BEHAVIOUR OF CLASS I LIGHTNING CURRENT ARRESTERS UNDER VERY FAST TRANSIENT OVERVOLTAGES

J. Meppelink, J. Mehl
Meppelink@t-Online.de
Fachhochschule Südwestfalen University of Applied Sciences, Germany

J. Trinkwald
Trinkwald.tbs@obo.de
OBO Bettermann, Germany

Abstract: This paper contributes on the performance of class I lightning current arresters under very fast transient overvoltages (VFTO) in low voltage power mains. The behaviour of a class I-arrester under VFTO, generated e.g. by interruption of inductive load is not known. Especially the protection level under VFTO as well as the generation of follow current caused by VFTO is of importance for the performance. Two kinds of arresters will be discussed, the conventional single spark gap arresters and a new technology of multiple spark gap arresters. Network simulations and laboratory tests will give the answer to the above-mentioned questions.

Keywords: Very Fast Transient Overvoltage, Class I lightning current arrester, Voltage-time curve, Multiple spark gap arrester.

1 INTRODUCTION

The purpose of a class I arrester is the potential equalization in case of a direct stroke into the lightning protection installation. The performance under direct or indirect strokes has been tested in laboratory tests with 10/350µs current impulses and is state of art [1,2]. Internal switching operations such as interruption of inductive load or melting of fuses generate very fast transient overvoltages (VFTO). Such VFTO may trigger the class I arresters also. However, when a metal oxide overvoltage arrester is connected in parallel to the class I lightning current arrester, the overvoltage arrester can also limit the VFTO, depending on the distance of the overvoltage arrester from the class I arrester and the rate of rise of the VFTO.
The class B arrester should not spark-over at any VFTO below the protection level. However the protection level is defined for 1,2/50µs lightning over voltage. Each spark-over of a class I arrester may lead to a power mains follow current, which causes a voltage distortion as well as ageing of the spark gaps of the class I arresters and may also result in a interruption of a fuse.

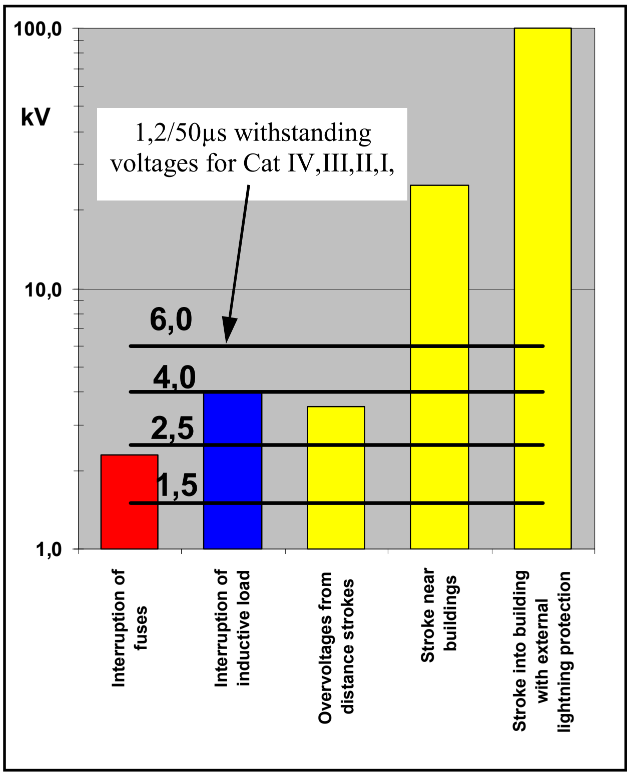

Fig.1 Overvoltages caused by switching operations and lightning strokes. Overvoltage data from published data. Stroke into building: 200 kA stroke distributed by 12,5% into the grounding resistor of 1 ohm. Stroke into building: 200 kA stroke distributed by 50% into the grounding resistor of 1 ohm.

2 OVERVOLTAGES IN POWER MAINS

Fig.1 shows the approximate values of overvoltages caused by switching operations as well as such caused by lightning strokes. Interruption of inductive load occurs frequently in low power mains. The generated overvoltage is of very fast rise time and occurs as multiple burst of fast transients. Such very fast overvoltages (VFTO) are characterised as burst impulses according to

[4]. To simulate VFTO in low power mains the standardised burst impulse 5/50 ns [4] can be used for simulations as well as for laboratory tests.

