LIGHTNING ARRESTERS WITH SPARK GAPS. REQUIREMENTS AND FUTURE TRENDS OF DEVELOPMENT AND APPLICATION

Jan Meppelink.
Meppelink@T-Online.de
Universität GH Paderborn, Germany

C. Drilling, M. Droldner, E.G. Jordan.
Info@bet-menden.de
BET , Germany

J.Trinkwald
Trinkwald.esv@bettermann.de
OBO Bettermann, Germany

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. In laboratory the testing devices have to be adapted to lighting current parameters and follow currents driven from the low voltage power supply. The international standards have to be taken into consideration.

The aim is to show a summary of these requirements which have to be taken into consideration during the development of a new technology for such spark gaps.

Keywords: Closed multiple spark gap, Lightning current arrester, graphite technology, voltage time characteristic, follow current.

1. INTRODUCTION

Lightning arresters are used for transient potential equalisation in low voltage networks, to protect the equipment from overvoltages [1]. They are designed to handle large currents which occur in case of a lightning stroke into the external lightning protection equipment.

The paper summarises the impact of lightning parameters and follow currents to 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 lighting flash to a building
- Electrical breakdown 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
- Aging of material

Furthermore the lightning current arrester will be installed in an electrical low voltage installation where e.g. lots of loads are switched, short circuits have to be disconnected which result in transient overvoltages. Therefore the network parameters have to be taken into consideration too. The lightning current arrester will be installed in a low voltage distribution. This is normally a metal housing where other apparatus are installed. Therefore the effect of high lightning currents in lightning arresters on the installation has to be studied.

The lightning current arrester shall be taken out of the installation for testing e.g. of the maximum spark over voltage.

All the above mentioned parameters provide the basic engineering parameters for a new technology for lightning arresters with spark gap.

Different solutions are already on the market, e.g. [2,3].

But there is still a potential for a new applied principle which 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.

2. BEHAVIOUR OF A CONVENTIONAL SPARK GAP ARRESTER

Fig. 1 shows a group of three lightning arresters as model installation for a network model. Fig. 2 shows a model for one phase only to simulate the behaviour. The conventional lightning current arrester LA 60 B[2] is represented using a macro model. Fig.3a shows the network behaviour. The gap triggers at 3,8 kV. The lightning current of 60 kA with a shape of 10/350µs follows but contains a power frequency follow current which is shown in fig. 3b together with the voltage across the gap with higher resolution. Due to the properties of the LA 60-B the arcing voltage reduces the current. The current in a gap compared to the prospective current is shown in fig. 3b. The prospective current would appear if the arrester is replaced by a short. It is the property of the lighting current arrester to reduce the prospective cur-

