spark gaps requires special measures for triggering at 1,2/50 μ s [5]. As shown in fig 5 the first upper gap triggers first, followed by the next due to capacitive voltage grading. Fig. 11 shows the measured voltage time characteristic of a multiple gap arrester. Compared to the spark gap arrester [2] (one gap only) the multiple gap arrester shows a lower spark-over voltage of 2 kV. The time to breakdown is lower due to the better provision of initial electrons from the parallel plate graphite electrode in the multiple gaps, compare fig.6. Fig.11 shows also the successive trigger of all gaps of the multiple spark gap arrester. Also the arcing voltage can be compared in fig.11. The spark gap arrester with one

gap only shows a few 10 volts of arcing voltage and the multiple spark gaps shows some 100 volts. Fig.12 shows the voltage-time curve. Since the multiple spark gap arrester starts with the breakdown of the first gap and ends with the final breakdown after triggering of all gaps, the time dependence of the voltage curve in fig. 12 shows both the first and the final breakdown.

3.3 Performance under multiple lightning impulses

Multiple lightning occurs in the negative downward flash. As shown in [6] multiple lightning impulses can be generated as hybrid impulses in laboratory. Each impulse starts with a 1,2/50 μ s voltage impulse. When the gap has triggered, the generator produces an 8/20 μ s current impulse. Fig. 11 shows the performance of the multiple gap arrester under four impulses. The gap triggers finally below the desired protection level of 2 kV. This test shows how fast the gap recovers from the ionisation from the previous impulse. The small gap distance provides fast recombination of ions into the electrodes.

3.4 EMC design of new arresters

As required in [6] the connection of the new lightning current arrester to the net is realised using a double clamp for V-connection. Fig. 1 shows the details of the connection in case of a TT-net. Fig.14a shows the recommended connection according to [6]. Fig. 14b shows the equivalent circuit. The voltage drop in this case is: $U = 2L \frac{di}{dt} + U_R$

The better solution is the V-shape connection as shown in fig. 14c with the equivalent circuit in fig. 14d. The voltage drop in this case is given by (3) were the inductance of leads has no effect. The voltage drop in this case is: $U = U_R$

4. REFERENCES

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- [6] Kallweit, J.; Ludewig, S.; Meppelink, J.; Schoene, J.: Development of a 10-stage multiple lightning surge hybrid generator with variable time interval and peak value.
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Fig. 1 Class I lightning arresters in a TT-net. Approved by VDE, KEMA, and ÖVE.

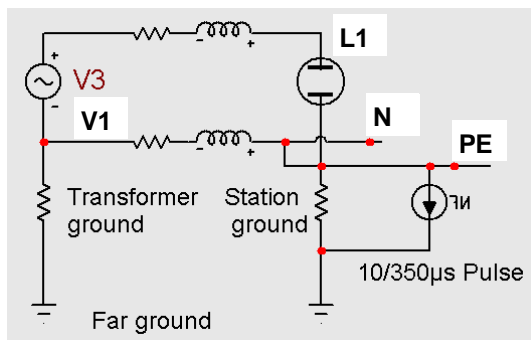


Fig.2 Circuit for simulation of basic, principal behaviour of one lightning arrester in a 1-phase network. Transformer of 650 kVA, and 100 m cable 70 mm². Station ground R= 5 ohm; transformer ground 2 ohm

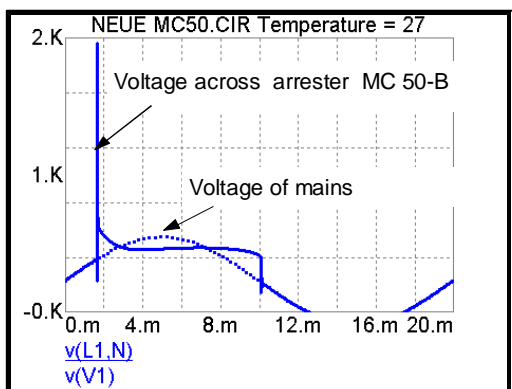


Fig.3a Voltages calculated in fig.2

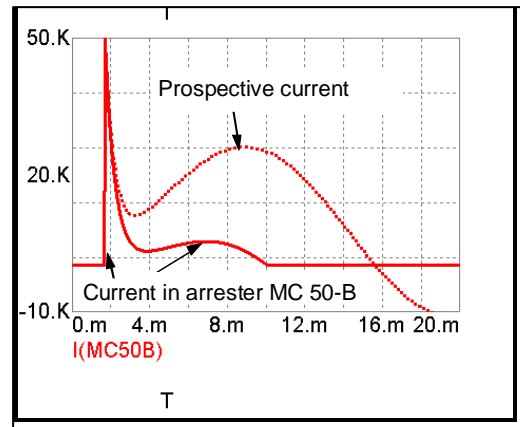


Fig. 3b Currents calculated in fig.2.