3 BEHAVIOUR OF LIGHTNING CURRENT ARRESTERS UNDER VERY FAST TRANSIENT OVERVOLTAGES

3.1 Multiple spark gap arresters

Multiple gap arresters are presented in [1]. Fig. 5b shows the LightningController MC 50-B VDE with 9 spark gaps. The equivalent circuit is shown in fig.2. The first gap is a real open gap without any resistor or capacitor to ground. All the other gaps are connected to a capacitive grading circuit (CE) as shown in fig. 2. When a burst impulse is applied to the circuit, the first gap will trigger at first. After the first gap has triggered the voltage appears across the second gap, depending on the ratio of the capacitance of the gap CP and the grading capacitance CE. Finally all gaps trigger if the voltage is sufficiently high which is the case at lightning overvoltages caused by direct or near by strokes.
It is interesting to find that very fast transient overvoltages trigger some of the first gaps but the last or some of the last gaps cannot trigger because the capacitive grading circuit acts as a parametric filter. The capacitance of the grading circuit absorbs the energy of the very fast transient overvoltage. Fig.3a shows a computer simulation [5] of the behaviour of the LightningController MC 50-B VDE under a 5/50 ns single impulse with a prospective value of 2 kV, (refer to v(open circuit) in fig.3a)). The arrester does not spark over completely because the steepness of the incoming burst impulse 5/50ns is reduced by the grading capacitors CE. At a voltage impulse 5/50 ns with a prospective value of 4,8 kV and above, the arrester shows a complete spark over at app. 1,25 kV as shown in fig.3b. The residual voltage after the spark-over is the sum of the anode and cathode voltage drop as shown in fig 3b after the

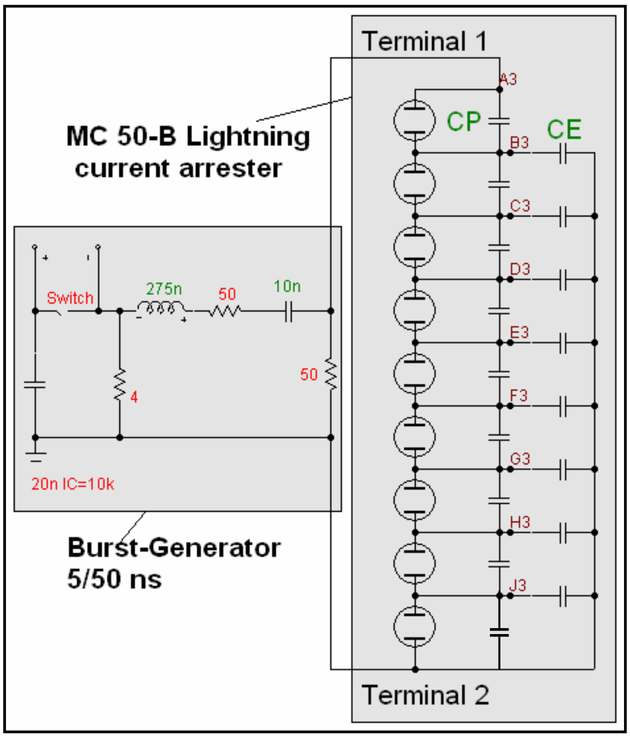

Fig.2 Equivalent circuit of a multiple gap LightningController MC 50-B VDE which is connected to a burst impulse generator. CP: Parallel capacitance of the gap. CE: Grading capacitor.

