TEST PROCEDURES AND ARCING PHENOMENA IN H.V. FUSE LINKS NEAR THE MINIMUM BREAKING CURRENT

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ABSTRACT

Most high voltage fuse links have an uncertain zone of interruption, from the largest melting current (just above rated current I_N) to I_3, at about 2 - 4 times I_N.

However, the minumum breaking current I_3 has come closer to I_N, and the melting time has increased to several minutes. For the fuse links belonging to the classes General Purpose or Full Range, the melting times are more than one hour.

We have been testing fuses at I_3 in a "synthetic" test circuit (melting current by low voltage) according to IEC 282-1 clause 13.2.2.1, but with melting currents different from the arcing current. The results showed that the different melting currents have very little influence on the min.breaking current I_3. The calue of I_3 is mainly dependent on the H.V.-current, anyway if the melting current is so small that the fuse link melts by the M-spot.

Some physical properties at the interruption process near min. breaking current are presented in the paper. The sand quality is very important, and can give large variations in attainable min. breaking current.

INTRODUCTION

The problem for high-voltage current limiting fuses to interrupt small overcurrents has initiated much attention and research work in the past, and is still a phenomenon of further study.

Most construction principles for fuses affect the breaking performance, and smaller changes in the design can result in large varations in obtained minimum breaking current I_3.

Central design-parameters, as far as I_3 is concerned, are: fuse-element-material, fuse-element "design", use of M-spot, sand-quality and sand-grain size.

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A continous increase in the fuse-quality has taken place, and the minimum breaking current has come closer to the rated current I_N of the fuse. Fuses of the class "General purpose" with I_3 resulting in a melting time more than one hour, and "full-range"-fuses with I_3 lower than the smallest current that can melt the fuse have been designed. Low I_3 means long melting times t_m of the fuses and time-consuming and expensive testing at this current.

Acc. to IEC 282-1 clause 13.2, there are two alternative test methods for Test Duty 3:

<u>a</u> Testing at the specified voltage for the full test period.

<u>b</u> Melting of the fuse by low-voltage and switching to high voltage for the conclusion of the test.

Alt. <u>b</u> is the only possible method for testing modern H.V.-fuses with melting times of several minutes at I_3. If a new test method at I_3 reducing the melting time without changing the breaking performance of the fuse can be found, this would be of interest for development and certification of fuses. This article will indicate such a method. However, only "conventional" back-up fuses of different design have been investigated.

<u>ARCING PHENOMENA</u>

The arcing process in c-l. fuses near I_3 is fundamentally different from the process at short circuit current. Arcing time is longer, arcing performance is less distinct and the fuse is not current limiting.

For fuses with M-spot the melting process starts in one of these spots. Then the other M-spots melts until the current density in the remaining intact fuse-element(s) is so high that melting occurs in the constrictions (fig. 1).

The arcing time starts from this moment with burn-back of fuse element and increase of arc-voltage. Acc. to investigations at NTH (Tech.university of Norway) (1), P. Rosen (2) and our own laboratory (3) the arcing current is carried by one single parallel fuse element in turn during the arcing periode. See also fig. 2.
The current will repeatingly commutate to the element with lowest insulation level until eventually the last element obtains the withstand voltage equal to the system voltage and interrupts the current. If the current is below I_3, the insulation level will not reach the system voltage, and this results in explosion (4).

At currents higher than I_3 the arcing time will be a function of I_3 (fig. 3), with increasing arcing time for decreasing current.

The silica-sand must have the ability to sustain high voltage withstand very quickly at current zero. The voltage increase and also heat transfer ability are important parameters in the arcing process. Different sand qualities have been tested, and smaller amounts of "pollution" (< 2%) e.g. Fe_2o_3 or mica has a damaging effect. The grain size is of particular significance for the value of I_3. Identical sands, except for the grain size, have been tested (3) with the following result:

I_3 = 1,2 x In with average grain Ø at 0,70 mm
I_3 = 1,6 x In with average grain Ø at 0,20 mm

This is confirmed by R. Oliver et.al (9) who mentions large grain-size favourable for interruption of small overcurrent.

I_3 is heavily influenced by the design of the fuse element and especially the constrictions. The length, smallest cross section and number of constrictions all affect on I_3. Number of fuse elements also affect I_3.

