# A CONTRIBUTION TO THE BEHAVIOUR OF LOW VOLTAGE CIRCUIT BREAKERS UNDER LIGHTNING IMPULSE CURRENT 10/350µs

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**Abstract**

**If lightning current arresters are installed in low voltage installations, the lightning impulse current will flow to app. 50% through the earth and to 50% through the low voltage installation. The lightning current will pass the main fuse at the entrance of the power supply into the building. There are cases with low power consumption such as mobile phone telecommunication stations which are protected by a fuse with a nominal current of 25 ...35 A. Such fuses may explode under full level of lightning impulse current 10/350 µs. How can such problem be solved? One solution can be a low voltage circuit breaker instead of a fuse. The aim of this paper is to show the effect of lightning current to circuit breakers in comparison to fuses .**

**Keywords:** Lightning arrester, Fuse, circuit breaker, 10/350µs Lightning impulse current.

## 1. INTRODUCTION

The basic functions of lightning arresters are shown in Table 1. As lightning arresters spark gap arresters or metal oxide varistors are used for potential equalisation. Overvoltage arresters with metal oxide varistors are used for overvoltage limitation. Both functions of potential equalisation and overvoltage limitation can be combined in one overvoltage arrester with sufficient current carrying capability in some applications. For optimal protection the combination of lightning arresters with spark gap and overvoltage arresters is used with a decoupling of both elements using a coil with an inductance of some 7-15 µH. Fig. 1 shows the principle. If the required power is low, e.g. 35 A Fuse F1, the lightning current through the lightning arrester will melt the fuse and the power supply is interrupted. Furthermore the fuse will explode under high lightning currents as shown in fig.5. To provide power also after a lightning has passed the low voltage installation, the

**Table 1** Basic functions of lightning arresters.

| **Trigger** | **Carry lightning current** | **Interrupt follow current** |
|---|---|---|
| Trigger < 4 kV | Potential equalisation | Carry follow current |
| Constant spark over voltage | At multiple lightning currents | Interrupt follow current at multiple lightning currents |
| Trigger also in case of multiple lightning currents | Capable to withstand short circuit current | Dielectric strength after interruption of follow current |

fuse can be replaced by a automatic cut-out or by a circuit breaker. Table 2 summarises the performance

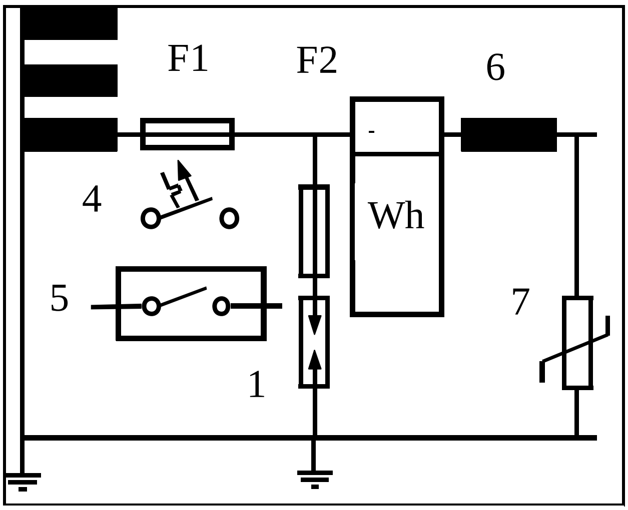



**Fig.1.** Simplified principle of the installation of lightning arrester (1) with overvoltage arrester (7) decoupled using a coil (6). F1,F2, Fuses. 4: Alternative MCB. 5: Alternative circuit breaker.

