HIGH VOLTAGE CURRENT LIMITING FUSE-LINKS CAPABLE OF BREAKING ALL CURRENTS THAT CAUSE MELTING OF THE FUSE-ELEMENT

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Summary.

Conventional H.V. current limiting fuse-links, as they are available now, have some marked disadvantages. First it is the fragility of their fuse-elements provided with a number of notches and second is their inability of breaking low value over-currents.
Holec has recently developed a range of current-limiting fuse-links, branded "Fullran" which don't possess those disadvantages. "Fullran" fuse-links are able to break all currents which cause melting of the fuse-elements, whilst the construction is such that the fuse-elements are extremely resistant against the effects of shock and vibration.
The excellent breaking capabilities have been obtained by splitting-up the fuse-elements in a very large number of parallel strips. The mechanical strenght of the fuse-elements is assured by fixing the parallel strips, over their entire lenght on a support tube.

For breaking all currents, from minimum melting currents up to short-circuit currents, only current limiting elements are employed. Unlike other recently developed fuse-links, no series elements, such as expulsion elements are being used.
In this paper a discription is given of the design of the fuse-links, the test circuits and the test results. A number of those tests are not specified in IEC 282-1,such as e.g. breaking of minimum melting currents and verification of resistance against shock and vibration.

INTRODUCTION

IEC Publication 282-1 - High Voltage current-limiting fuses, distinguishes two categories, known as "Back-Up" fuses and "General-Purpose" fuses.
For some time now a third category is being marketed known, however unofficially, as "Full-Range" fuses.

A Full-Range fuse could be described as "A current-limiting fuse capable of breaking, under specified conditions of use and behaviour, all currents from the rated breaking current down to the current that causes melting of the fuse-element".
Although this is not a formally accepted phrasing, it might cover the concept "Full-Range".

IEC Publ. 282-1 mentions three Test duties for the verification of respectively:

. The rated breaking current I_1 (T.d.1)
. The critical breaking current I_2 (T.d.2)
. The minimum breaking current I_3 (T.d.3)

Consequently Back-Up fuses and General-Purpose fuses will not be tested on the verification of operation with currents in the zone between the minimum melting current (I_{mmc}) and the minimum breaking current (I_{mbc}). Therefore it is not to be assumed that overloads in this particular zone will always be cleared properly.

Full-Range fuses are capable of breaking all currents that cause melting of the fuse-element hence also currents between I_{mmc} and I_{mbc}. Fig. 1.

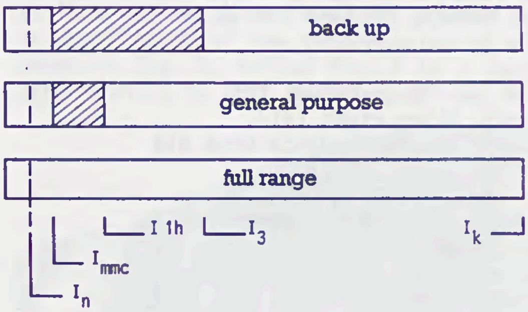


Fig. 1 -  zone where breaking of fault-currents is not guaranteed.

I_n = rated current
I_{mmc} = minimum melting current
I_{1h} = 1 hour melting current
I_k = rated breaking current (FULLRAN = 40 kA)
I_3 = minimum breaking current

THE CONSTRUCTION OF FULLRAN FUSE-LINKS

Fig. 2 shows an exploded view of the fuse-link. The silver strips (4), provided with notches are attached to a tube made of quartz glass (2). This tube supports the strips over their entire length. By doing so it is possible to apply a large number of parallel strips. In the centre the strips are provided with a low melting point metal and at the ends connected to common sleeves (6).

The connection between the common sleeves and the silverplated brass endcaps (10) is made by toroidal, helically wound, springs made of silverplated beryllium bronze (7). This multiple contact arrangement with high contact pressure, results in a connection with low contact resistance. These contact springs also centre and support the tube radially in the porcelain outer-tube (1).