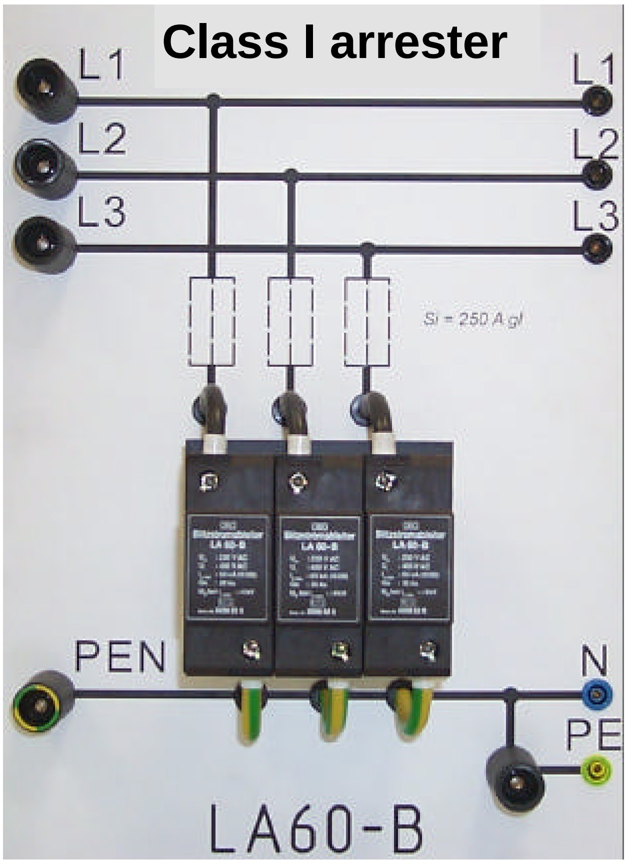


Fig. 1 Installation of four lightning arresters in a network model

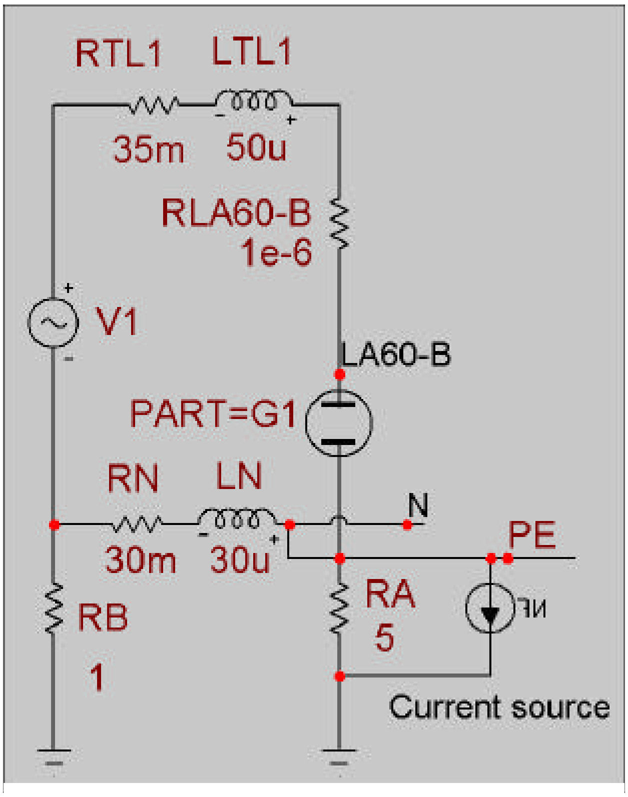


Fig.2 Circuit for simulation of principle behaviour of one lighting arrester in a 3-phase network. Transformer of 650 kVA and 100 m cable 70 mm^2

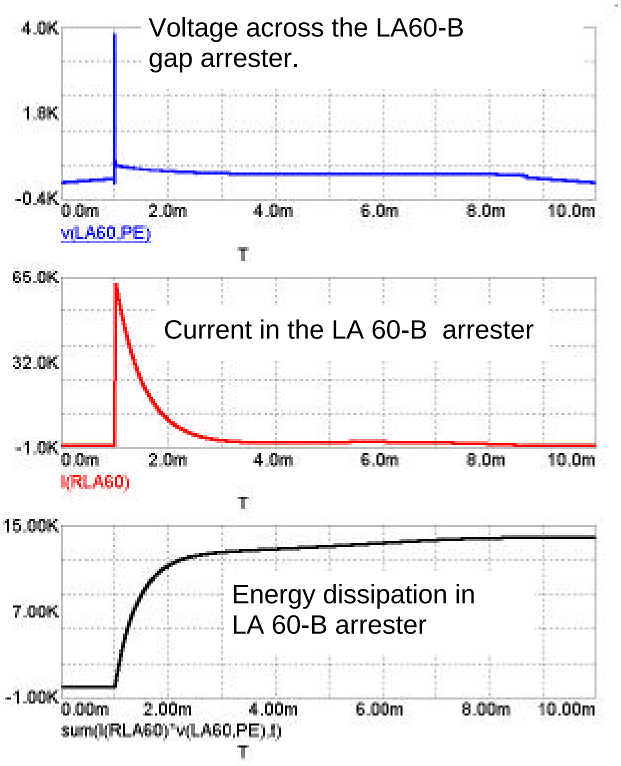


Fig 3a Results of simulation of circuit in fig.2.

