Considerations regarding testing of low voltage equipment at electrical arc and thermal factor actions

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Abstract: Within paper there is made a synthesis of IEC standards requirements for testing at overload and short-circuit currents of low voltage equipment: switches, disconnectors, switch- disconnectors, contactors, fuses and fuses combinations with these.
After this there is presented testing circuit for withstand ability at overload and short-circuit currents passing of low voltage equipment for a large range of currents through realisation of a special circuit for load adjustment.
Also are described experiments performed on low voltage fuses - as type tests - and are established appreciation criteria regarding the behaviour at electric arc action due to overload and short-circuit currents.

Keywords: low voltage equipment, tests, standards, data acquisition and processing

1. Introduction

In order to certify the quality of products at sectorial level within reglemented domain, according to European Directive 73/23 CEE for free circulation on international market of products marked CE, low voltage equipment must be tested at electric arc and thermal factor action due to overload and short-circuit currents passing.
In this aim must be performed tests according to actual IEC standards within specialised laboratories, endowed with corresponding equipment for achieving the test circuits.
In order to establish the test circuit we must analyse the requirements of IEC test standards [1] specifically for low voltage apparatus and equipment.

2. Requirements of testing standards

In order to appreciate the withstand ability of low voltage equipment at overload and short-circuit currents passing there are performed type tests according to IEC standards [1]. The IEC requirements establish that tests to be performed with five test duties in a certain order and at specified tests parameters (voltages, currents, power factors) [1,2].
Testing standards establish: number of tests to be performed, nominal duty cycles (for switches apparatus), testing circuits, appreciation criteria of test behaviour and apparatus status after test.

Testing of low voltage equipment and apparatus are very complex and they seek for verification of following operating capability:

- in service at rated currents (temperature-rise test)
- at short-circuit currents (making and breaking test, short-time and peak current withstand test, short-circuit test etc)
- overload currents test [1][2]

As a synthesis of testing standards requirements [1][2] we present test duties for commutation apparatus in Table 1 and for fuses in Table 2.

Table 1 - General scheme of test duties for low voltage switchgears and controlgears

Test sequence	Test	Cycles
I – General performance characteristics	- Overload performance. - Temperature-rise - Overload releases	
II – Rated service short-circuit breaking capacity	- Rated service short-circuit breaking capacity. - Temperature-rise - Overload releases	O-t-CO-t-CO
III – Rated ultimate short-circuit breaking capacity	- Overload releases - Rated ultimate short-circuit breaking capacity. - Temperature-rise - Overload releases	O-t-CO
IV – Rated short-time withstand current	- Overload releases - Rated short-time withstand current - Temperature-rise - Short-circuit breaking capacity at maximum short-time withstand current - Overload releases	O-t-CO
V – Performance of integrally fused circuit-breaker	Stage 1 - Short-circuit at selectivity limit current - Temperature-rise	

Test sequence	Test	Cycles
V – Performance of integrally fused circuit-breaker	Stage 2 - Overload releases - Short-circuit at 1.1 times take-over current - Short-circuit at ultimate short-circuit breaking capacity - Overload releases	O-t-CO

O – opening cycle
CO – close-opening cycles

Note: Rated breaking capacity at short-circuit, short-time maximal rated current are established by manufacturer. Also it specifies, for circuit-breakers and contactors, the utilisation category and, for fuses, constructive type.

Table 2 - General scheme of test duties for low voltage fuses

Test duty / Type		Parameters		
		Ur	I	cosφ
Test duty 1		110^{+5}_{0} Un	$I_1 \leq 20$ kA $I_1 > 20$ kA	0.1-0.2 0.2-0.3
Test duty 2			$I_1 \leq 20$ kA $I_1 > 20$ kA	0.1-0.2 0.2-0.3
Test duty 3	s		$I_3 = 3.2\ I_f$	0.3-0.5
	a		$I_3 = 2.5\ k_2\ I_n$	
Test duty 4	s		$I_4 = 2\ I_f$	
	a		$I_4 = 1.6\ k_2\ I_n$	
Test duty 5	s		$I_5 = 2.5\ I_f$	
	a		$I_5 =\ k_2\ I_n$	

Un – rated voltage
Ur - recovery voltage
I - test current
I_1 - rated breaking current
I_2 - breaking current for maximum energy
I_3, I_4, I_5 - overload currents
I_f - fuse melting current
I_n - fuse rated current
K_2 - calculus coefficient (see IEC 60269)

3. Testing circuit

Testing circuit for verification of the withstand ability of low voltage equipment at overload and short-circuit currents passing are presented in Figure 1.

