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EVALUATION OF FUSES FOR PROTECTION OF LIGHTNING CURRENTE ARRESTERS CLOSE TO TRANSFORMERS OF HIGH RATED POWER

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Abstract: Class I lightning current arresters in low voltage power systems need a protection by a fuse if the actual short circuit current at the location of the arrester is higher than the rated short circuit current. The aim of this paper is to focus on the installation problems near a transformer station with high rated power.

1 Introduction

A lightning current arrester has to divert the lightning current into the power mains and has also to interrupt the power mains follow current. In installations far from a power transformer the lightning current is equally distributed over the phase and neutral conductors and the prospective power mains follow current is limited by the impedance of the power cable and the impedance of the transformer.

If the lightning current arrester is placed some meters away from a transformer the lightning current flows mainly over the neutral conductor and the prospective power mains follow current will be very high.

The rated short circuit current of a lightning current arrester has to be evaluated in a high power test lab according to IEC standard 61643-1. If the prospective short circuit current of a system is higher than the rated short circuit current of the lightning current arrester, a fuse is required to avoid a damage of the lightning current arrester.

To design such a protection, the value of the fuse has to be carefully evaluated under consideration of the impedances of the transformer and cable or bus bars and the short circuit current which is also depending on the arc interruption capability of the lightning current arrester and the characteristic of a fuse.

The evaluation of a fuse needs a calculation of the specific energy which stresses the fuse. The fuse characteristic is known from the fuse manufacturer. The impedances of transformers and cables can be calculated or taken from manufacturer's data. The lightning current arrester has to be represented as a model which provides the characteristic of the arcing voltage depending on the current. After collection of all these data a calculation can be performed using a commercial network analysis programme. As a result one can find the shape of the current and the specific energy which stresses the fuse. The correct fuse can be evaluated from a data base from the fuse manufacturer.

2 Short circuit current of transformers

The prospective short circuit current of a transformer (current appears at the short circuit at terminals of the transformer) is shown in fig.1. If a distribution is installed near the transformer, very high short circuit currents occur in case of a short circuit inside the distribution.

3 Lightning protection of a distribution

A protection of a distribution is required when the building has an external lightning protection. Using a class I arrester the low voltage distribution is protected against lightning currents and over voltages.

There are special cases where the actual prospective short circuit current at the location of the distribution is higher than the rated short circuit current of the arrester. In such cases the recommended fuse as declared by the manufacturer is no longer applicable. A careful selection of a fuse is required.

4 Evaluation of a fuse

The required fuse can be derived from the calculation of the actual current in the class I arrester when a lightning stroke hits the building. The current in the arrester will be an impulse current, followed by the mains follow current which depends on the instantaneous voltage phase angle of the mains voltage.
For such a calculation a model of a class I arrester is required which can be derived from the test data of the arrester.

4.1 Testing of the class I arrester

A preconditioning test according to /1/ is performed according to fig.2. A 8/20 current impulse triggers the class I arrester and the AC source will deliver the mains follow current. Fig.3 shows the result of such a

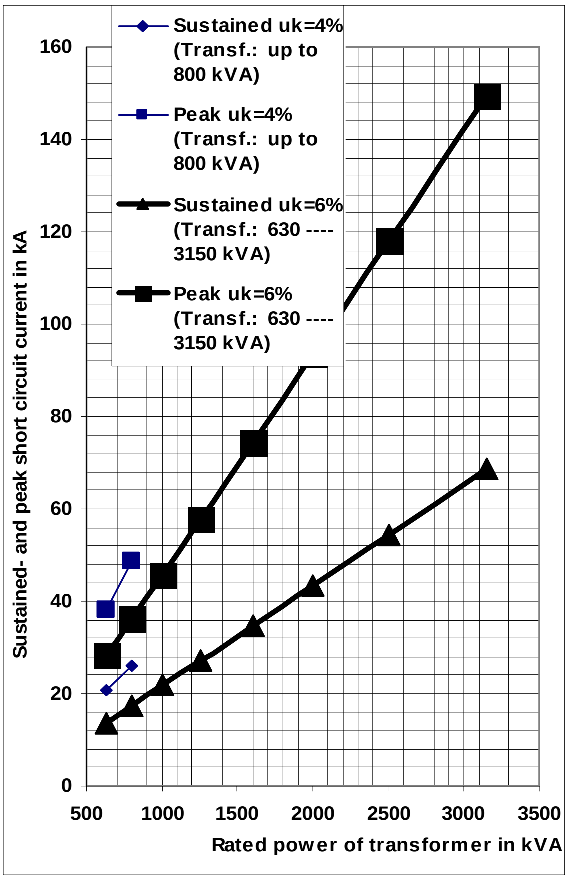

Fig.1 Prospective short circuit current of a transformer depending on rated power and short circuit voltage.