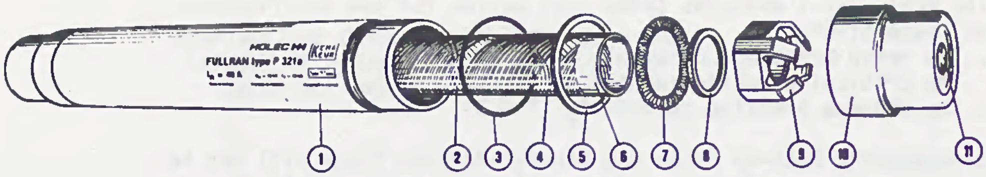


Fig. 2 - Exploded view of a FULLRAN H.V. fuse-link.

Flexible plastic spacers (9) and rubber buffer rings (8) provide for correct axial positioning of the supporting tube, along with protection against the effects of shock or vibration.
Rubber washers (5) between porcelain barrel and endcaps together with silicon rubber bands (3) in the hemming grooves enable an air-tight construction.

After filling the fuse-link with fine quartz-granules, the filling hole is sealed with a gas-tight blind rivet (11).
Dimensions of 12kV FULLRAN fuse-links are in accordance with DIN 43.625.

For the current-rating 6,3A - 40A the diameter of the porcelain outer-tube is 54 mm. The fuse-element of this series consists of 15 parallel strips of similar design except for their thickness and resistance, which vary per current-rating (6,3A - 8A - -10A - 12,5A - 16A - 20A - 25A - 31,5A and 40A).
For the series 40A - 80A the diameter of the porcelain outer-tube is 76 mm, accommodating a fuse-element with 35 strips in parallel. The fuse-element is now composed of 2 parallel supporting tubes with 20 and 15 strips respectively. Like the series 6,3 - 40A the basic pattern of the fuse-elements of this series (40A-50A-63A and 80A) is also identical except for their thickness and resistance.

PRINCIPLES OF OPERATION

In FULLRAN fuse-links the breaking of fault currents after fusing of the elements proceeds in one of two fundamentally different ways.
In the zone of high fault currents ($>10.I_n$-$20.I_n$), the currents are carried by parallel conductors formed by silver strips and/or arcs. The respective arcs continue to exist side by side because they are in the so-called positive part of the arc-characteristic.

In the zone of low fault currents ($<10.I_n$ - $20.I_n$) there always is only one conductor, strip and/or arc, carrying the current after fusion of the melting-element. Parallel arcs cannot continue to exist because they are in the negative part of the arc characteristic.

When a fuse-link is being charged with a high fault current, this current is split up in as many parallel arcs as there are parallel strips. As a result the arc-energy, developed during arcing-time, is efficiently spread over the arc-quenching media.

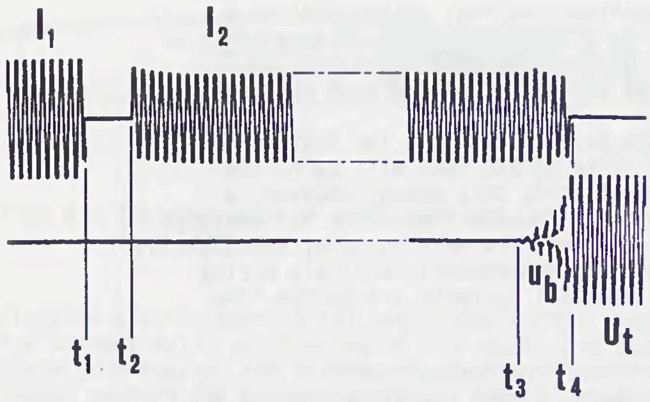
The arcs are exposed to optimum cooling, which leads to a relatively high arc-voltage gradient. In FULLRAN fuse-links of the 12 kV series, having 520 mm long melting strips, an arc-voltage gradient of 50 to 60V per mm has been obtained.