**Table 2.** Comparison of parameters of fuses, automatic cut-out and circuit breakers acc. to manufacturers data.

| **Properties** | **Fuse Example NH 16 -50A** | **Automatic cut-out Example LS 16-50 A** | **Circuit breaker Over current tripping 16-40 A Short circuit tripping 400 A** |
|---|---|---|---|
| Breaking capacity | > 100 kA, 690V | 3,6 or 10 kA | 50 up to 100 kA 380/415V |
| Additional arcing chamber | No | Yes, but small | Yes |
| Remote operation after trip | No | No | Yes |
| Indication of trip | No | No | Yes |
| Reclosure:<br>after overload<br>after short circuit<br>after lightning | <br>No<br>No<br>No | Manually<br>Yes<br>Yes, dep. on conditions<br>Yes, dep. on conditions | Remote operation<br>Yes<br>Yes, dep. on conditions<br>Yes, dep. on conditions |
| Overload protection (Line) | Sufficient | Good | Good |
| Short circuit protection (Line) | Very good | Good | Good |
| Aging | Pre damage of fusing conductor | Making and breaking | Making and breaking |

parameters of automatic cut-out and circuit breakers compared with a fuse. The performance of circuit breakers under lightning currents is not known. Therefore a series of commercial available circuit breakers (C.B.) from different manufacturers as shown in table 3 has been studied. The aim of the tests was to find out :

- What causes opening of the C.B.?
- Do the contacts melt on their surface?
- What causes a trip of the C.B.?
- Does the contact resistance change?
- Does the trip characteristic change ?
- What level of lightning current damages the C.B. ?

**Table 3.** Data of the circuit breakers**.**

| **Breaker Nr.:** | **Rated current [A]** | **Thermal circuit breaking-current set to: [A]** | **Trip current set to: [A]** | **Rated-breaking current [kA]** |
|---|---|---|---|---|
| **A** | 125 | 125 | 1250 | 25 |
| **B** | 125 | 63 | 630 | 25 |
| **C** | 125 | 16 | 500 | 25 |
| **D** | 160 | 100 | 600 | 100 |
| **E** | 160 | 160 | 800 | 50 |
| **F** | 160 | 25 | 250 | 50 |
| **G** | 250 | 200 | 1500 | 100 |
| **H** | 160 | 125 | 1920 | 65 |
| **I** | 40 | 25 | 320 | 35 |
| **J** | 100 | 100 | 800 | 40 |
| **K** | 100 | 50 | 400 | 40 |
| **L** | 100 | 16 | 400 | 40 |
| **M** | 100 | 100 | 800 | 25 |
| **N** | 80 | 80 | 680 | 10 |
| **O** | 10 | 10 | 142 | 3 |

## 2. EXPERIMENTAL TEST SET UP

Fig.2 shows the experimental test arrangement. A 10/350µs impulse current was injected into the breaker under test. A still camera was used to record the arcing phenomena. To identify the moment when the contact of the C.B. lifts off a DC source was connected parallel and a measuring current of 100 mA was injected into the C.B. This current was measured as voltage drop u(t) across a resistor. During the impact of the current onto the C.B. a relief motion occurs which is caused by current forces on the contact surfaces as well as by electrodynamic forces from the array of the loop of the contact connection.

Fig.3 shows the measured voltage u(t) and the current through the breaker contact i(t), compare fig. 2. With the inception of the lightning impulse current the contact starts to move which interrupts the current from the DC-Source and results in a voltage drop. After the lightning impulse current is zero, the movement reverses, the breaker is closed. After 6,5 ms the C.B. opens completey (trip) due to the injected energy which interacts with the mechanical opening systems of the C.B.

Fig. 4 shows an example from another shot of the measured voltage across the contact of the C.B. If the C.B. opens the arcing voltage can be observed for the duration of current flow over the contact of the C.B.. If the C.B. opens complete the voltage across the contact rises as shown in the figure and indicates that event.
Please note, both oscillograms in fig3 and fig. 4 are taken from different shots.

