THE STRIKER SYSTEM IN THE FUSE SWITCH COMBINATION

A. Ofte and W. Rondeel

ABSTRACT

While the requirements to high-voltage fuse-links of the current limiting type are covered by the IEC Publication IEC 282-1, and the load-break switches (or disconnectors) by Publication 265, the fuse switch combination is covered by a special Publication IEC 420. The latter is at the present under revision. Important factors influencing the requirements which will have to be specified in Publication 420 are

- the operation of the striker system, specially in those cases where the fuse link trips the switch in a current region where the current is not interrupted by the fuse.

- The maximum permissible arcing time in the fuse link whitout explosion or expulsion of gases which may initiate a flash-over in the three-phase system.

A systematic study into these two aspects are reported in this paper. The main conclusion being that normally the maximum permissible arcing times will by in excess of the minimum time necessary to have the fault current cleared by the in series connected switch. A malfunctioning of the combination could be experienced due to extreme fuse-link body temperatures, especially in enclosures, - or immediate explosion of fuse-link at the instant of arc initiation.
With the present IEC recommendations a better guarantee for a proper functioning of the combination can only be secured if the fuse link is tested in the current range between I_3 and the minimum melting current.

INTRODUCTION

By combining a load-break switch, which can interrupt load currents and low fault currents, with a current-limiting fuse, which can interrupt high fault currents and normally having problems with the lower currents, an ideal combination is obtained. In addition to the special IEC publications for load-break switches and switch-disconnectors, IEC 265, and for current-limiting fuses IEC 282-1 a special document for the combination, IEC 420 exists. The latter has not been unanimously accepted, and is still under discussion within the IEC.

A. Ofte and W. Rondeel are with
A/S Norsk Elektrisk Brown Boveri   Switchboard and Switchgear Group.

The combination of load-break switches, or switchdisconnectors, and current-limiting high-voltage fuses, are commonly used for the protection of transformers in distribution networks. The combination may of course also be applied for the protection of motors, capacitor banks and cables.

Often (especially in markets dominated by the BS and DIN/VDE Standards) the switch is equipped with automatic fuse-tripping, which implies that the switch will be tripped by the striker system of the fuse upon melting of the latter. The cooperation between these two devices is perfect in that respect that the fuse will interrupt the high fault currents (which the switch is unable to interrupt), while the switch (being tripped by the fuse-link striker system) will interrupt the low fault currents. Most current-limiting fuses are not able to interrupt currents below 2-4 times their rated current. In the diagram of figure 1, the mentioned cooperation between fuse and switch is explained in a diagram. The current region where the transition from interruption by the switch to the interruption by the fuse takes place, is called the "take-over-current".

High voltage fuses are tested according to IEC 282, and in figure 2 are indicated the current zones for the three test duties 1, 2 and 3. The lower limit for safe operation, verified by Test Duty 3, is the so-called minimum-breaking-current.

Below the minimum-breaking current, the safe operation of fuse-switch combination is dependent on the tripping of the switch by the fuse-link striker system. The proper functioning of the striker is then important. Figure 3a shows one possible mechanical construction of a spring operated striker system, while 3b shows the electrical connections.

The resistance of the individual silver fuse elements varies from about 0,8 to 0,005 ohms, while the resistance of the striker element is between 9 and 30 ohms, dependent on the rated current and voltage. Due to this difference in resistance, the striker element will carry only a negligible current during normal operation. In the overcurrent region, when the melting times are in the order of seconds or minutes, each of the parallel fuse elements will melt one by one. At the moment when the last element melts, the current path will be commutated to the striker element. When the current path is commutated to the striker element, the striker release wire will melt first, as the cross section of this wire is smaller that that of the striker element. Hereby it is guaranteed that the release wire will melt before the current path is interrupted. The release wire releases the charged spring, and the striker pin activates the switch mechanism.

Except for the very small arcs which are formed during the initial melting of the fuse elements, no real arcing takes place in the fuse before the striker system is activated.

Below the minimum-breaking-current, the melting times for the fuse may be extreme, and both fuse and striker may reach very high temperatures. This causes heavy demands on the striker system. At temperatures around 250°C, which are possible in fuses with pure silver elements, a spring operated striker system may change its characteristics. Low.loss fuses with so-called M-effect (melting point reducing alloy) are advantageous in this connection.