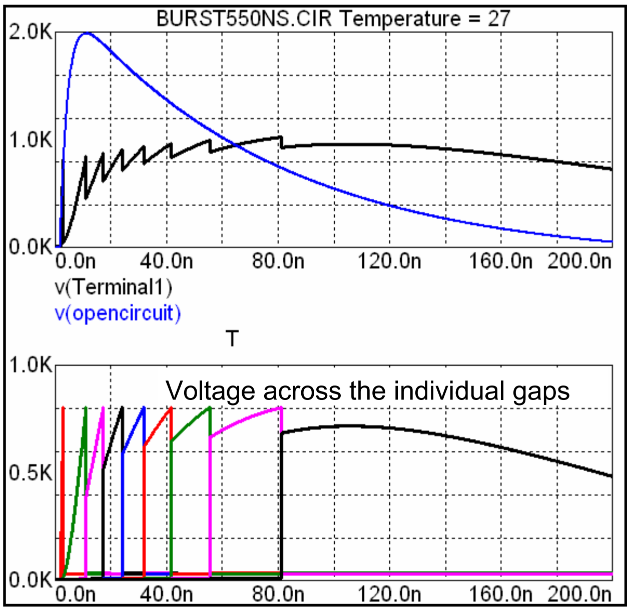

Fig.3a Arrester under 5/50ns impulse with 2 kV prospective peak value without complete triggering.

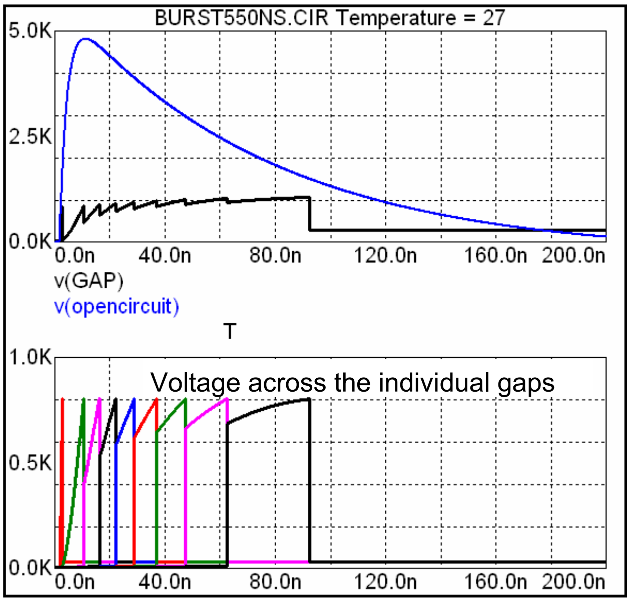

Fig.3b Arrester under 5/50ns impulse with 4,8 kV prospective peak value with complete spark-over.

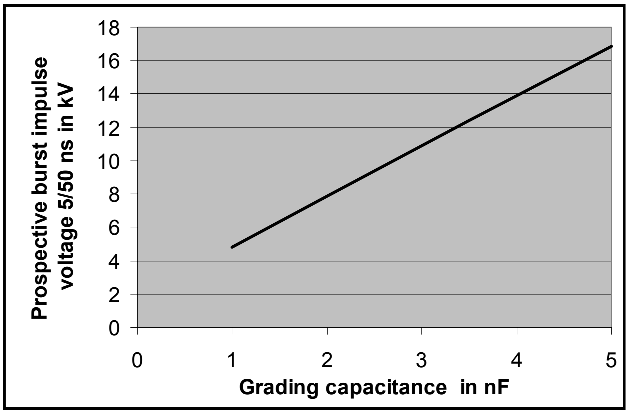

Fig.4 Prospective value of a burst impulse voltage 5/50 ns for triggering of a multiple gap MC 50-B VDE depending on the grading capacitance per gap.
Note: Prospective value is the open circuit voltage of the 5/50 ns impulse generator when no arrester is connected.

complete spark over.
The grading capacitors determine the spark-overvoltage of a multiple gap arrester as shown in fig.4. If the grading capacitance is increased, a higher prospective peak value of the 5/50 ns impulse is required to reach a complete spark-over. For example if a grading capacitor of 3 nF is used, a prospective burst voltage up to 11 kV peak would be absorbed by the capacitors of the arrester without a complete spark over and no mains follow current would occur. A prospective burst voltage above 12 kV peak would cause a complete spark-over of the arrester.
The transient behaviour was measured according to fig.5 using a impulse generator which was connected to the arrester via a coupling capacitor. The arrester was connected to the power mains in order to identify mains follow current. The impulses with a maximum peak value of 8,1 kV could be synchronised to the power mains voltage. The peak value of the burst impulse was increased to reach a spark over of the complete arrrester under test. By changing the phase angle the power mains follow current can be identified.
The dynamic behaviour of the arrester can be shown in a voltage time curve. To obtain these curves the arrester was directly connected without coupling capacitor and mains voltage.
To measure the time to breakdown of a multiple spark gap MC 50-B VDE with a residual voltage of some 100 volt, it is essential to measure the voltage across the last series connected spark gap. Therefore the voltage across the complete gap U1-9 as well as the voltage at the last series connected gap U9 was measured as indicated in fig. 5.
Up to a prospective peak voltage of 6,75 kV the multiple gap arrester does not spark over completely but absorbs the energy of the impulse voltage as shown in fig.6. The partial spark gaps 1-8 have triggered but the voltage across the last series connected gap U9 remains without