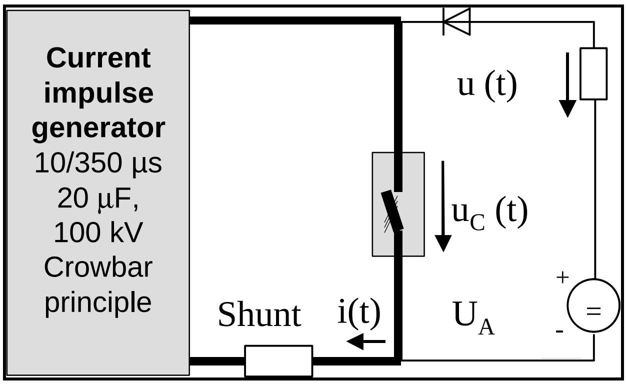



**Fig. 2.** Test arrangement for investigation of C.B. under 10/350 µs impulse currents.

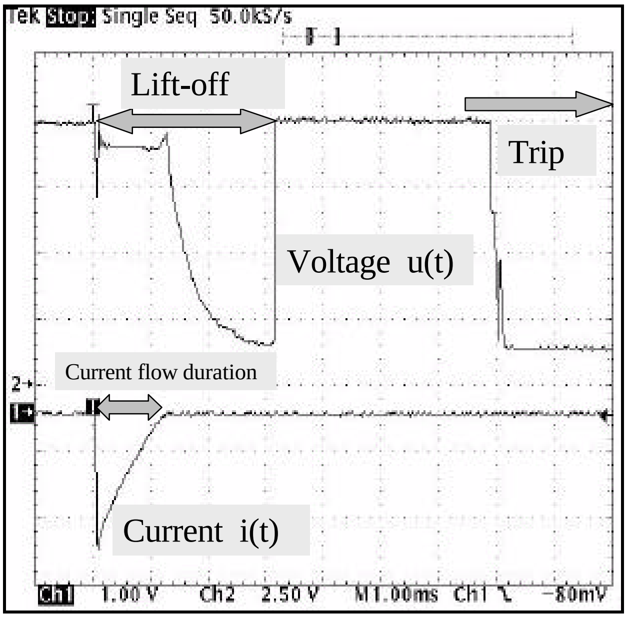



**Fig.3.** Voltage u(t) and current i(t) measured in the test arrangement according to fig.2. Current is measured in one contact only, peak current 16 kA.

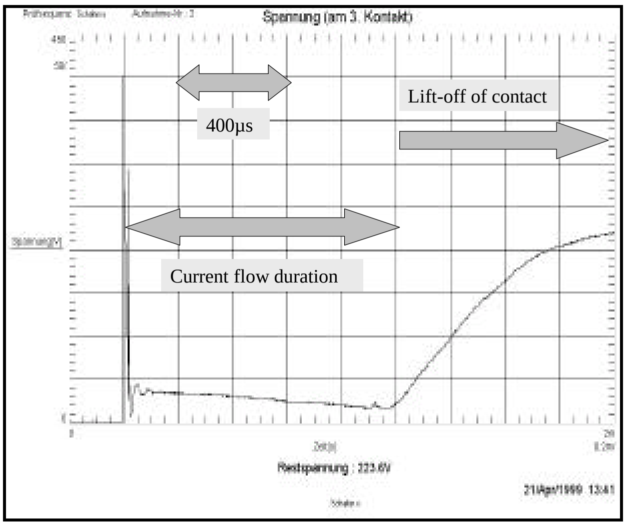



**Fig. 4.** Voltage $u_C(t)$ and current measured in the test arrangement according to fig.2. This is not the same shot as shown in fig.3. Time scale: 200µs/Div, Voltage: 50V/Div.

## 3. RESULTS OF TESTS

### 3.1 Measured Contact lift-off duration and contact opening time

From the measured data the movement of the contact could be derived from oscillogramms, shown as examples in fig.3 and 4. The contact lift-off duration as well as the contact opening time (trip) depend on the specific energy W/R (1) of the injected lightning current impulse.

$$W/R = \int_0^\infty i^2(t)dt \tag{1}$$

This effect can be explained by the fact that the force impulse P (2) is the root cause for the movement of the contact.

$$P = \int_0^\infty F(t)dt \approx k\int_0^\infty i^2(t)dt \tag{2}$$

Up to a certain value of the specific energy W/R (1), which depends on the C.B., only lift off is observed. With increasing specific energy the C.B. will finally trip. The experimental results are shown in fig. 5 and 6.