In the fuse-switch combination with trip release initiated by the fuse-link striker, the following points are critical:

1. The minimum arcing time the fuse link can withstand without explosion or expulsion of any ionized gases, has to be longer than the maximum trip-open time plus interruption time of the in series connected switch.

2. Even after extremely long melting times, at low fault currents below the minimum-breaking current, when the fuse-link has become very hot, the striker system has to function properly.

3. The circuit must be able to supply the striker system with sufficient power, voltage/current to melt the release wire.

4. The take-over-current, i.e. the current for which the minimum possible trip-open time of the switch is equal to the arcing time in the fuse-link, must be below the maximum interruption performance of the switch.

The last point is illustrated in figure 4, which shows the arcing time as a function of the fault current in the Test Duty 3 test curcuit. Below the minimum-breaking-current the arcing time is infinite.

Normally a fuse-switch combination is arranged in such a way that if one (or more) of the 3 fuses in a three-phase system fuses, the switch is tripped in all three phases. If the switch is tripped by one of the fuses, due to the intrinsic variation in the melting time of the fuses, or because the fault currents in the three phases are unequal, the switch contacts may open when current is still flowing in the two remaining phases. With two phases in series, the switch will have to interrupt the fault current. (We assume that the fault current is in excess of the minimum-breaking-current, and the first fuse to melt interrupted the current). This aspect, together with the problem of the take-over-current, determines the requirement to be met for the interruption performance of the switch. This investigation is concentrated on the fuse-link striker system, with reference to the critical points already mentioned.

MEASUREMENTS ON DIFFERENT BACK-UP TYPE HIGH-VOLTAGE FUSE-LINKS.

Measurements of temperature distribution, permissible arcing times and electrical and mechanical characteristics on four different types of commercially available fuse-links, all rated 12kV and 40 Ampere, have been carried out. The purpose of these measurements has been to obtain a better knowledge regarding the critical points which have been mentioned.

TEMPERATURE MEASUREMENTS.

In a commercially available fuse-base according to DIN 43625 the temperatures were measured in 5 different locations on the fuses. All fuses were brought to the fusing temperature with melting times in excess of 1 hour. In most cases the melting time was between 65 and 120 minutes, and the melting current (chosen according to data supplied by the manufacturers) between 65 and 90A. The current, which had been chosen to give melting times of approximately 60 minutes, was kept constant during the melting periode for the fuses rated 40A. The location of the 5 thermocouples are shown in figure 5, toghether with a schematic presentation of the results. In figure 5 the maximum temperatures recorded for the four fuse-types are given for the three most interesting locations, i.e.:

- On the porcelain fuse body.
- On the electrical contacts spot between fuse-base and fuse-link.
- On the cabel connection to the fuse base.

The cable connection arrangements are also shown in the figure.

As can be seen from the diagram, maximum temperatures of more than 400°C, have been measured for fuses type "C" and "D". These fuses are without the melting point reducing M-spot, - where the melting point of the small amount of applied tin on the silver fuse-element determines the melting point. From the diagram also can be concluded that the temperature of the mechanical part of the striker system will have to sustain maximum temperatures of around 200°C for a longer periode of time, depending on the melting current. For striker systems based on spring actuation in fuse-links without melting point reducing action, special material qualities will have to be applied.

ARCING TIME MEASUREMENTS.

At the moment when real arcing commences in a fuse-link, the striker system will be activated. Most load-break-switches need approximately 50 ms to open the contacts, and on the average another 10-15 ms to interrupt the current. Some manufacturers of switches even delay the switch opening in order "to give the fuse more time to clear the circuit". It is then of some interest to investigate whether a fuse-link can sustain arcing below the minimum-breaking-current for a periode of 50 to 100 ms without explosion or expulsion of ionized gases.
In a Test Duty 3 circuit according to IEC 282-1, with a power factor 0,4-0,6, the four fuse-links (type A, B, C and D) were tested below I_3. Figure 6 shows the test circuit, with a specially developed automatic switch-over system for disconnecting the low-voltage-circuit and connectin high-voltage at the moment of arc initiation in the fuse-link. Systematic comparison between I_3 values obtained in this test curcuit, and other laboratories where change-over to h.v. has been made just before arc initiation, never have revealed any difference between these two test methodes. This comparison has been made for fuses with and without M-effect.