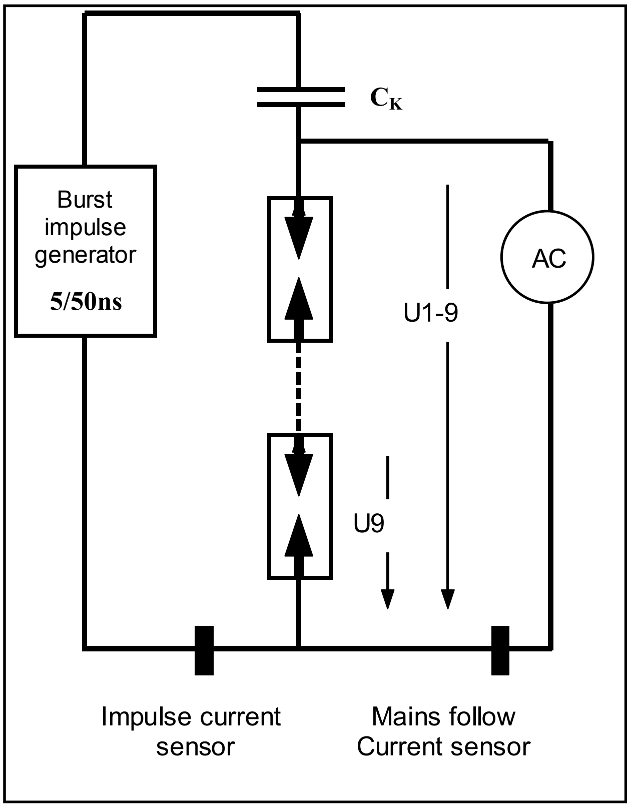

Fig. 5 a Laboratory test set up for measurement of the spark over voltage of a 9 stage multiple spark gap arrester MC 50-B VDE. CK: coupling capacitor.

Fig 5b LightningController MC 50-B VDE

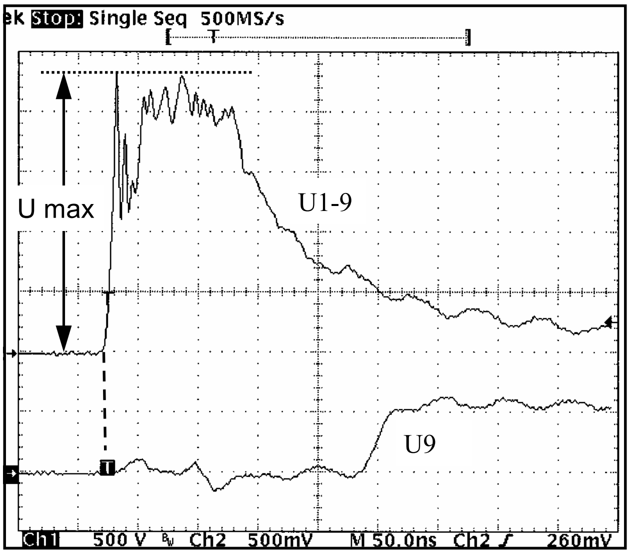

Fig.6 Voltage across the LightningController MC 50-B VDE with triggering of gap 1 to 8 but without breakdown. Prospective peak of the applied 5/50 ns voltage impulse 6,53 kV. CH1;CH2: 500 V/DIV.