### 3.2 Mechanism of damage

The limit for the damage of the C.B. depends for the various C.B. on the internal construction . The specific energy of the lightning impulse current causes the damage. Compared to a fuse which can explode during a lightning current stress the housing of the C.B. will just crack without flying parts as observed with an exploding fuse.

### 3.3 Change of contact resistance.

The electric resistance does not change much after a series of shots. During lift off of the contact an arc burns with anode and cathode fall voltage. The energy dissipation in the surface of the contacts leads to some melted areas on the surface. Fig. 7 shows the normalised resistance of contacts of a sample C.B. after a series of shots with lightning impulse current 10/350µs. Fig. 8 and 9 show the surface pictures after the current stress according to fig.7.

### 3.4 Change of trip-characteristic.

The trip characteristic did not change after a series of surge currents because of a very small scatter in measured time values from shot to shot.

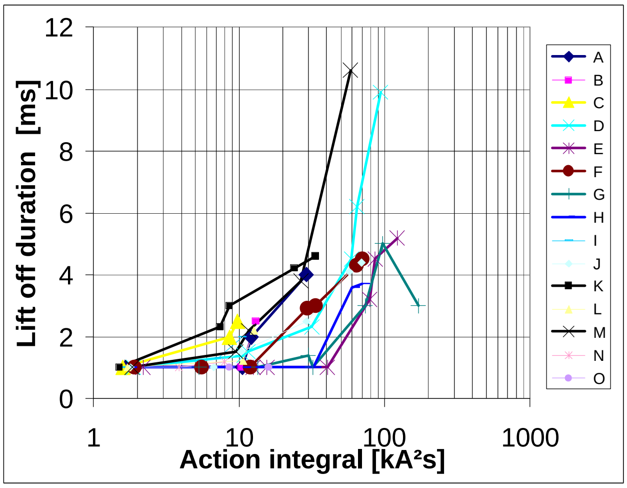



**Fig.5.** Lift off duration depending on specific energy of the injected lightning current impulse 10/350µs for the circuit breaker according to table 3.

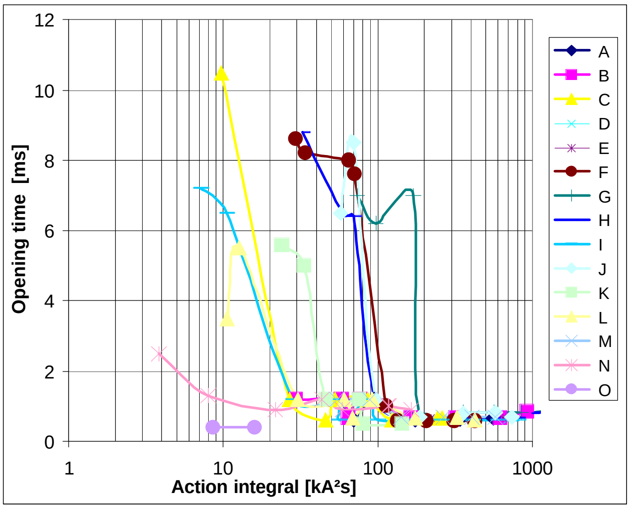



**Fig.6.** Opening time (time to trip) depending on specific energy of the injected lightning current impulse 10/350µs for the circuit breaker according to table 3.

## 3.5. Arcing of contacts

The arcing of contacts is shown in fig.8 and 9. The pictures were taken by a still camera. All three contacts were connected to the impulse generator. It can be observed that all the contacts start to arc. The intensity increases with the peak of the applied surge current 10/350µs.

## 4. COMPARISON BETWEEN FUSE AND CIRCUIT BREAKER

The circuit breaker can be installed with advantages in case of low power installation e.g. mobile telecommunication towers, small buildings, etc. In such cases the fuse of the incoming line protection is about 35....63 A.