The arcing time from arc initiation to explosion or expulsion of ionized gas, was measured by using the signal from the charge-over-switch tripping device to start the time counting, and an

impuls from a photodetector (registering the light from the fuse explosion) to stop counting. Time delays in this measuring system was calibrated and corrections were made.
The results from these measurements are given in table 1. In the table the "arcing time to failure" is the measured arcing time to explosion or expulsion of ionized gas. The observed minimum-breaking current I_3" given in table 1, is not necessarily equal to the I_3 given by the manufacturer. The I_3 in table 1 is estimated from our own measurements during this investigation. Only test results at current levels which led to failure is given in the table.

The following conclusions can be made from the data given in the table:

- The spread in tolerable arcing time is substantial.
- The safety margin in a fuse-switch combination where the switch has a mechanical opening time of approximately 50 ms is acceptable.
- For one of the tested types of fuses, the fuse-link exploded before the switch would have had any possibility to interrupt the circuit. This was never observed for any other fuse-link.

Reignitions, leading to failures, but also in some cases effectively interrupted, were observed for a number of fuses. It may be concluded that retaining the full recovery voltage for at least 60 seconds after first interruption during Test Duty 3 is of great importance. (All four fuse-link bodies were made of porcelain).

Figure 7 shows some of the oscillograms recorded during the tests. The upper oscillogram shows the normal arc voltage behaviour - with the characteristic voltage build-up after switching over from low to high voltage. The "dead-time" is very short, and arcing before change-over is negligible.
The abnormal behaviour of the fuse-links that exploded immediately after change-over, is shown in the lower oscillogram. In this case there is no voltage build-up, the arc voltage is the arc voltage of a free burning arc from the very first moment.
A possible reason for the abnormal behaviour could be sought in the fuse-body porcelain quality, combined with thermo-mechanical stresses caused by the elevated temperatures obtained during the long melting time of approximately 1/2 hour.

MECHANICAL AND ELECTRICAL CHARACTERISTICS OF STRIKERS.

During the test carried out on a substantial number of different fuse-links, none of the strikers failed to operate. Both from cold conditions and after the heat treatment caused by at melting time in excess of 1 hour, all strikers fullfilled the IEC requirements for the energy/force characteristics, IEC 282-1 Am. No. 3 Table XII medium type.
Electrically the striker systems, one of which had an explosive drive, were tested in a low-voltage circuit with a supply voltage of 210 Volt. All strikers functioned properly, with a melting time of 100-150 ms. As no real arcing can be sustained at this low voltage, the conclusion can be drawn that in a normal H.V. circuit, the delay time of the striker (i.e. from the moment of arcing until striker movement) is negligible.

DISCUSSION AND CONCLUSIONS.

Fuse-switch combinations where fuse-tripping have been relied upon in connection with the interruption of currents below the fuse-link minimum-breaking current, have been in practical use for many years without too many failures being recorded. It is therefore not surprising that this limited investigation did not reveal any major shortcomings. Nevertheless, a few negative observations should be noted:

- surface temperatures measured at a fuse-links subjected to small fault currents and long melting times were in excess of 400°C. In compact switchgear where the fuse-link may be surrounded by organic insulation material (as epoxy resin) these temperatures could be harmful.

- one brand of fuse-link examined exploded immediately after arc initiation, leaving the switch no time to clear the circuit. This was only experienced for melting times longer than approximately 30 minutes.

- most manufacturers seems to be rather "optimistic" when the minimum-breaking-current of a fuse-link is given in the data sheet.

- fuse-link failure below the minimum-breaking-current appeared both as an explosion where the porcelain body ruptured, and as a burn-through where the arc penetrated the contact ferrules. In an open 3 phase system the ultimate result would be the same in both cases: a flash-over between phases, and a full short-circuit.

On the positive side must be concluded:

- the permissible arcing time of a fuse link below the minimum-breaking -current is far beyond the time needed to trip the switch, i.e. the switch will have interrupted the circuit before any ionized gases are expelled.

- the tested striker systems all fullfilled the IEC requirements, even after being subjected to melting times (and high temperatures) longer than 60 minutes.

During these tests it was observed that reignitions, of which some led to complete fuse failure, occured after time intervals up to 30 seconds. Holding the recovery voltage for at least 1 minute therefore seems to be of outmost importance. The most important conclusion to be drawn from this investigation is that if <u>full guarantee</u> for a proper functioning of a fuse-switch combination is wanted with the present IEC recommandations, <u>the actual combination</u> of fuse-link and switch will have to be tested in the low-current region. As a minimum requirement the fuse-link should be tested in the current range between the minimum-<u>breaking</u>-current and the minimum-<u>melting</u>-current.