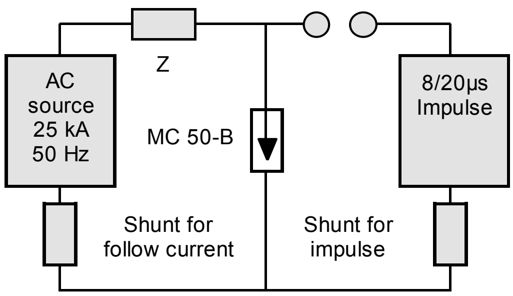

Fig.2 Circuit for preconditioning test

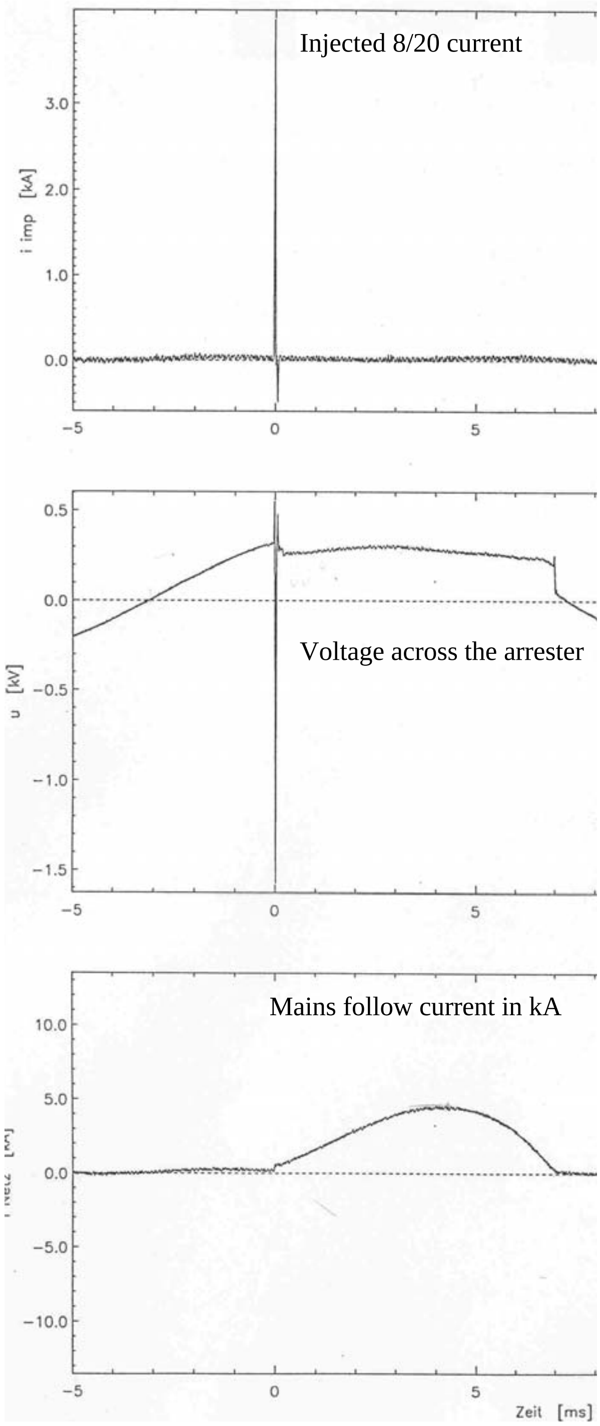

Fig. 3 Oszillogramm of the recorded current and voltage during type testing of a 50 kA class I arrester.

test with a synchronization angle of 60 Degrees.
4.2 Modelling of the class I arrester

Fig. 4 shows a circuit for the simulation of the test described in 4.1. The class I arrester is represented by a suitable model. The model of the class I arrester can be compared with the test data. Fig. 5 shows the calculated wave shapes and a comparison of the test data in fig.3 and the model data in fig.5 shows a good agreement of both results.
With the model of the class I arrester the actual current in the class I arrester can be calculated now in any network configuration.