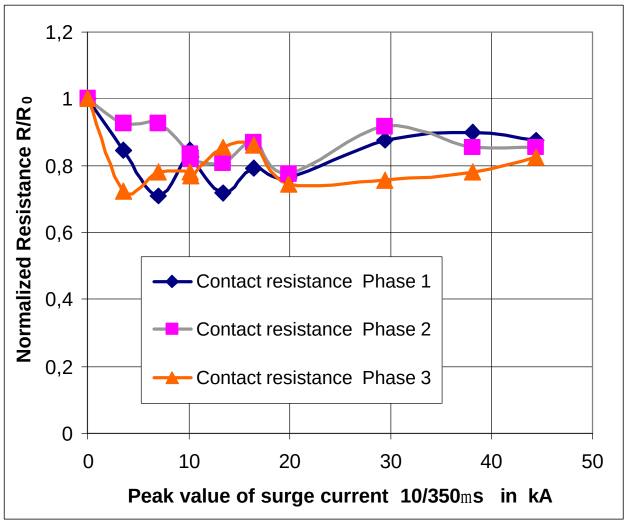



**Fig.7.** Normalised resistance of a sample contact after a series of lightning impulse current applications 10/350µs.

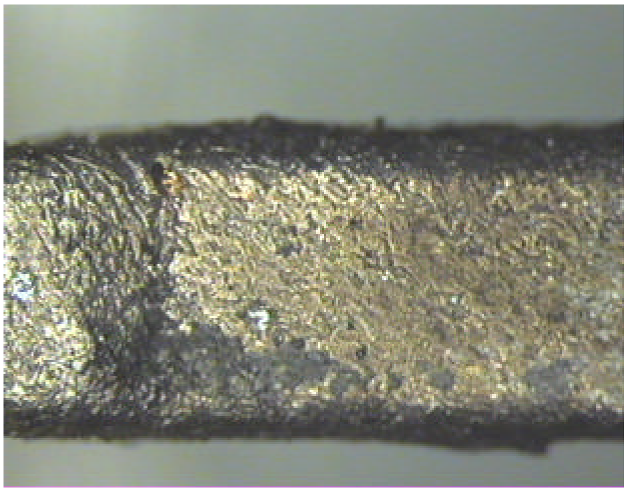


**Fig.8.** Surface of the sample contact after a series of lightning impulse current applications 10/350µs. Shown is the moving contact.

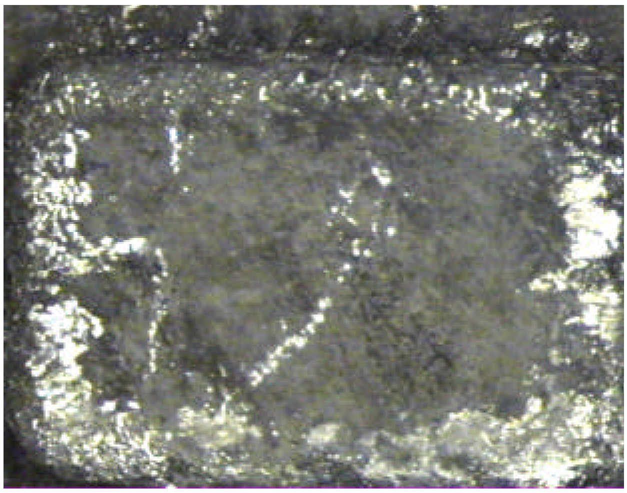
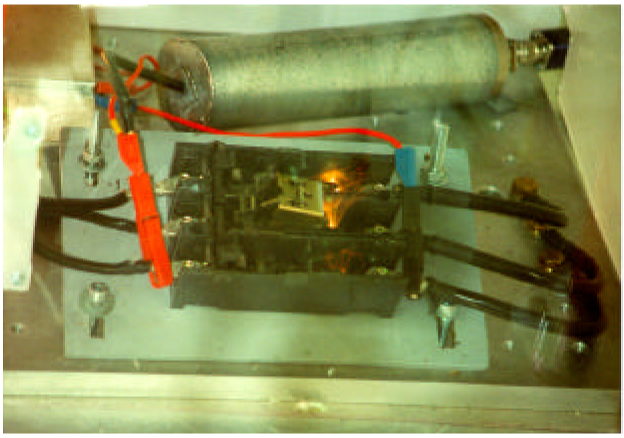
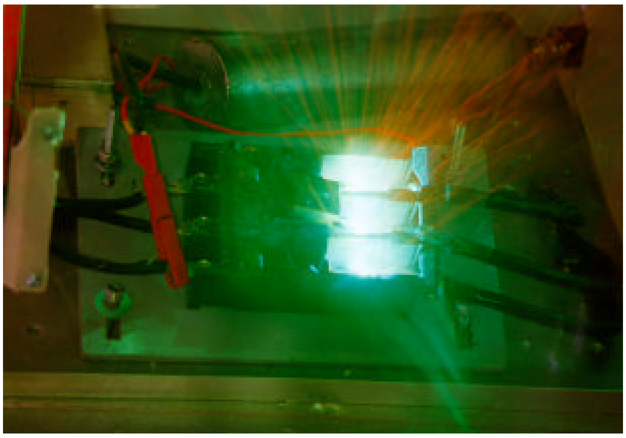