After a fuse-element melts as a result of a low fault current, there is always only one strip or arc that will carry the current. For each individual strip this means, however, a relatively high fault current. FULLRAN fuse-links are designed such, that after melting at their low melting-point spot, strips also melt on their notches and consequently multiple arcing occurs. This again means that all currents are broken "the current limiting way".

Fig. 3 shows a fulgurite of a FULLRAN fuse-link I_n= 40A after breaking a short circuit current of 40kA r.m.s. at 10.4 kV, being the test voltage of a 12 kV system.
An oscillogram of the interruption of a low fault-current is shown in fig. 4, whilst fig. 5 is a photograph of the fulgurite appertaining to this oscillogram.

Fig. 3 - Fulgurite of a 40A fuse-link after breaking 40 kA in a 12 kV system.

Fig. 5 - Fulgurite appertaining to oscillogram of fig. 4.



t_2-t_1 = change-over time (< 0,2 s)
t_3-t_0 = melting time (1 hr.)
t_4-t_3 = arcing time (120 ms)
I_1 = 1 hr. current (I_1= 68A)
I_2 = test current (I_2= 50A)
u_b = arc voltage
U_t = recovery voltage (U_t= 12 kV)

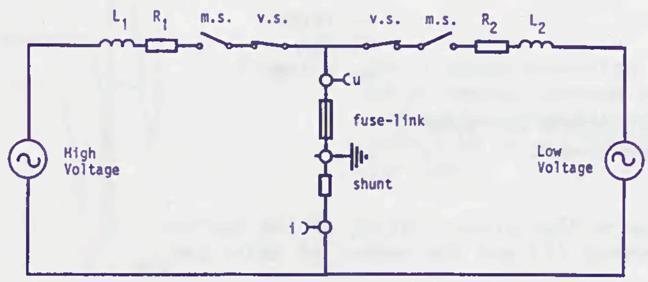
Fig. 4 - Oscillogram showing the breaking of 50A at 12 kV by a FULLRAN fuse-link 40A.

TYPE TESTING, CERTIFICATION AND SUPPLEMENTARY TESTS.

For H.V. Current-Limiting fuse-links IEC Publ. 282-1 is the best accepted recommendation for various National Standards.
FULLRAN fuse-links are tested and certified by KEMA in accordance with IEC Publ. 281-1 as being "General-Purpose" fuses.
Supplementary tests have been made to prove their "full-range" qualities. Separate tests have shown that fuses of the 12 kV series can be used in 3,6 kV and 7,2 kV systems without undue voltage-surges.

Testing of low fault currents Testing the behaviour of H.V. fuses at low fault currents can usually not be fully performed in a H.V. circuit.
Long melting times of minutes or even hours would cause insurmountable problems of heat dissipation in the circuits of the testing laboratories. Therefore those tests are made in a dual circuit.
The fuses are preheated in a L.V. circuit until melting of the fuse-element starts. Just before final melting occurs, the fuse is connected to the H.V. circuit after less than 200 milliseconds change-over time. This test is in accordance with the conditions described in IEC Publ. 282-1, clause 13.2.2.1.
Final melting of the fuse-element occurs in the H.V. circuit so the verification of breaking of (very) low fault currents is done eventually in a "direct" circuit.

In case tests are to be made at currents higher than or equal to the 1 hour melting-current, the value of the test-currents in both the L.V. circuit and the H.V. circuit are indentical.
FULLRAN fuses have also been tested at currents lower than the 1 hour melting-current. During these tests the L.V. circuit is set at the 1 hour current and the H.V. circuit at the desired value, which shall be less than the 1 hour current.
In this way tests have been made in the KEMA-laboratories at $1.25.I_n$ in free air and at I_n in an insulation enclosed Holec Magnefix unit.
The diagram of the test-circuit for low fault currents is shown in fig. 6.



Circuit components.