TYPE	Rated current	Rated voltage	Observed min.br.c.	Test current	Melting time	Arcing to failure	REMARKS
	I_N	U_N	I_3''	I_t	t_s	t_a	
fuse-link	A	kV	A	A	min.	mS	Observation
A	40	12	85	84	18	670	
	"	"	"	75	-	710	
	"	"	"	"	-	830	
B	40	12	120	100	25	28200	Interrupted, reignited and exploded.
	"	"	"	85	-	810	
C	40	12	100	84	27	220	
	"	"	"	"	26	1250	
	"	"	"	"	27	145	
D	40	12	120	84	21	0	Fuse exploded at arc initiation.
	"	"	"	"	39	0	
	"	"	"	"	32	530	

TABLE I

Total arcing time to failure below the minimum breaking current for the fuse-links type A, B, C and D.

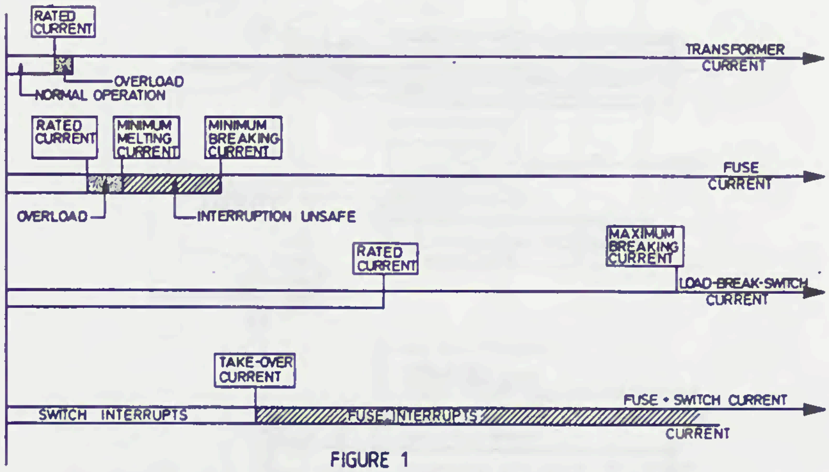

FIGURE 1
Coordination between load-break-switch and fuse

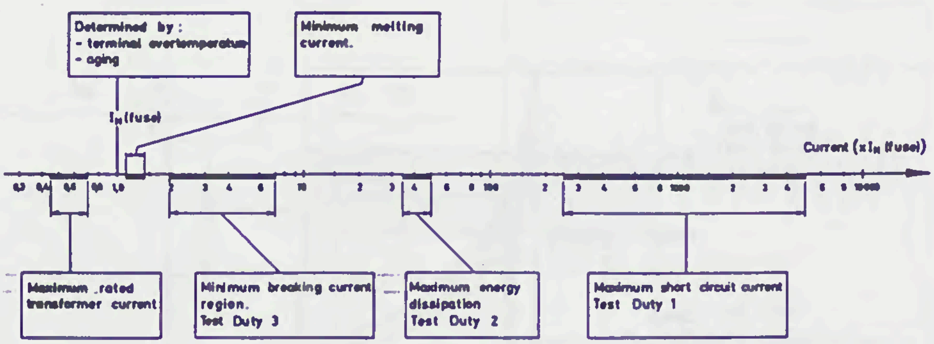

Figure 2
H.V. fuse link rated current with reference to normal load and test currents according to IEC 282-1