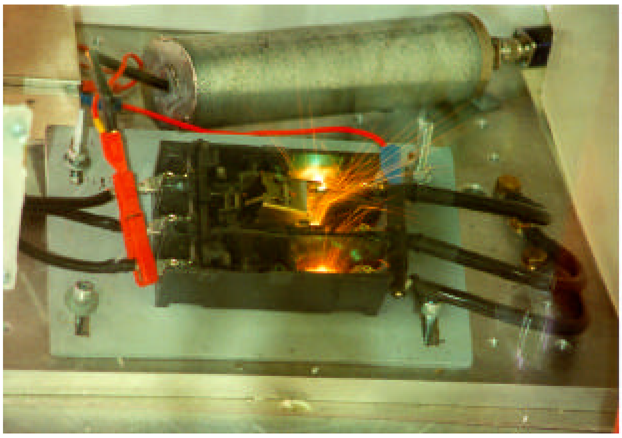
**Fig.9.** As per fig. 8, but shown is the fixed contact.



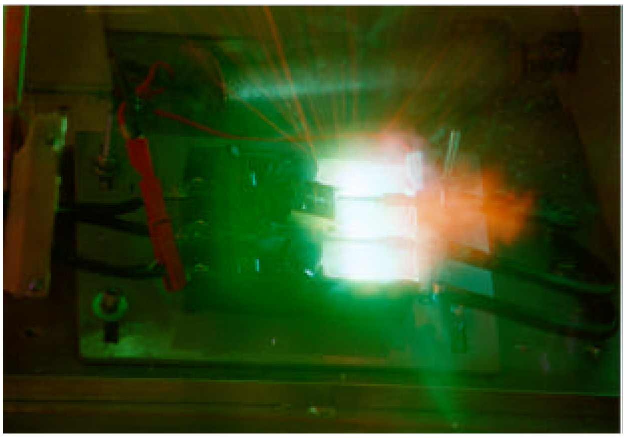
**a) 3,3 kA per contact**



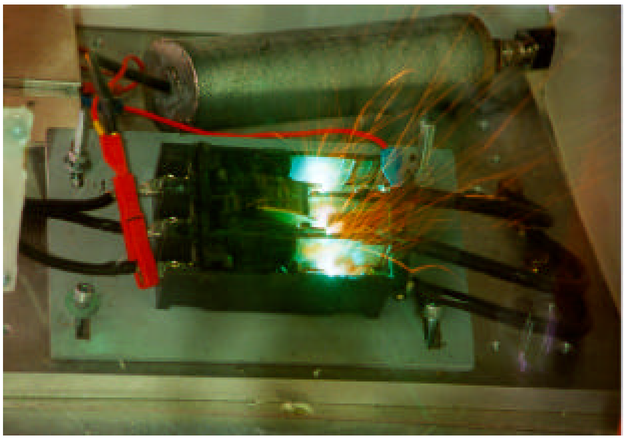
**d) 13,3 kA per contact**



**b) 6,7 kA per contact**



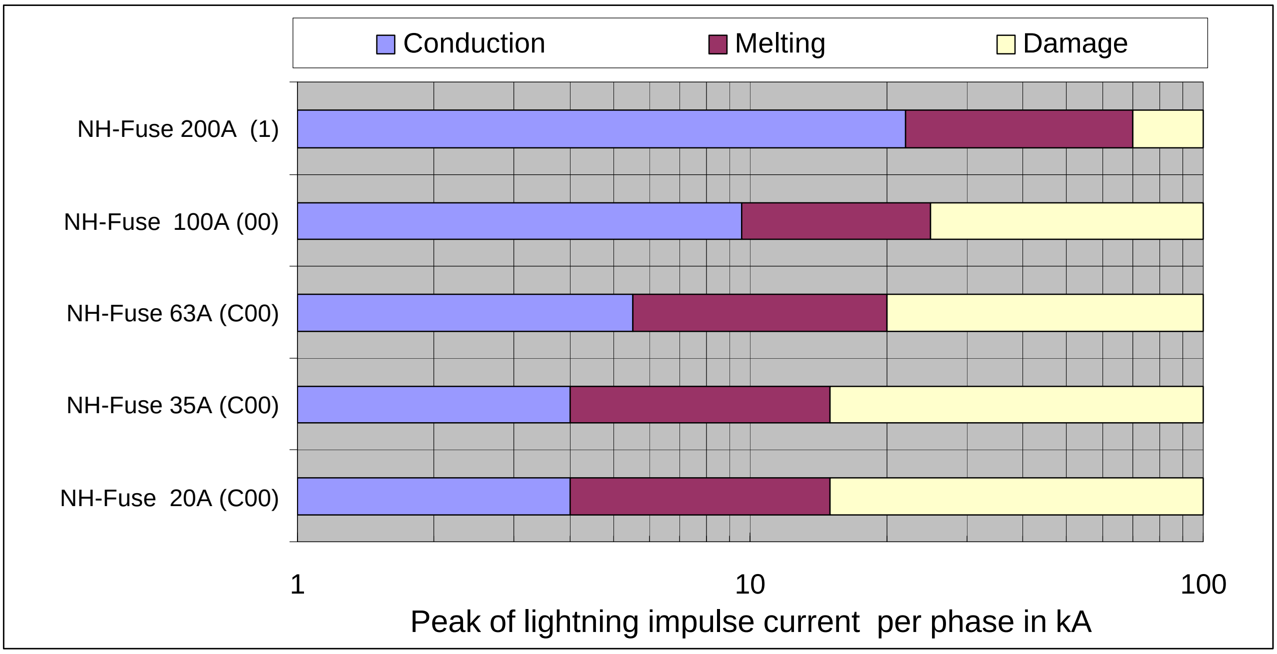
**e) 16,6 kA per contact**



**c) 10 kA per Contact**

**Fig.10. a)...e):** Still pictures from arcing of contacts during application of lightning impulse current 10/350µs. The indicated currents are the current through only one contact. This particular C.B. was not damaged. The cover of the housing was removed for better access to the arcing phenomena.

For such cases the fuse will be damaged in case of a lightning current 10/350. It is the question when the fuse can be used and when does a circuit breaker has advantages. First of all the values of fuses [1] and C.B. are compared in fig. 11. The results in fig.11 show that e.g. a fuse of 20..35 A can be replaced with a circuit breaker F25A. The fuses melt from 4 kA upwards and explode at 15 kA upwards. The circuit breaker F25A leads the lightning current up to 20 kA per contact ( 60 kA for all three phases) without trip and provides the required over current protection as well as the short circuit protection. If it is considered that the lightning current will flow to 50 % into the local earth and to 50 % into the network, the circuit breaker would successfully perform at a lightning stroke of 120 kA into the external lightning protection. On the other hand the circuit breaker F25A will trip in case of lightning currents above 60kA for all three phases but can be reclosed again. The worst case of a 200 kA stroke can be handled with such a breaker. On the other hand circuit breakers with higher rated currents can be used. The breaker E (compare table 3) can lead the lightning current without trip up to 30kA per contact ( 120 kA for all three phases and neutral conductor) and would survive a lightning stroke of 240 kA.