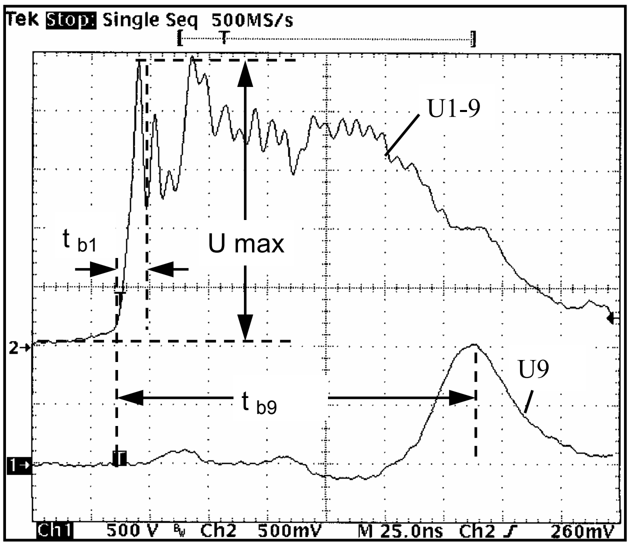

Fig.7 Voltage across the LighntingController 50-B with breakdown. Prospective peak of the applied 5/50 ns voltage impulse 7,2 kV. tb1: time to break down of the first gap. tb9: time to break down of all gaps. CH1,CH2: 500 V/DIV.

spark over. The prospective peak value of the applied 5/50ns impulse was 6,53 kV but the arrester limits the voltage to a value of U max = 2,3 kV due to the grading capacitance which acts as a parametric filter.
If the prospective peak value is increased above 6,75 kV all series connected gaps spark over but the voltage across the arrester is limited to 2,45 kV, refer to fig. 7.
Fig. 8 shows the voltage time curve of a MC-50-B VDE LightningController. The prospective peak value of the 5/50 ns impulse voltage was increased until the complete breakdown has been observed. This value was

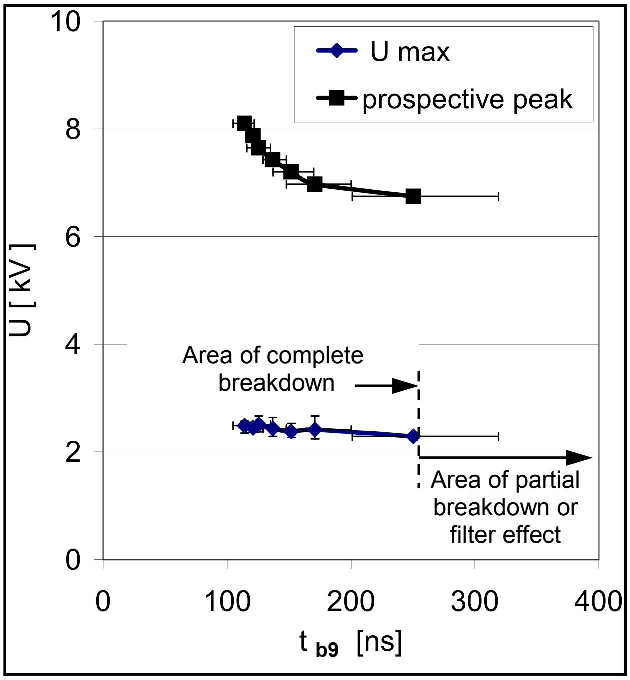

Fig 8: Voltage time curve for complete breakdown of a LighntingController MC50-B VDE under positive 5/50 ns impulse voltage. Prospective peak voltage and U max versus time to break down for breakdown of the complete gap.