L_1 and R_1 = control inductance and resistor in H.V. circuit
L_2 and R_2 = Do. in L.V. circuit
m.s. = make switch
v.s. = breaker
u = voltage measurement
i = current measurement

Fig. 6 - Test circuit for low faultcurrents.

Resistance against transformer inrush currents The amplitude of inrush currents of offload transformers is depending on the design of the transformer itself, the firing angle and the fault-level of the supply system.
If a transformer at the H.V. side is protected by fuses, then those fuses have to withstand all inrush currents of that particular transformer.

The effects of inrush currents on FULLRAN fuses have been extensively investigated in a 10 kV supply system.
The aim of these tests was to determine
. the highest fuse rating at which inrush currents can cause melting of the fuse element, and
. whether the fuses will adequately break inrush currents.
Fig. 7 shows a diagram of the test-circuit.
The tests have been made at a 500 kVA-substation tranformer 10/0,4 kV.

The fault-level of the supply system amounts to 280 MVA. The maximum recorded inrush current was 450A or 15.5 times the rated current of the transformer. The tests were conducted in a three phase system. Except where melting had already occured, each current rating was tested 10 times. The firing angle was random.

Fig. 7 - Test circuit for inrush currents of off-load transformers.

Table 1 gives information on the current rating of the various fuse-links, the peak currents ($\hat{i}$) and the number of tests per current-rating (n).
The fuses I_n= 40A and I_n= 31,5 did not melt and neither mechanical nor thermal ageing of either the silver strips or the low melting point spot could be observed.

I_n (A)	Type no.	$\hat{i}$ (A)	n
40	P321a	55 - 440	10
31,5	P321a	20 - 450	10
25	P321a	130 - 390	6
20	P321a	160 - 390	2

Table 1.

One fuse I_n= 25A melted during the first test and another one during the sixth test. One fuse I_n= 20A melted during the second test.
In all three cases the fuse exposed to the highest peak current melted and the fuse has cleared the current properly.
The two remaining fuses were unaffected, and there was no detectable ageing.

Fig. 8 is the oscillogram of the melting and breaking of an inrush current by a fuse I_n= 25A.
A photograph of the fuse-element after breaking this inrush current is shown in fig. 9. It can clearly be seen that melting of the strips took place at the notches, whilst the tin spots are still intact.
The conclusion for this particular test is that, as far as inrush currents are concerned, this 500 kVA transformer (I_n= 28,8A) can be protected by a FULLRAN fuse I_n= 31,5A.

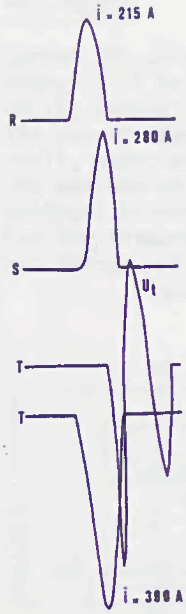


Fig. 8 - Oscillogram recording the breaking of an inrush current of a substation transformer 500 kVA - 10/0,4 kV by a FULLRAN fuse-link I_n= 25A.

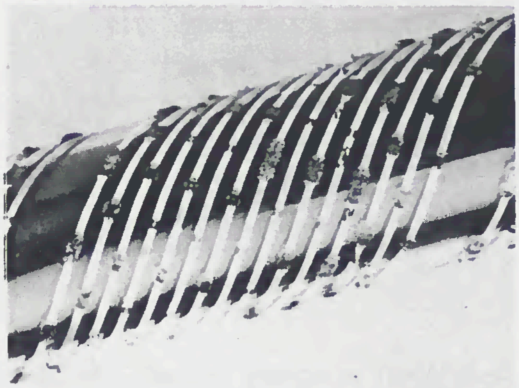


Fig. 9 - Detail of the fuse element after breaking the inrush current. Clearly to be seen is that melting occurs at the notches; the tin-spots are still intact.