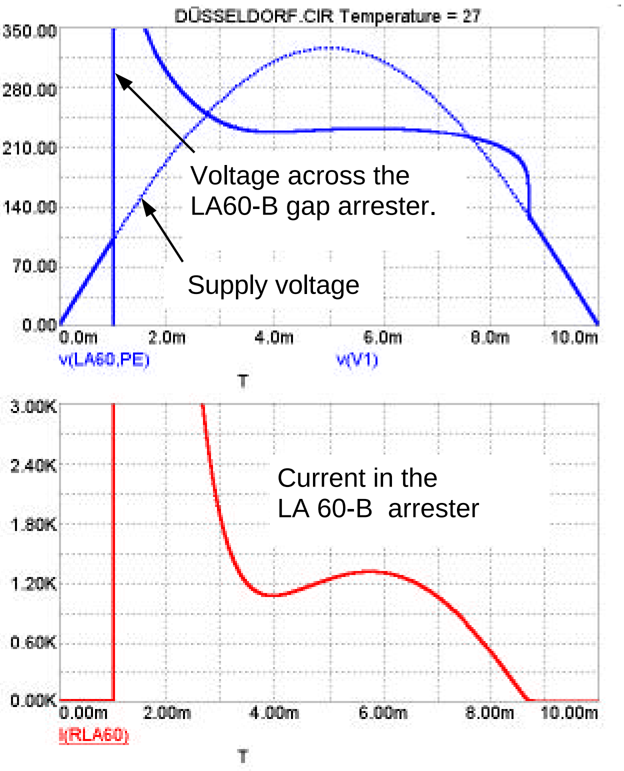


Fig. 3 b Results of simulation of circuit in fig.2 with higher resolution.

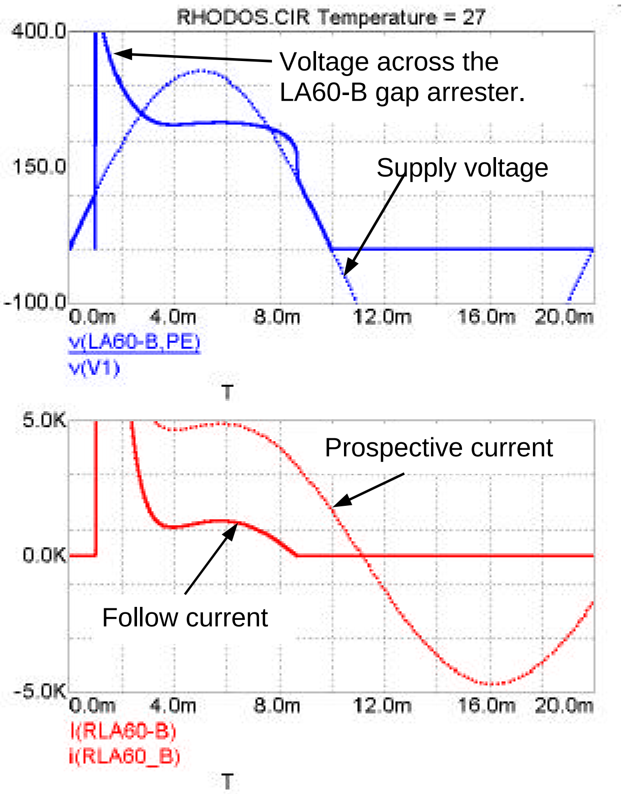


Fig.3b Follow current and prospective current of lightning arrester LA 60-B

rent by development of an arc voltage 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 such an experiment. It is a disadvantage to blow out hot plasma and it requires special precautions for the installation in a housing such as pressure release. But what follow currents do occur in low voltage networks? Fig. 5 shows typical short circuit currents in low voltage 3 phase systems for comparison. The current reaches values less than 20 kA under worst case conditions of short cable length between transformer and fault location.

Out of the simulation of the behaviour the basic design parameters for the development of a new gap can be summarised as follows:

- Spark over voltage of less than 4 kV
- Rated current 25 kA AC

3. DEVELOPMENT OF A NEW GAP

3.1 Existing solutions

The existing solutions are based on metal electrode gaps. The arcing voltage is generated by cooling of the arc, extending the length of the arc, by application of hard-gas or a combination with various arc-control devices. The disadvantages are: The stability of the spark over voltage is depending on the erosion of electrodes due to metal vaporisation and therefore on the number of lightning impulses and their cumulative charge. The arc is blown out [2]. Some solutions provide closed arcing chambers but the follow current interruption capability is at present limited to some kA.