4.3 Calculation of the actual current of a class I arrester

Fig.6 shows an example of a three phase circuit which consists of a 1000 kVA transformer and a connection cable to the distribution with the installed class I arresters. In this circuit the synchronization angle was varied from 0 to 360 degrees in steps of 30 degrees and the current shape was calculated. From the calculated current the specific energy was also evaluated. Fig 7 shows an example of such a calculation for a synchronization angle of 30 degrees. The result of the calculation is shown in Table 1 and gives the actual stress of a fuse and compares with the rated values of specific energy for fuses.
The lightning current in the class I arresters depends on the impedance of the transformer and cable and the distance from a transformer. Fig 8 shows that at short distance the lightnig impulse current is higher on the neutral conductor. After a certain length of cable the currents in neutral conductor and phase conductor are

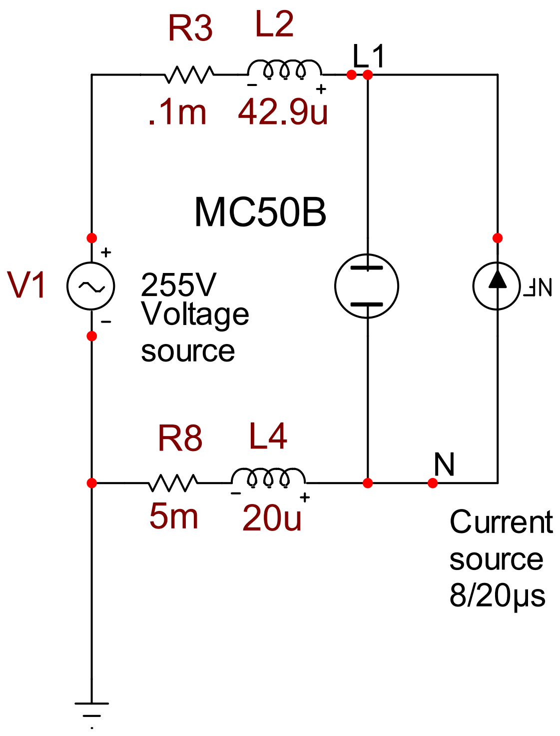

Fig. 4 Simulation circuit for evaluation of a class I arrester model

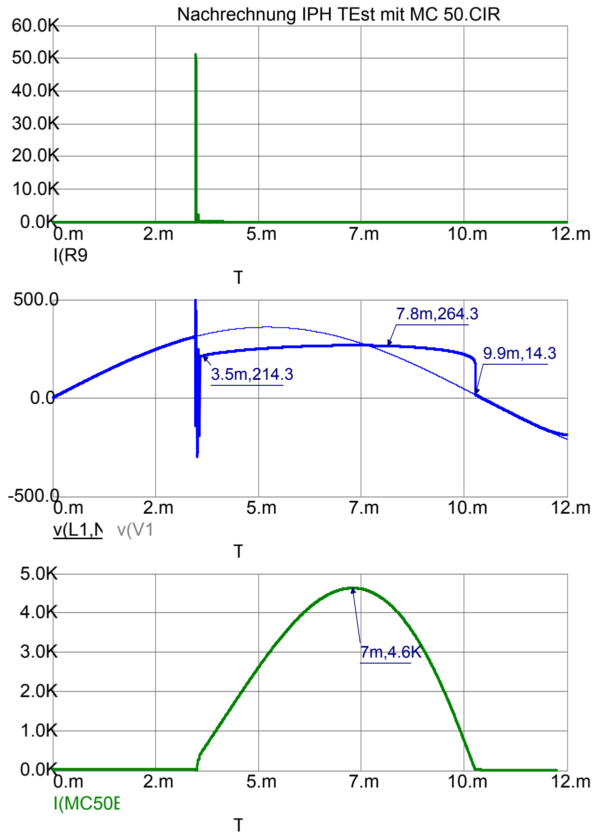

Fig. 5 Results of a computer simulation of the circuit in fig.4.

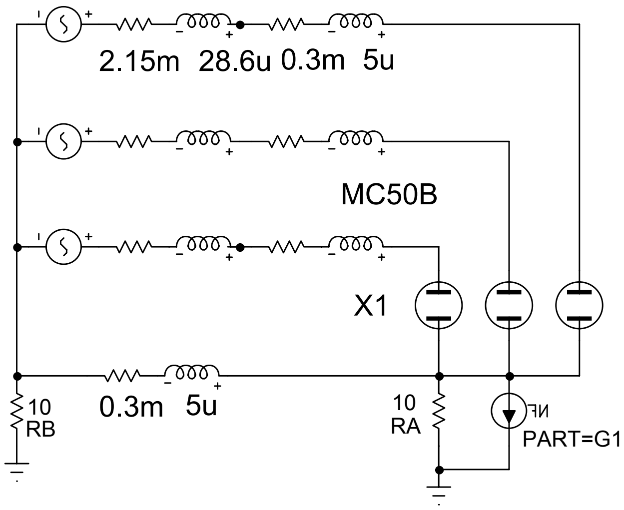

Fig 6 A 3 phase model for calculation of currents in the class I arresters in a given low voltage installation with a 1000 kVA transformer and a cable of 5 m 240 mm^2. Impulse current 200 kA.
RA: Local ground. RB: Station ground.