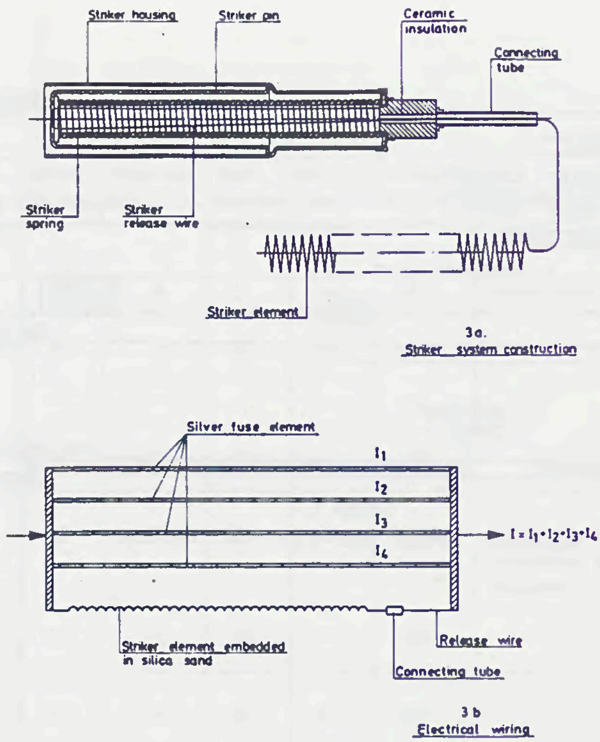

Figure 3
Striker system

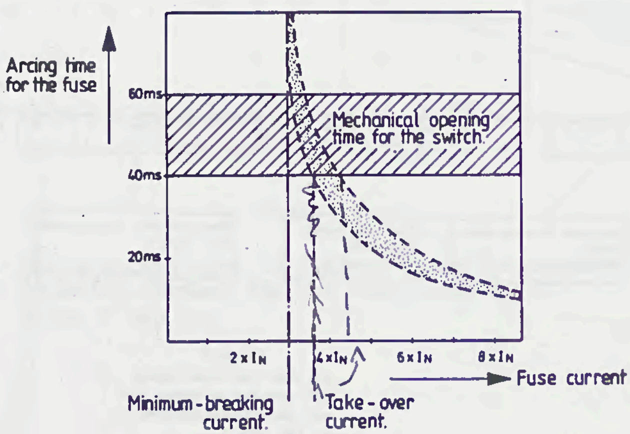

Figure 4

The arcing time in the fuse compared with the mechanical opening time of the switch

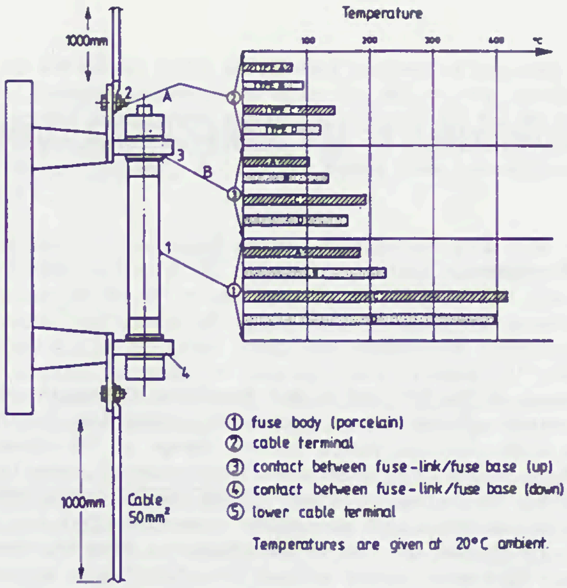

Figure 5

Temperature distribution at the moment of fuse melting.

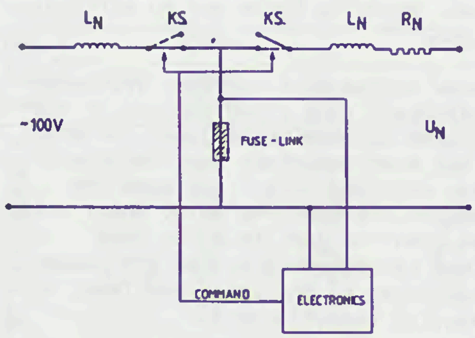

Figure 6

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

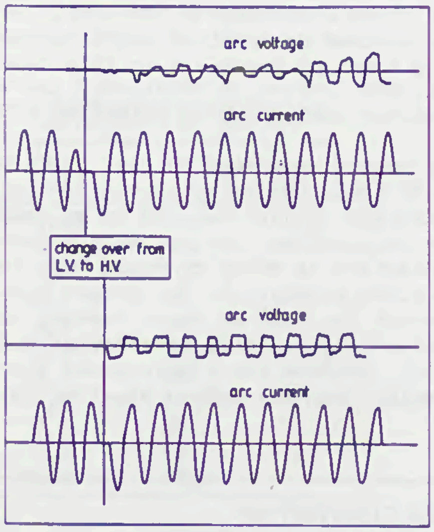

Figure 7

Arc voltage during the first arcing periode. The upper diagram shows the normal behaviour, the lower when fuse explosion takes place immediately after arc initiation.