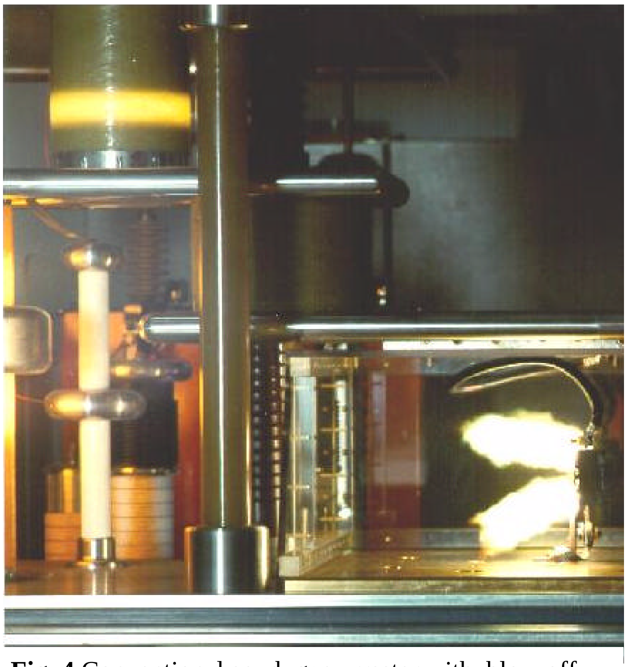


Fig. 4 Conventional spark gap arrester with blow off chamber during test with impulse 10/350µs 60 kA.

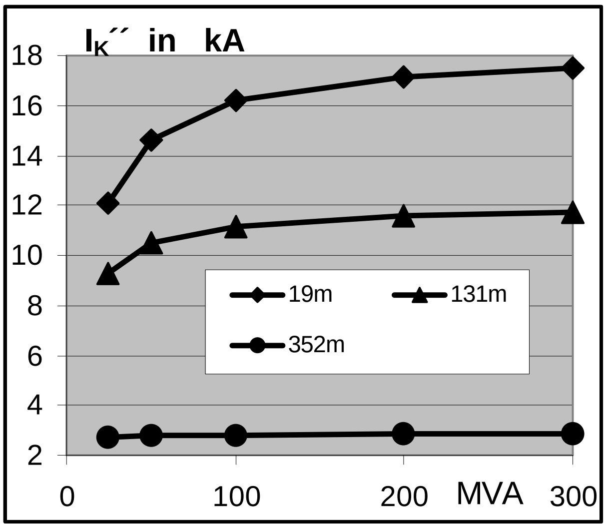


Fig. 5 Initial short circuit current I_K´´ depending on the short circuiting power. Parameter: cable length of a ca-

3.2 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. 6 shows a principle cross section drawing of

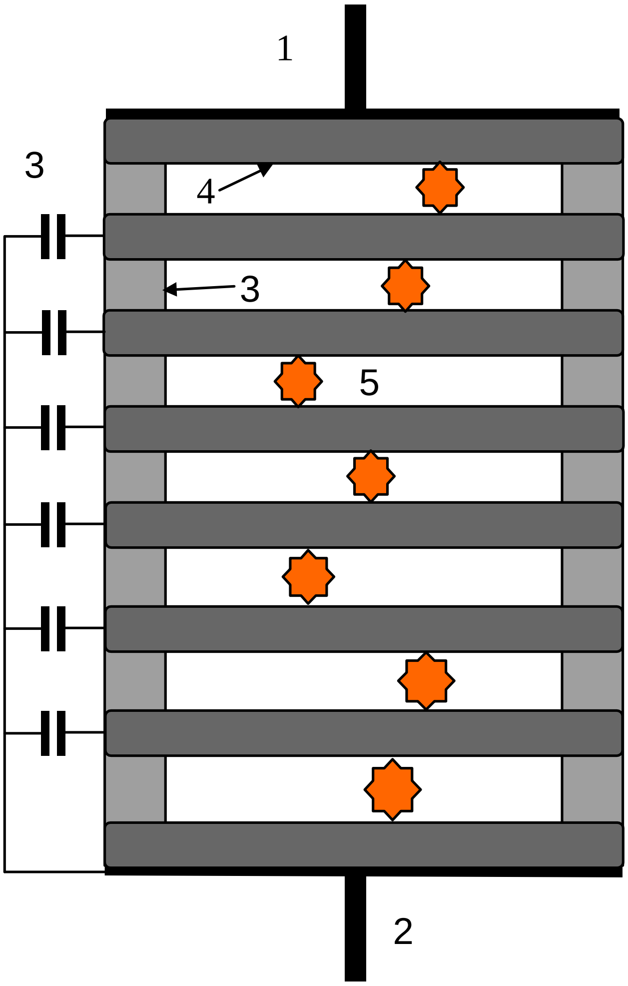


Fig. 6 Multiple spark gap with capacitive grading.
1,2: Connections; 3: Capacitive grading; 4: Graphite Electrode; 5 Sparks in sealed chamber between electrodes.