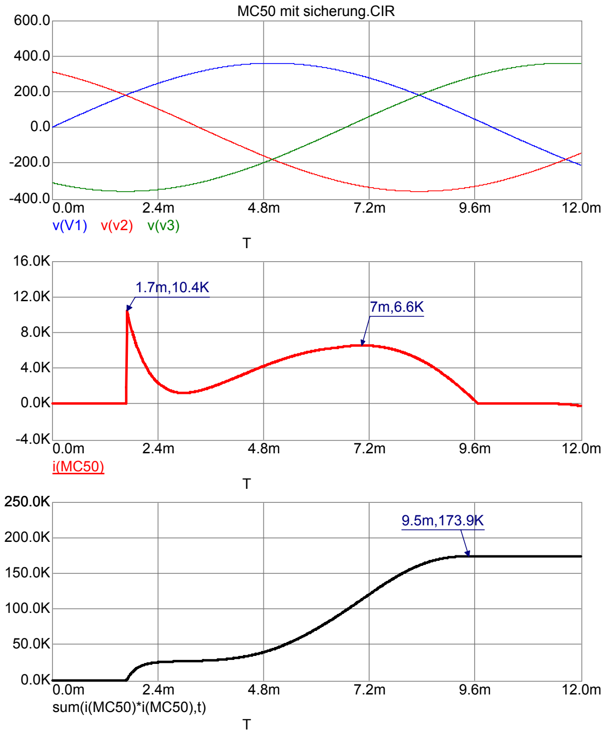

Fig.7 Sample of the calculation of the actual current and the specific energy in a class I arrester.
Synchronization angle: 30 degrees. 5 m 240 mm2 cable

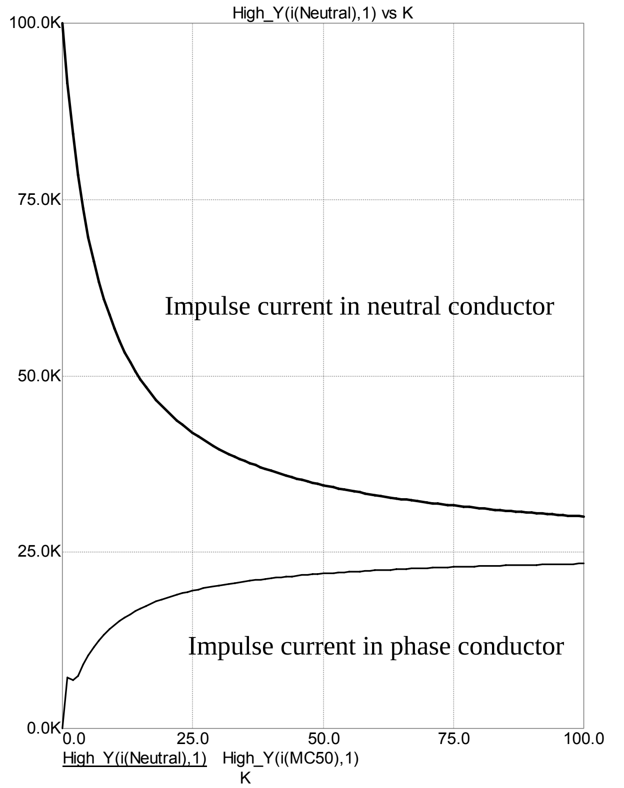

Fig. 8 Lighting impulse current in phase and neutral conductor versus length of cable in m 1000 kVA Transformer , phase angle 30 degrees. Cable 240 mm2.
K indicates the length of the cable in m. Calculation with 200 kA injected current , compare fig. 6.
Note: Current is diverted into station and local ground.