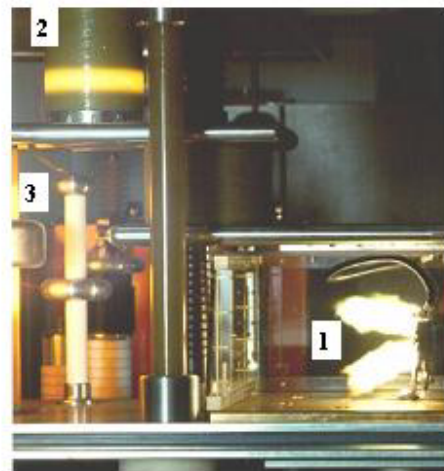


Fig. 4 Conventional spark-gap arrester with blow off chamber during test with impulse 10/350µs impulse of 60 kA in laboratory [7] using a crow bar generator. 1:conventional arrester, 2,3: spark gaps of lightning current generator.

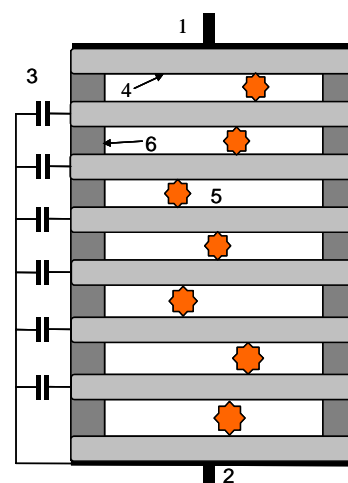


Fig. 5 Multiple spark gap with capacitive grading.1, 2: Connections; 3: Capacitive grading; 4: Graphite electrodes; 5 Sparks in sealed chamber between electrodes. 6 Teflon insulation disc.

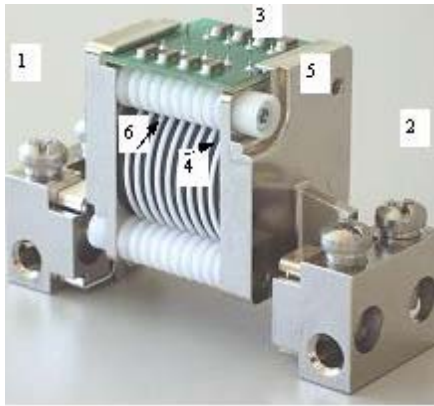


Fig. 6 Phase arrester with multiple spark gaps with capacitive grading. 1,2: Connections; 3: Capacitive grading; 4: Graphite electrodes; 5 plug in active part, 6 Teflon insulation disc.



Fig. 7 Twin spark gap arrester as N-PE arrester.



Fig. 8 Phase arrester with housing

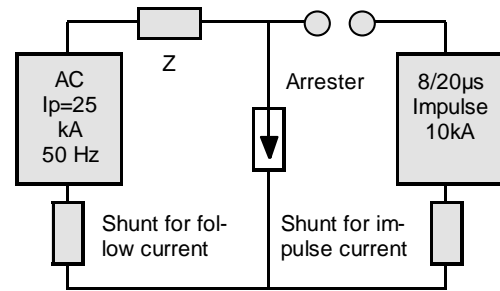


Fig. 9 Principal test arrangement for combined testing of gap arresters with surge current and follow current.

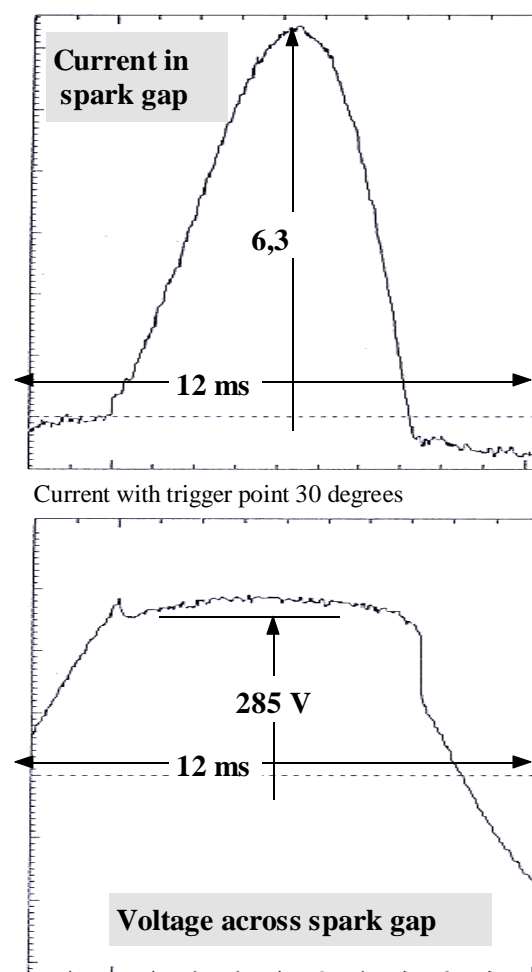
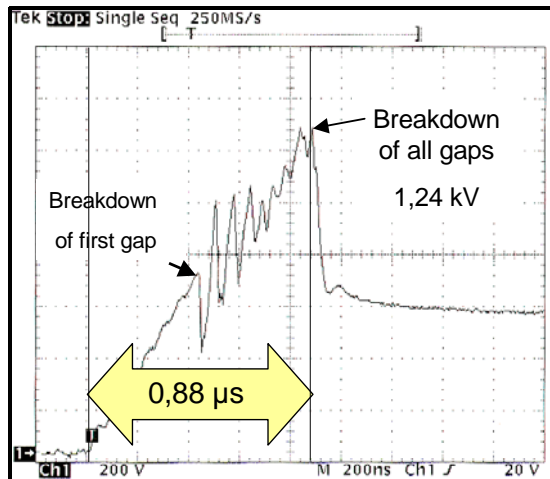
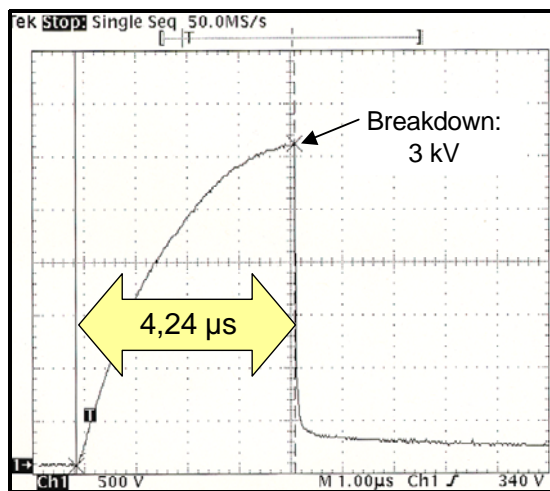