a multiple gap arrester. The arcing voltage is generated using the anode- and cathode drop in each closed pressure chamber. The total arcing voltage is therefore

$$U_{arc} = n \bullet [U_{Anode} + U_{Cathode}] \qquad (1)$$

The arc in a chamber is negligible and therefore there is no energy dissipation due to the length of an arc as known form existing solutions were the arc voltage is caused by increased length of the arc. This advantage of an arc length of app. zero allows closed chambers for each gap and leads to high follow current interruption capability.

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. The surface of graphite electrodes remains smooth even after some 10000 shots of 100 kA 10/350µs in crow bar generator spark gaps [4]. Therefore graphite electrodes can handle large lightning currents.

As shown in fig. 1-3 after the lightning current has passed the gap, follow current is driven by the power supply voltage. The gap has to extinguish the follow current. The arcing voltage acts as a opposing voltage and therefore the actual follow current in the gap is less than the prospective current. The behaviour of the multiple gap under follow current was tested according to fig.7 [5] and the results are shown in fig. 8. The prospective current is defined as :

$$I_P = \sqrt{2} \bullet I''_K \qquad (2)$$

In this test the gap is triggered using a 8/20µs surge current of 10 kA at a defined angle of the power supply voltage. At a angle of 30 degrees the voltage at the gap remains app. 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 current [5] the actual follow current in the gap is only 6,3 kA peak. A similar behaviour is shown at 90 degrees. During the tests no plasma was visible from outside. The temperature of the graphite electrodes were acceptable.

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. With a higher number of chambers it is even possible to build a gap which does not create any follow currents at all since the arcing voltage as shown in (1) is then higher than the peak of the power supply voltage.

The series connection of spark gaps requires special measures for triggering at the high rate of rise voltage which is given in the standards for lighting arresters as 1,2/50µs [5]. In fig 6 the first upper gap triggers at first followed by the next due to capacitive voltage grading.