Synchroniza-tion angle	Mains follow current	Specific Energy	Specific energy of a 254 Volt fuse kA^2s					
Degrees	kA	kA^2s	500 A gl	400 A gl	355 A gl	315 A gl	250 A gl	224 A gl
30	6,6	174	1670	1236	859	716	368	297
60	6,1	156	1670	1236	859	716	368	297
90	4,1	80	1670	1236	859	716	368	297
120	0	36,6	1670	1236	859	716	368	297
150	0	22	1670	1236	859	716	368	297
180	-7,3	214	1670	1236	859	716	368	297
210	-8,7	337	1670	1236	859	716	368	297
240	-9,1	309	1670	1236	859	716	368	297
270	-7,4	146	1670	1236	859	716	368	297
300	-4,4	38	1670	1236	859	716	368	297
330	-1,3	19,7	1670	1236	859	716	368	297
360	6,7	177,8	1670	1236	859	716	368	297

Table 1 Summary of the calculation of the actual values of a class I arrester in network as shown in fig. 6 compared to the switching capability of fuses as per data from a manufacturer of fuses.

4.4 Characteristics of a fuse

Fig 9 shows the basic characteristic of fuses as one can find in the data of the fuse manufacturers. It shows the relation between the sustained short circuit current and the peak short circuit current for various cosφ-values (upper straight lines) and the tripping behaviour of fuses with different rated currents (dotted lines).
As a fuse begins to melt, the multiple internal arcs create a high arcing voltage. After sintering of the conductor inside the fuse with the sand a high resistance occurs and the current is limited. This behaviour is shown by the dotted lines in fig.9. It is shown that a fuse with lower rated current is capable to reduce the current more than a fuse with higher rated current.

4.5 Evaluation of a fuse for class I arrester for rated values of a class I arrester.

Why is a fuse required? If the class I arrester causes a malfunction a fuse shall clear the fault. The value of a fuse has to be evaluated in a test according to [1]. Fig 9 shows test data for a given class I arrester. This particular class I arrester was tested in a external high power lab IPH [2]. The test according to the requirements as described in [1] starts with the measurement of the prospective current of the test circuit when the test circuit is completely short circuited (no fuse , no arrester). This was done with a cosφ=0,25, a peak short circuit current of 37,5 kA and a sustaining short circuit current of 17,8 kA as shown in fig 9 as a square point.
After installing a 500 A fuse and the class I arrester the test was repeated and the fuse tripped but the class I arrester was still alive. The measured values were a peak short circuit current of 30 kA and a sustaining short circuit current of 17,8 kA as shown with a dot in fig.9.
From these tests one can derive the rated values for the protection of the class I arrester by a fuse. A 500 A fuse protects the class I arrester in a network with 30 kA peak short circuit current and cos φ=0,5. The manufacturer may give other values as rated values to put in some safety margin, e.g. 25 kA peak short circuit current.