VERFICATION OF RESISTANCE AGAINST SHOCKS AND VIBRATION

IEC Publ. 282-1 does not contain recommendations for the verification of shock and vibration resistance of H.V. fuses.

FULLRAN fuse-links have been tested in own laboratories to check whether they are shock and vibration resistant.
The fuses have succesfully passed following tests:

Vibration tests The tests have been made in a vibrating frame with variable frequency and amplitude control.

. According to Veritas specifications: Vibrating at a resonance frequency or 25 Hz and an amplitude of 2 mm for 1 hour.
. According to Lloyds specifications: Three dimensional vibrating. In the zone 1 Hz-13,2Hz at an amplitude of 1 mm. In the zone 13,2 - 100 Hz with an acceleration of 0,7 g, vibrating time 2 hours at a resonant frequency or 13,2 Hz.

Shock test This test is meant as a transport simulation test. Three fuse-links in their original packing have been tested on the vibrating frame.
Vibration in vertical direction at an amplitude of 12 mm and resonance frequency for 15 minutes.

Drop test This test is a free fall test according to IEC 68-2-32, test Ed. It contains a vertical free fall of unpacked fuse-links on a 20 mm steelplate.
Fullran fuse-links withstand this fall from a height of 500 mm without fracture of the fuse-element.

Operation test This contains withdrawing and inserting 3 fuse-links in a Magnefix-unit. Inside this unit the fuses were continuously charged with their rated current. In total 500 operation tests have been made at a rate of 25 times per day.

ARC ENERGY

During the current-breaking process in a fuse a certain arc energy will be generated. This arc energy is the integral of arcing current, arcing voltage and arcing time.
The amount of arc energy generated in FULLRAN fuses is relatively small, especially when breaking low fault currents.
The maximum arc energy will be generated during breaking of critical currents.
For the fuse ratings of 25A, 40A and 80A measured values of arc energy are given in the graphs of fig. 10.

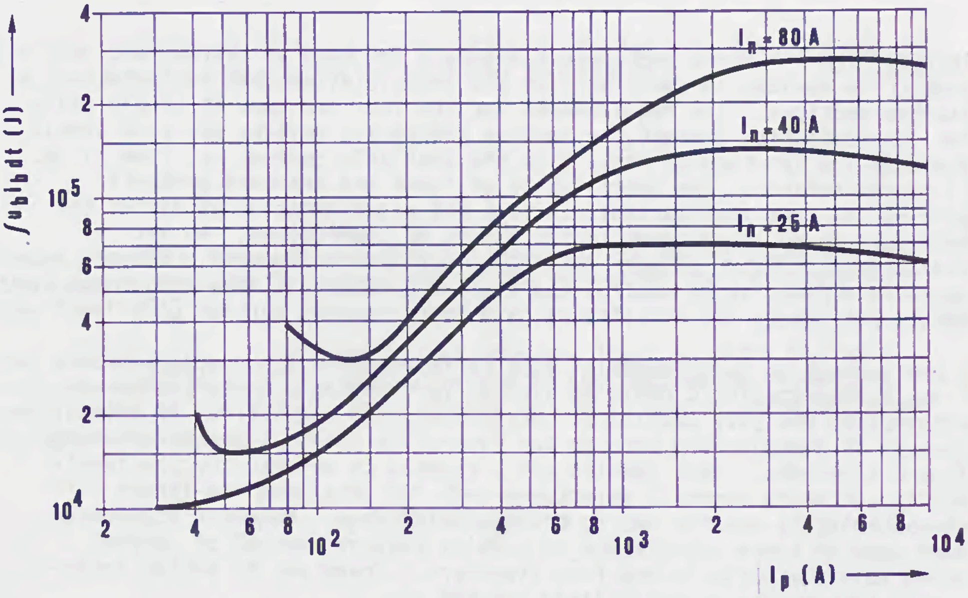


Fig. 10 - The arc energy as function of the prospective current. Values shown are the maximum values.