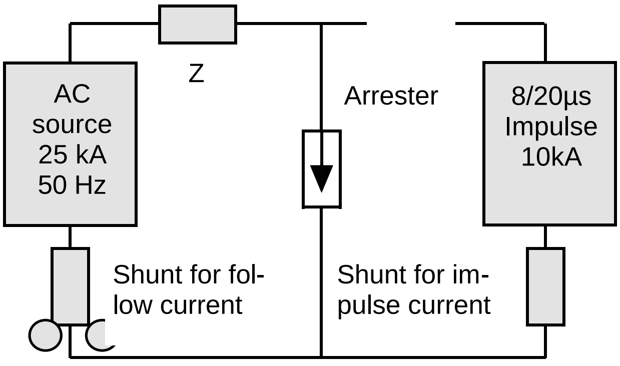
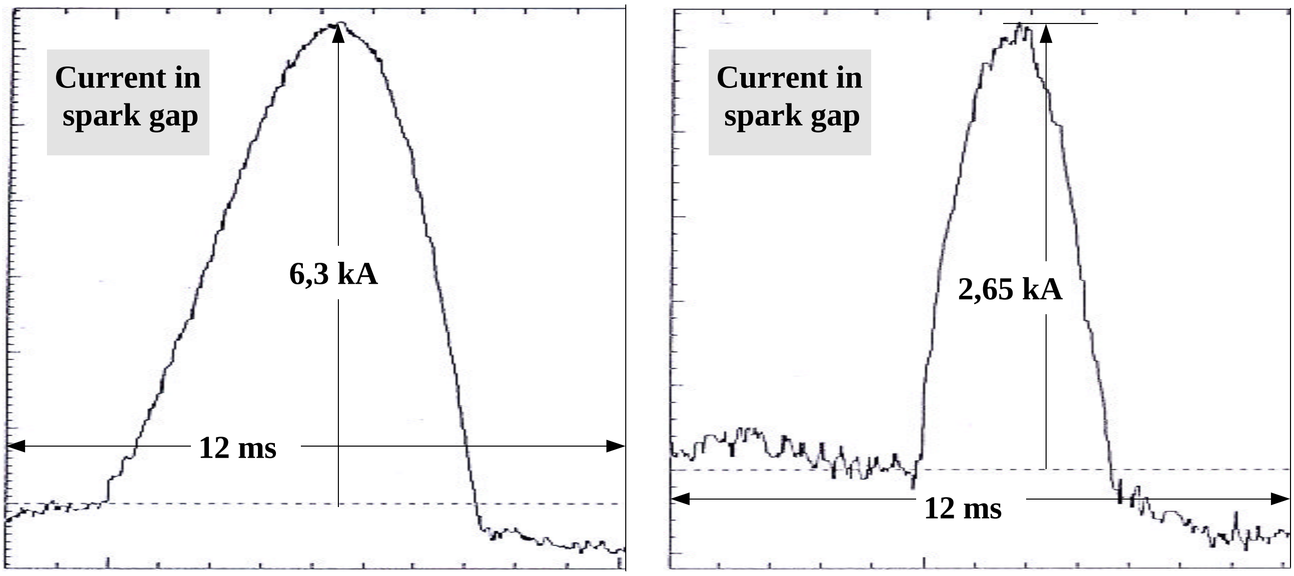
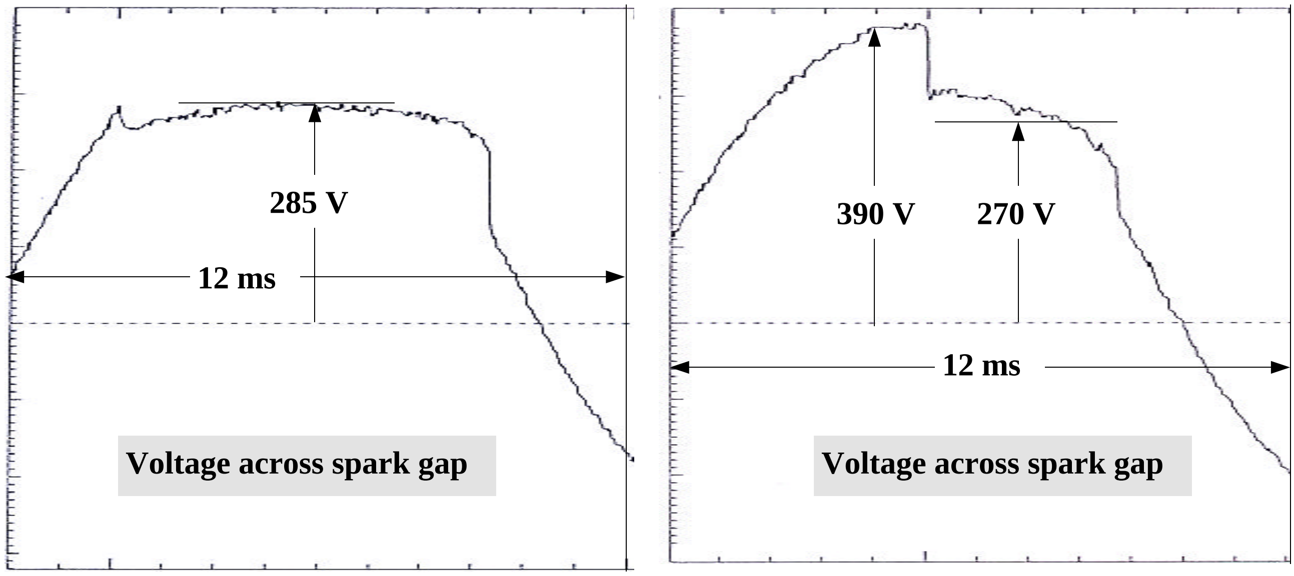


Fig.7 Principle test arrangement for combined testing of gap arresters with surge current and follow current.



Current with trigger point 30 degrees

Current with trigger point 90 degrees



Voltage with trigger point 30 degrees.

Voltage with trigger point 90 degrees.