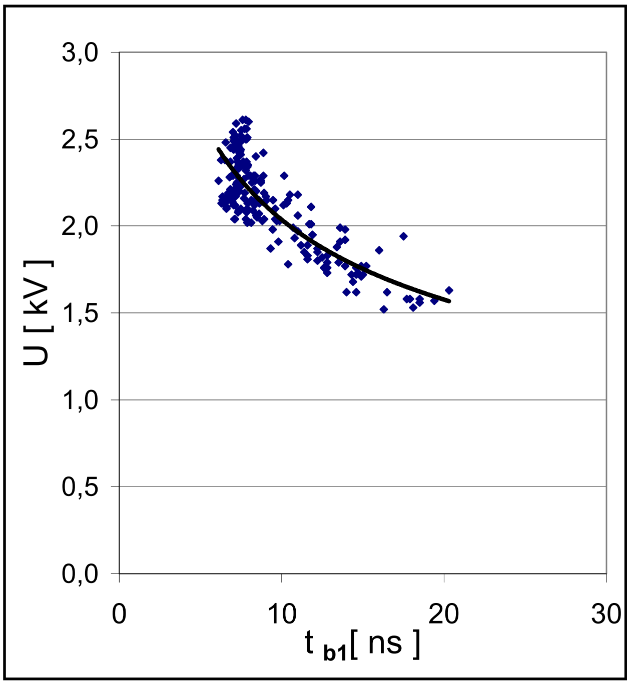

Fig.9: Voltage-time curve for the break down of the first gap for 5/50ns impulse voltage of positive polarity.

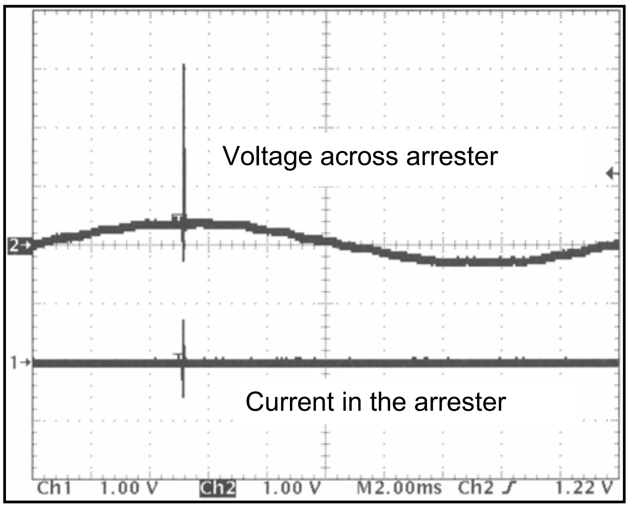

Fig. 10 Example of a combined test with power frequency mains voltage and superimposed very fast transient impulse 5/50ns. CH1 1,9A/DIV; CH2 1kV/DIV.

found to 6,75 kV peak. If an impulse voltage with a prospective value of < 6,75 kV is applied a number of the gaps will trigger and absorb the energy but no final break down occurs. This is the case when the voltage measured across the last gap Nr. 9 remains without breakdown as shown in fig 6. This area is indicated in fig. 8 as "Area of partial breakdown of filter effect".
When the prospective peak value is increased to values above 6,75 kV the MC 50-B VDE LightningController will show a complete breakdown.
The voltage across the terminals of the MC 50-B VDE LightningController is less 2,6kV even for a prospective voltage of 8 kV.
Fig. 9 shows the voltage time curve for the breakdown of the first gap only with high time resolution. The first gap acts very fast and limits the overvoltage even under very fast transient overvoltages to a value which is inside Cat III and II requirements according to fig.1.
Fig. 10 shows an example of a test with superimposed 5/50ns impulse on the power frequency mains voltage.

3.2 Single spark gap arresters

Fig. 11 shows the internal parts of a single spark gap lighting current arrester LA 60-B. In case of spark-over and subsequent flow of a lightning current as well as a mains follow current, this kind of arrester extends the arc between the electrodes and blows out hot ionised plasma.
The voltage time curve was measured according to fig. 12. As shown in fig.13 the break down voltage is much higher compared to the multiple gap arrester as shown in fig. 7. The voltage-time curve of the single spark gap lightning current arrester LA 60-B is shown in fig. 14. It is clearly to see that this single gap arrester sparks-over at higher voltages as permitted according to fig1. How ever the values in fig. 1 are valid for 1,2/50 µs. At fast

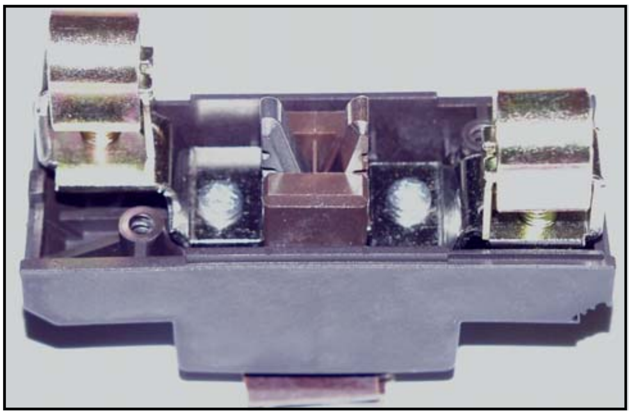

Fig.11 Lightning current arrester LA 60-B with one spark gap and open exhaust chamber.