It is difficult to find a general formula for the I_3 taking care of all the factors influencing it. However, the fundamental notion is to create several arcs in series very fast to increase voltage (5). If these multiple arcing can be controlled to particular points on the fuse elements, the value of I_3 can be reduced even more.

Special designs have been developed to control the multiple arcing. H.W. Mickulenky (6) uses an auxiliary element ("arc electrodes") for each fuse element to start the arcing process (fig. 4).

Control of the arcing process for low currents by thermally insulating parts on the elements is also used (fig. 5) (7) (8).

TEST PROCEDURES

According to IEC 282-1 clause 13.2.2.1 Test Duty 3 (I_3), the fuse can be tested in a low-voltage test circuit (with correct current value) for the major portion of the test period and then switched to a high-voltage test circuit for the conclusion of the test. The switching time must be less than 0,2 sec.

The switching device (fig. 6) used for the tests referred to in this paper operates when the voltage across the fuse exceed approx. 50 V. Two mechanical interlocked vacuum switches interrupt the low-voltage circuit and closes the high-voltage within 20 ms (see fig. 2)

The influence of the melting current I_m (melting time t_m) on the arcing process for currents near I_3 is tested for four types 12kV 40A fuses of four different makes. Two of the fuses have M-spots, the other two have not, and all fuses are of the type back-up of a "conventional" design. Melting current varies within the interval 1 - 3 times minimum breaking current.

Some differences in arcing time (t_a) occur, but no obvious trend in t_a with respect to I_m and t_m can be drawn, especially if the l.v. melting current is less than about 2 x I_a.

DISCUSSION

All tests show that the value of I_3 is very constant for the particular design, and not much dependent upon the melting time.

The arcing process is completed long before the voltage increase seems to reach the actual voltage of the circuit (fig. 2). Interruption completes at current-zero, and the very good voltage recovery of the silica-sand enables successful interruptions.

Two different fulgurites at I_3 are observed for the fine and coarse sand respectively. The fulgurite of the fine sand is made of molten sand grains at the inner part of it, and is very compact. Coarse sand has porous fulgurite with crushed sand-grains. The fulgurite is also larger with coarse sand. This observation indicates two different physical processes.

The arcing time in table 1 is used as an indication of the low current clearing ability (fig. 3). Influence of the melting current for the I_3 interruption is because of this indicated by the arcing time. The test material is limited and a 100 % reliable conclusion of the influence of the melting current can not be drawn. Still, the test results indicates that the melting current (and melting time) has very little influence on the breaking performance, and the value of I_3.

With reduced melting time (and increased current), the total heating of the fuse is reduced, but the fuse-elements and the sand close to them reaches the same temperature as for smaller melting current. The arcing time is short compared with the thermal time constant of the sand. Therefore, the temperature of the fuse at reduced melting time is similar to the temperature at "correct" melting time, as far as arcing condition is concerned.

If the melting time is essentially shorter than correct melting time, another commencement of the melting processes may occur. E.g. melting in a constriction instead of M-spot, or melting in several constrictions simultanously. As the melting is the basis of the arcing, this must be avoided. For the fuses mentioned in tab. 1, the melting process is different for melting times shorter than a few seconds. This explains the successful result of fuse type C with melting time t_m = 3,7 sec. and I_a = 84 A.

The test circuit used in the tests is not exactly acc. to IEC 282-1 recommendations. Acc. to this standard the high-voltage has to be switched in for the conclusion of the test, before the melting of the last of the parallel fuse-elements. The test circuit used in the tests registres the melting of the last element and then switches to high voltage (in less than 20 ms). This is to ensure safety and identical switching for all tests, and has no influence on the arcing and I_3 value. See also (4).

CONCLUSION

Design parameters as silica-sand, fuse-elements and use of M-spot has significant influence on the value of I_3. Special additional requirements to ensure multiple arcing at low currents also influence I_3.

Acc. to international standards fuses can be tested for T.D.3 with melting at low voltage and switching to high voltage with the same current value I_3. Variation in melting current seems to have little influence on the value of I_3 and arcing performance as long as the melting current ensures that the arc initiation is the same as with the I_3 as low voltage melting current.