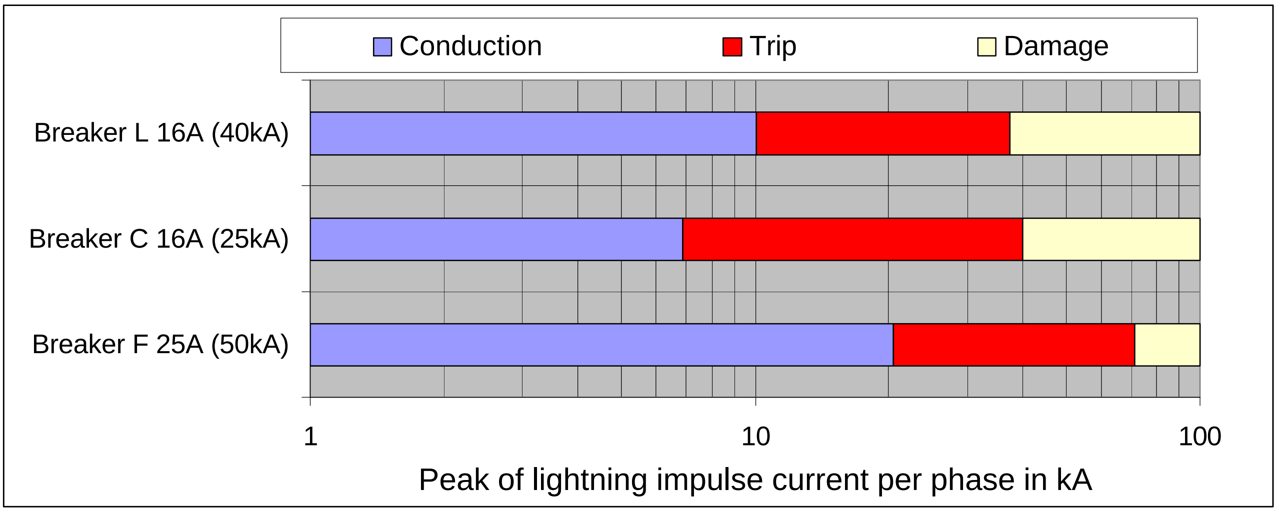




**Fig.11.** Comparison of fuses and circuit breakers versus peak value of surge current 10/350µs for area of conduction, melting, trip and damage. Upper diagram: fuses, lower: circuit breakers.

## 5. CONCLUSIONS

Fuses do explode under lightning current stress depending on their rated current, especially for the lower values which are used in installations with low power consumption. In case of a lightning stroke into the external protection, these fuses melt followed by interruption of power supply. In some cases, e.g., mobile telecommunication stations, continuous operation is required. For such cases the fuse can be replaced by an appropriate circuit breaker of same over current protection and short circuit protection. Such breaker can handle a 4 times higher current compared to a 25..35A fuse and can be reclosed in case of a trip, even remotely. In case of the ultimate performance requirements a breaker with higher rated current can be used because with a circuit breaker the over current trip level as well as the short circuit trip level can be adjusted for a case of lower rated operating currents in the network.

The studied circuit breakers were provided by commercial suppliers. They were not specified for lightning current data. The feed back of the results to the manufacturers might lead to even better performing circuit breakers under lightning impulse currents.

## 6. REFERENCES

[1] Noack,F. Schönau,J.; Brocke,R.: Einfluß der Blitzstromtragfähigkeit von Überstromschutzeinrichtungen auf den Blitzschutz in Niederspannungsnetzen. VDE/ABB-Fachtagung 1997. VDE Fachbericht 52, 1997 VDE Verlag.