Fig.8 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 current of I_P 25 kA. The trigger point was set to 30 degrees and 90 degrees. The voltage across the gap and the current in the gap were measured . Data reproduced as section from original oscillogramms for better reproduction.
Please note: Only the follow current of the AC source is shown in above oscillogramms.
Tests were performed at IPH Berlin.

Fig. 9 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 gap, compare fig.6. For comparison: The spark gap arrester according to [2] includes only a small rod to rod gap. Fig.9 shows also the successive trigger of all gaps of the multiple spark gap arrester. Also the arcing voltage can be compared in fig.9. The spark gap arrester with one gap only provides a few 10 volts of arcing voltage and the multiple spark gap shows some 100 volts.

Fig 10 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 voltage time curve in fig. 10 shows both the first and the final breakdown. From the voltage time curve one can conclude that the breakdown voltage remains near 2 kV up to large steepnesses of app. 20 kV/ µs.

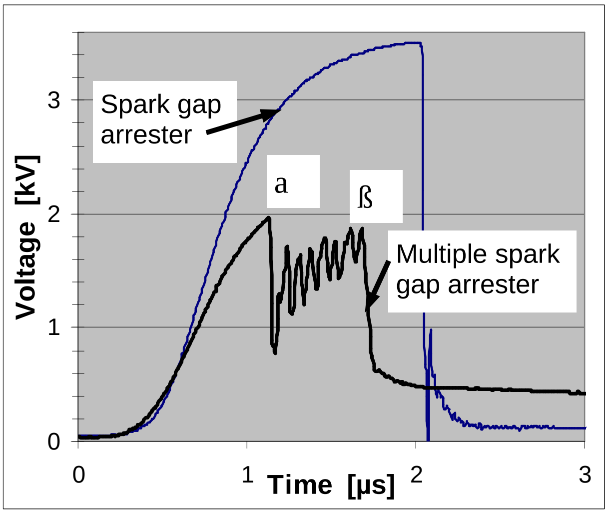


Fig.9 Voltage-time-characteristics of conventional spark gap arrester with one gap only compared with a multiple gap arrester with 9 gaps. The first breakdown of the multiple spark gap arrester is indicated with α, the final breakdown of the whole spark gap arrester is indicated with β.

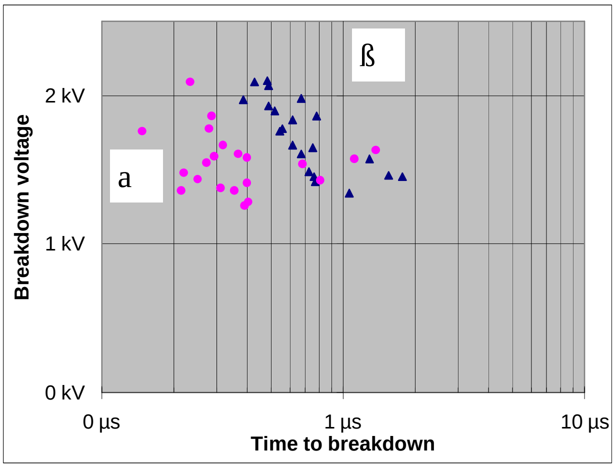


Fig.10 Voltage time characteristic of the multiple spark gap measured using lightning impulse voltage 1,2/50µs The time to breakdown and the corresponding breakdown voltage of the first gap is indicated with α and the time to breakdown of the complete 9 spark gaps and their corresponding breakdown voltage is indicated with β

4. CONCLUSIONS

The disadvantages of conventional open lightning arresters (exhaust of hot plasma, high inception voltage) can be avoided when a multiple spark gap arrester is installed in a closed chamber and the electrodes of the multiple spark gap are made of graphite.

The arc interruption principle is based on the utilisation of multiple anode and cathode voltage drop.

The multiple spark gap requires special measures to reach a successive trigger from the first to the final gap. It is realised using capacitive grading along the individual gaps.

Follow current interruption capability was successfully tested in an independent laboratory under 25 kA prospective short circuit current.

Using multiple spark gap arresters it is even possible to build lightning arresters which do not create any follow current at all.

Aging of electrodes does not occur compared to conventional metallic electrodes since graphite does not create any metallic plasma and abrasion of electrodes.

The voltage time characteristic of a multiple gap arrester shows a faster response compared to conventional one gap arresters.

5. REFERENCES

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