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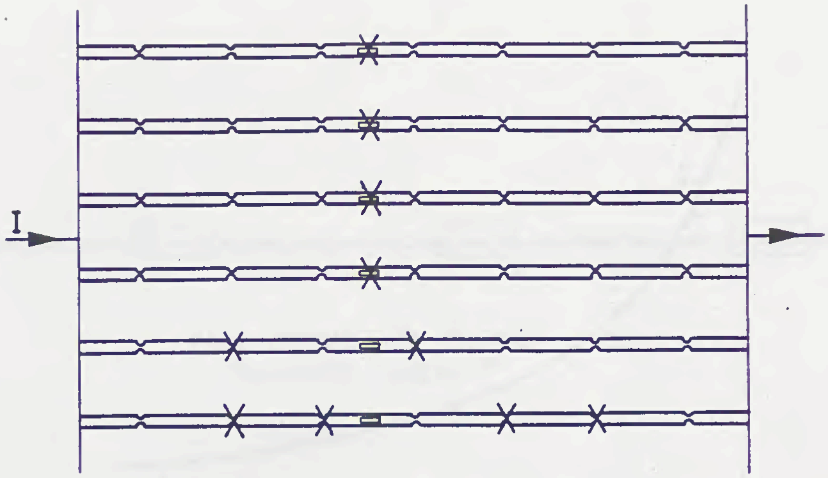
TYPE	Rated current	Rated voltage	Melting current	Melting time		Arcing current	Arcing time	Remarks
	I_N	U_N	I_m	t_m		I_a	t_a	
Fuse-link	A	kV	A	min.	s.	A	ms	Observation
A	40	12	84	17	08	84	240	
	"	"	"	17	05	"	75	
	"	"	145		27	"	55	
	"	"	"		24	"	70	
	"	"	"		20	"	55	
	"	"	"		25	"	55	
	"	"	252		0,52	"	28	
	"	"	100	6	30	100	30	
	"	"	"	5	41	"	30	
	"	"	"	9	00	"	95	
B	40	12	120	8	49	120	60	
	"	"	145	1	12	"	110	
	"	"	"		43	"	100	
	"	"	252		0,4	"	200	
C	40	12	84	26	35	84	∞	Exploded after 220 ms
	"	"	"	26	00	"	∞	——— " ——— 1250ms
	"	"	145		13	"	∞	——— " ——— 145ms
	"	"	252		3,7	"	105	
	"	"	102	13	30	102	40	
	"	"	145	2	54	"	70	
	"	"	252		3,6	"	30	
D	40	12	120	5	36	120	30	Reignited after 7,2 s and exploded.
	"	"	145		44	"	75	

Arcing time for different melting times
Fuselinks type A, B, C and D.