transient overvoltages 5/50 ns the single spark gap arrester will trigger at values above 6 kV which stresses adjacent equipment or the insulation if the class II metal oxide overvoltage arrester is some meters away.
The comparison of the tested conventional one gap-arresters with a multiple spark gap arrester MC 50-B VDE is shown in fig. 14 and shows the advantage of the LightningController MC 50-B VDE.

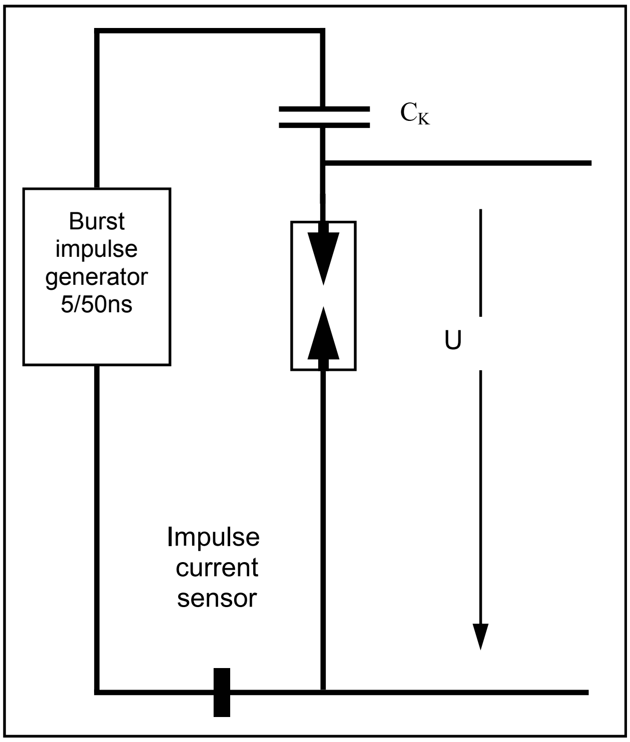

Fig.12 Test circuit for measurement of the spark over voltage of a single spark gap arrester LA 60-B.

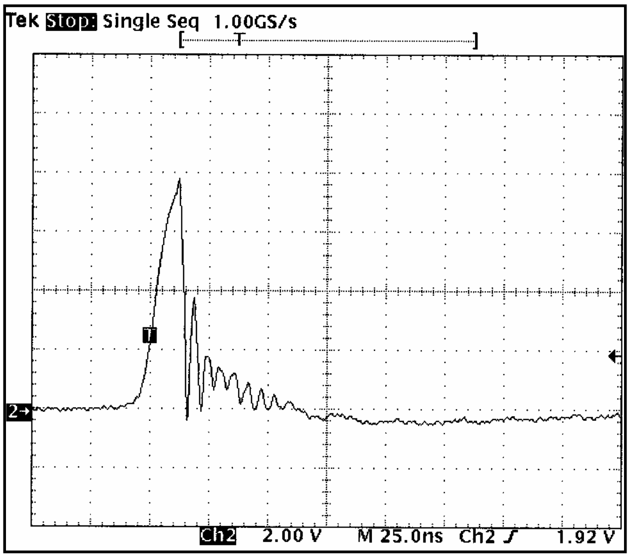

Fig. 13 spark-over of a single gap lightning current arrester LA 60-B at 5/50ns impulse. 2kV/DIV.

4 CONCLUSIONS

At 5/50 ns voltage impulses conventional one spark gap lightning current arresters show a breakdown voltage far above the insulation category IV. In such a case the insulation and adjacent equipment will be over stressed when the class II metal oxide overvoltage arrester is some m away. A deep investigation including travelling waves in such installation is required. The multiple spark gap LightningController MC 50-B VDE has the advantage of a capacitive grading circuit which acts as a parametric filter and absorbs part of the energy of the incoming voltage impulse 5/50 ns. The measured voltage-time curve shows a very good behaviour and remains below 2,5 kV. This behaviour can be designed by the value of the capacitance of the grading capacitors. Independent on the position of the Class II metal oxide overvoltage arrester the LightningController MC 50-B VDE provides full protection under a 5/50 ns burst impulse.