Fig. 10 Results of combined test with the multiple gap lightning arrester. The arrester was triggered using a surge current 8/20μs with 10 kA peak. The AC source was set to a prospective peak current of $I_p=25$ kA. The trigger point was set to 30 degrees. The voltage across the gap and the current in the gap were measured. Please note: Only the follow current of the AC source is shown in the above oscillograms.



A) Performance of the 9-stage multiple gap arrester



B) Performance of a conventional one gap arrester

Fig.11 Performance of the 9-gap arrester compared with a spark gap arrester with one gap only under the same lightning impulse voltage 3/50μs with the same prospective peak value.

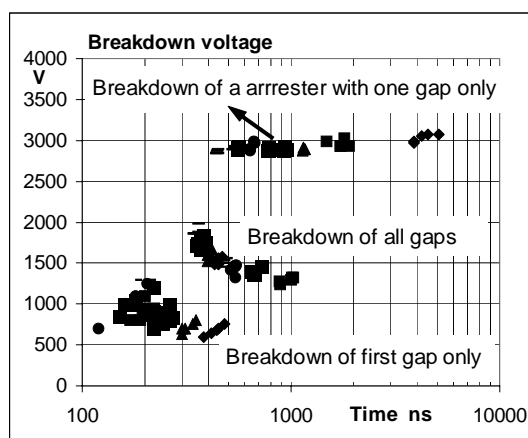


Fig.12 Voltage-time-characteristic of the multiple gap arrester with 9 gaps compared with a conventional spark gap arrester with one gap only.

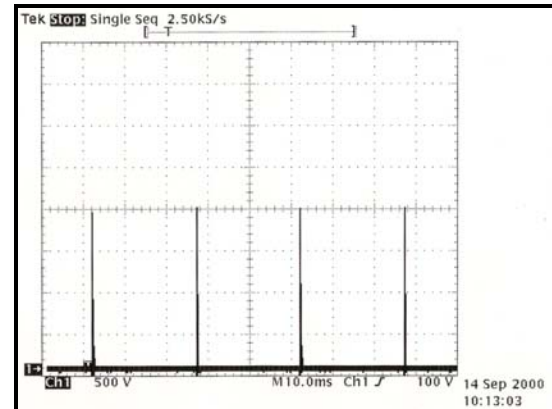


Fig. 13 Performance of the multiple gaps in a multiple hybrid generator with 1,2/50 μs open circuit voltage and 8/20μs impulse current after triggering.

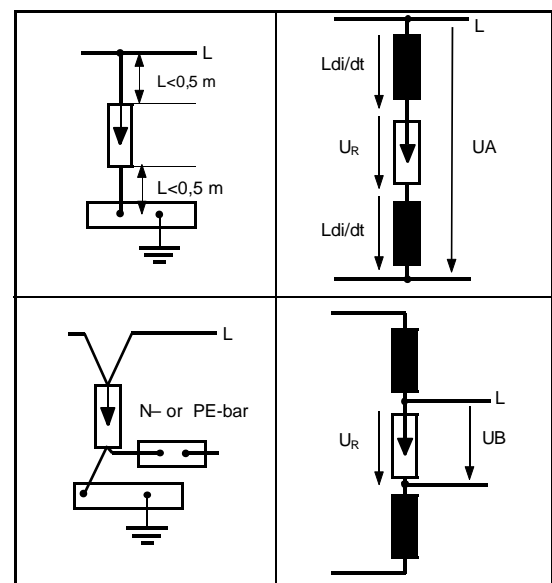


Fig. 14 V-shape connection of lightning current arresters according to [6]