Table 1



Melting process for M-spot fuses

Figure 1

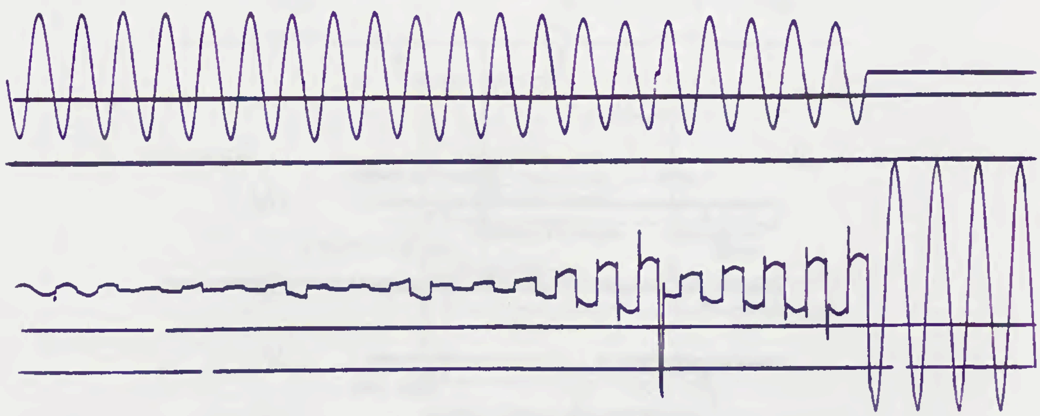
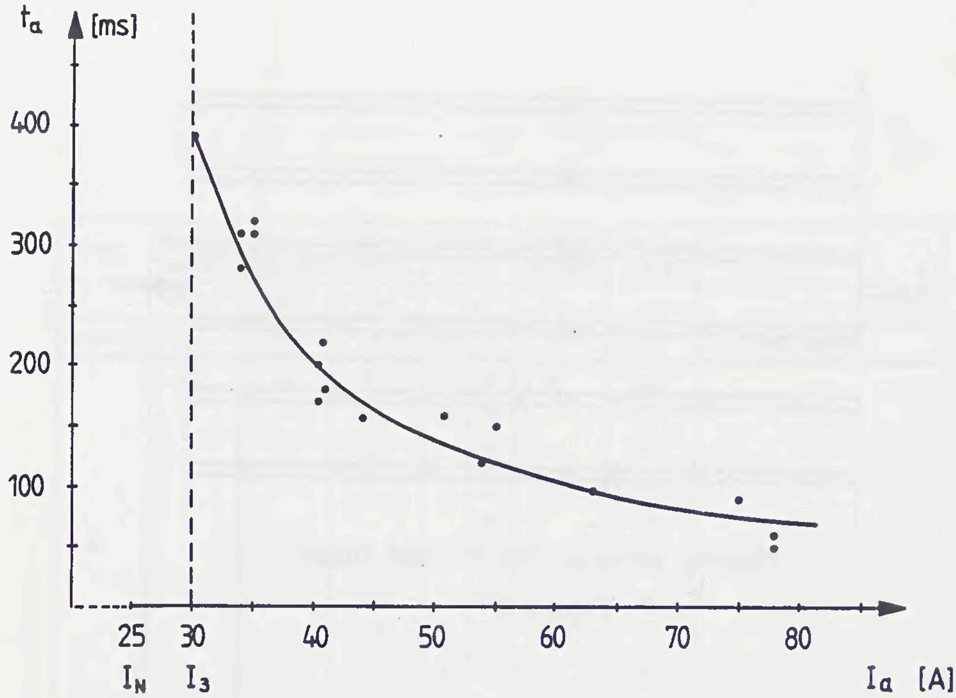
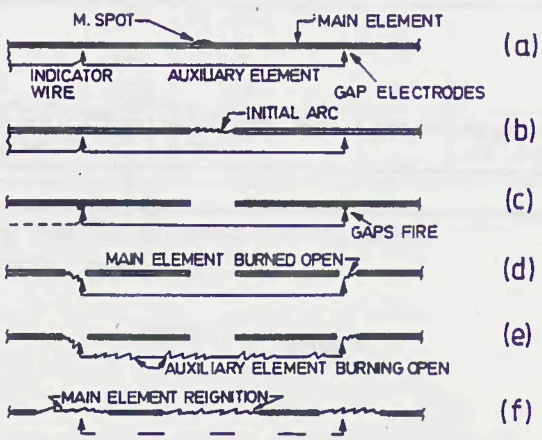


Figure 2



Example from developing tests of 17,5kV 25A fuse.

Figure 3



Sequence of operations for fuses with arc electrodes, lowcurrent interruption.

Figure 4

Fuse element with thermal
insulating beads.

Figure 5

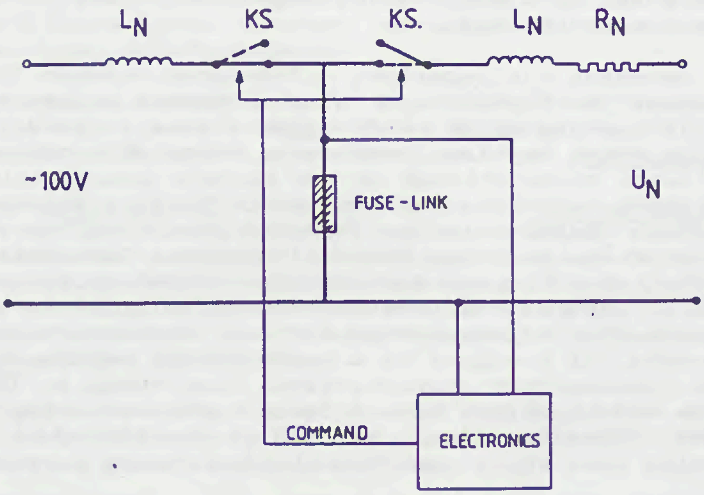


Figure 6

Special test circuit for
Test Duty 3 acc. to IEC 282-1