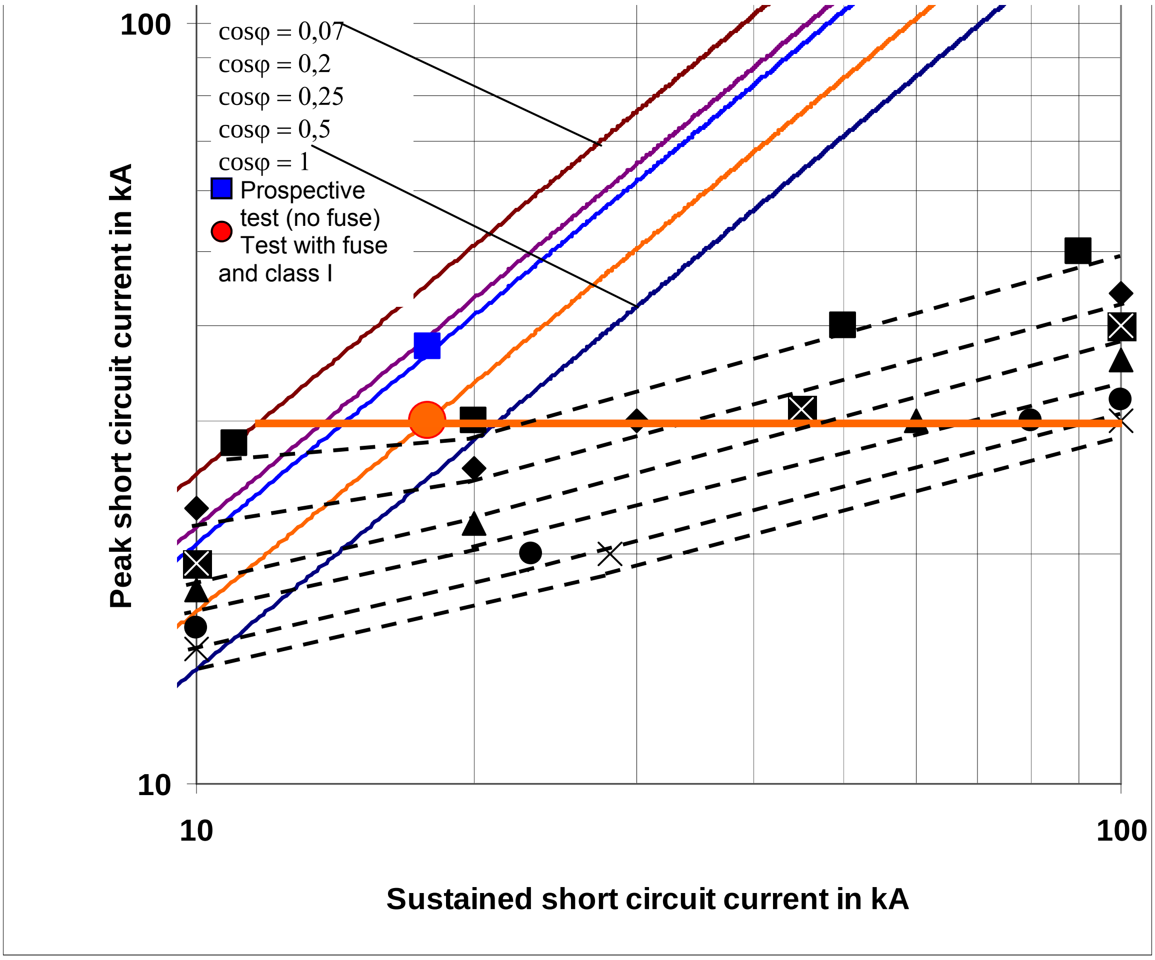

Fig. 9 Trip characteristic of fuses and test data for a given class I arrester.

4.6 Evaluation of a fuse for special applications.

If a class I arrester is installed in a power mains with a very high short circuit current e.g. close to a transformer with some 1000 MVA rated power the short circuit current exceeds the rated current of the recommended fuse for the protection of the class I arrester. If the rated value is a 500 A fuse for a peak short circuit current of 25 kA but the actual peak short circuit current is e.g. 70 kA, the fuse is overloaded and cannot interrupt such a short circuit current. In such a case the upper fuse or circuit breaker would clear the fault.

To maintain the selective control of a fault the fuse for a class I arrester must be evaluated based on the trip characteristic as shown in fig. 9.

As shown in fig. 9 the dot indicates the test with fuse and class I arrester under given prospective conditions as shown above the dot . A horizontal line indicates the permissible peak short circuit current for a given class I arrester. The crossing points with the trip characteristics (dotted lines) determine the sustained short circuit current.

For the above mentioned example of 70 kA sustained short circuit current the crossing with the horizontal line in fig 9 is between the fuse trip line of 250 and 315 A. For safety reason the recommended fuse would be the 250 A fuse. Based on this evaluation principle the table 2 shows the recommended fuses for the sustained short circuit currents.

5. Conclusions

In special cases a class I arrester has to be installed near a high power transformer. The class I arrester will be loaded with the lightning impulse current as well as with the mains follow current. If the class I arrester is installed close to the transformer the short circuit current can be very high and exceed the rated short circuit current of the class I arrester.
In case of a malfunction a fuse shall trip and clear the fault. The fuse has to be adapted to the sustained short circuit current. In such a case a fuse with a lower value has to be installed.
The fuse itself can be tripped by the lightning impulse current itself if the specific energy is sufficient. Fortunately if the fuse is installed close too the transformer, most of the lightning impulse current will be diverted into the neutral conductor and the phase conductors are less loaded. Therefore the class I arrester will be in operation because the fuse does not trip.

Sustained short circuit current of the power mains kA	Specification of the fuse
$0 \leq I_k \leq 17{,}8$	500 A gl
$17{,}8 \leq I_k \leq 30$	400 A gl
$30 \leq I_k \leq 40$	355 A gl
$40 \leq I_k \leq 60$	315 A gl
$60 \leq I_k \leq 80$	250 A gl
$80 \leq I_k \leq 100$	224 A gl

Table 2 Recommended fuses depending on the sustained short circuit current. The cosφ shall be >0,5.

References:

[1] IEC 61643 Part 1
[2] http://www.iph.de/