5 REFERENCES

[1] Jan Meppelink, Jürgen Trinkwald: New technology of spark gap arresters for protection of 130 volt low power mains.VI International Symposium on Lightning Protection, 2001, Santos, Brazil

[2] J. Meppelink, W. Höhnen; J. Trinkwald Insulation coordination of arresters in TT-net with a nominal voltage of 130 Volt. VI International Symposium on Lightning Protection, 2001, Santos, Brazil

[3] Jan Meppelink, Andreas König; Jürgen Trinkwald; Reliable Class B-Protection of telecommunication towers using lightning current arresters and circuit breakers. VI International Symposium on Lightning Protection, 2001, Santos, Brazil.

[4] IEC 1004-4-4 Electromagnetic compatibility (EMC); Part 4: Testing and measuring techniques; Section 4: electrical fast transient/burst immunity test.

[5] Micro-Cap 6 www.spectrum-soft.com

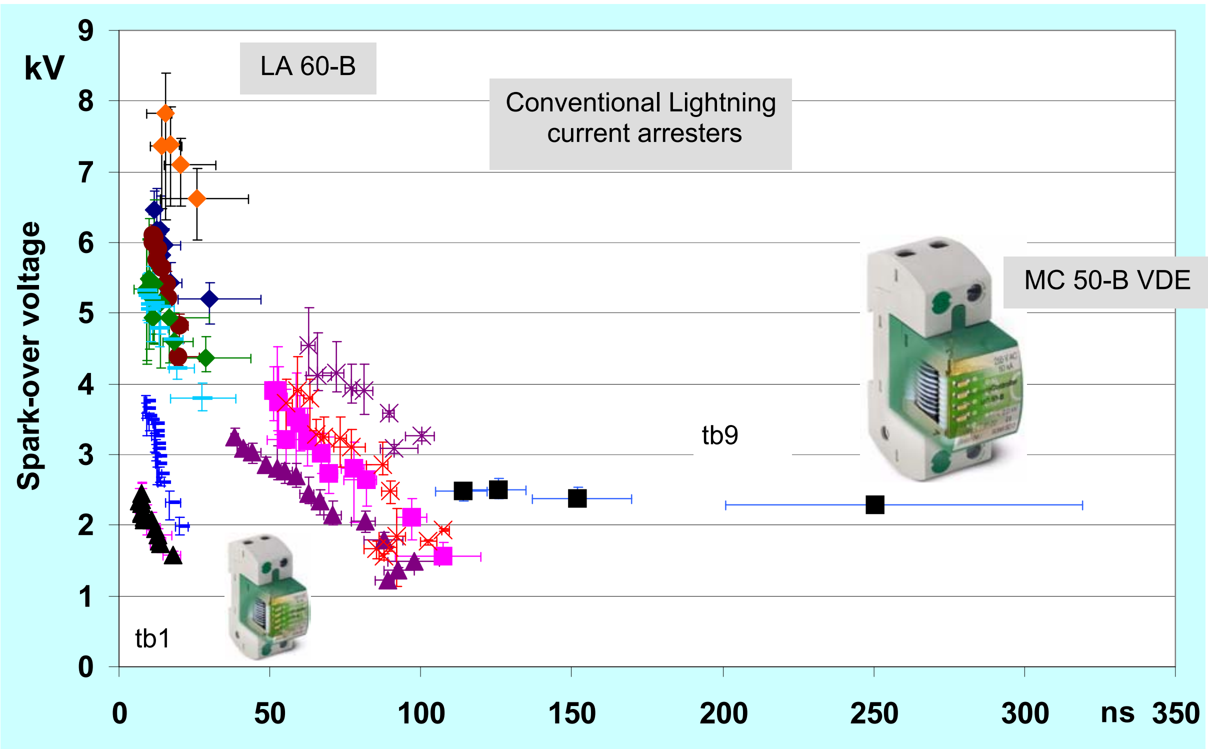

Fig. 14 Comparison of a Lightningcontroller MC 50-B VDE with a single spark gap arrester LA 60-B and others.