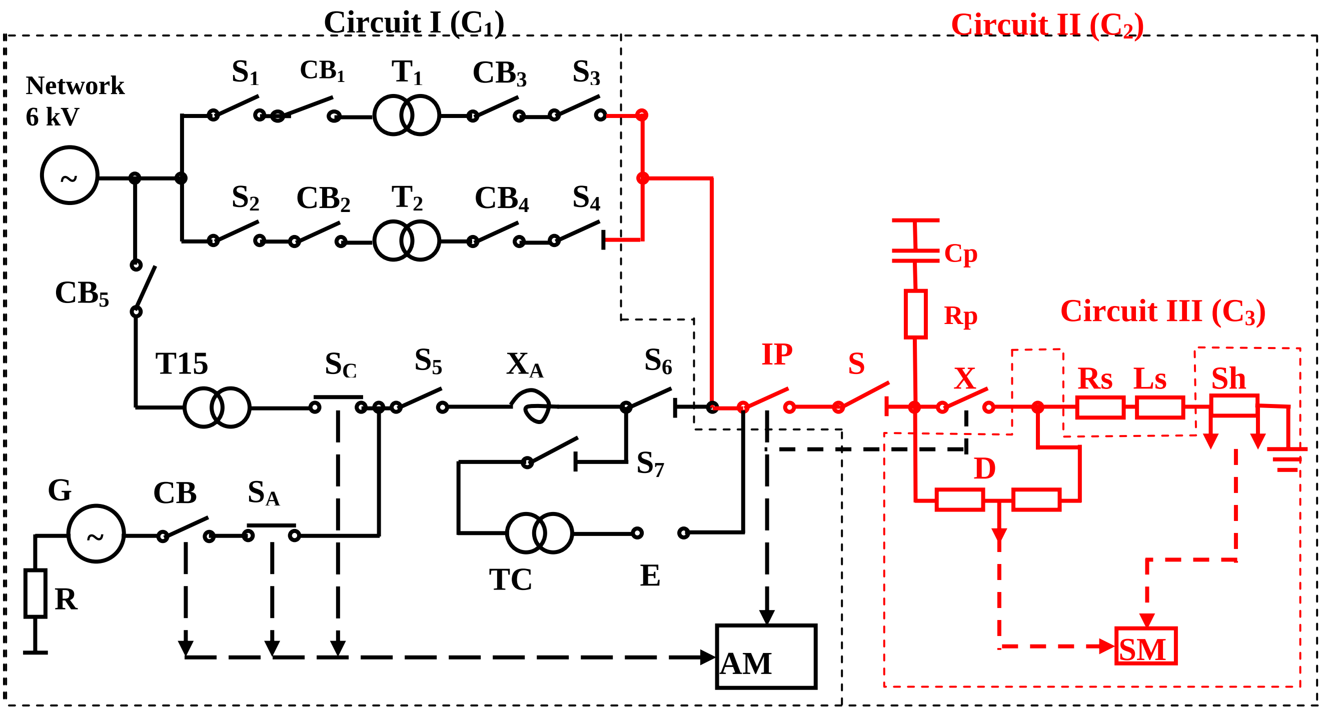

Figure 1 - Testing circuit scheme

T_{15}	-	Transformer 15 MVA, 10,5 / 6,3 kV
T_1T_2	-	Transformers 1000 kVA, 6 kV/0,4 kV
G	-	Generator 2500 MVA, 12 kV
S_1, S_2	-	Disconnector 6 kV / 1250 A
CB_1, CB_2	-	Circuit-breakers 12 kV / 1250 A
CB_3, CB_4	-	Circuit-breakers 500 V / 2000 A
S_3, S_4	-	Disconnector 0,4 kV / 1250 A
CB_5	-	Circuit-breaker 6 kV / 2500 A
Sc	-	Making switch 6 kV / 2500 A
X_A	-	Reactances 100 mΩ / 10 kA – 0,055 – 1,8 Ω / phase
X_B	-	Reactances 3 - 550 Ω / phase

CB	-	Generator circuit-breaker 12 kV / 120 kA
S_A	-	Making switch 12 kV / 330 kA
TC	-	Step-down transformers 10 MVA 10 / 0,5 kV
IP	-	Protection circuit-breaker 1000 V, Ir = 10 kA
X	-	Tested object
Sh	-	Shunts 2000 A ÷ 70000 A / 2V
Rs	-	Load resistances
Ls	-	Load inductances
Rp, Cp	-	Elements for adjustment of Transient Recovery Voltage
S	-	Disconnector 1000 V / 2500 A
SM	-	Measuring system
AM	-	Automatic programmer
E	-	Connections
S5,6,7	-	Disconnectors 12 kV / 1250 A
D	-	Voltage divider

According to Figure 1, testing circuit is composed of:

- high current and voltage supply circuit (C_1)
- load adjustment circuit (C_2)
- measuring and recording circuit (C_3)

As voltage supply are, depending of test performed, 6 kV network, 15 MVA network transformer, 1000 kVA power with step down ration 6 kV/1/0.5/0,25 kV or 2500 MVA short-circuit generator with variable voltage (1÷12 kV).

As impedance load, within load adjustment circuit, are used: resistors batteries (0.05 Ω - 125 Ω) and reactors batteries (0.25 mH - 250 mH). Resistors and reactors are series connected in circuit and in parallel are connected the capacitors and resistors to adjust the parameters of transient recovery voltage. In order to can perform tests in large range of currents (4 A - 7500 A) at voltage of 380 V; 660 V; 1000 V, there were determined, based on calculus, reactances and resistances values required for tests duties 3,4 and 5 (power factor: cosφ = 0.3 - 0.5).

For adjustment of load current according to test standards, resistors and reactors batteries were realised with no inductive resistors and inductance coils without iron core, in modular construction, with the values of resistances and inductances in geometrical progression with ratio 2. [3]

Resistors battery consists of four modules on each phase, endowed with adjust terminals, and reactors battery consists of inductance coils in single- and multilayer construction, having the values of: 0.25 mH; 0.5 mH; 1 mH; 2 mH; 4 mH; 8 mH and 16 mH. The arrangement of coils modules is rectangular symmetrical (90^o) to avoid coupling inductances at overload currents passing.

Measuring and recording circuit consists of:

- current transducers: Rogowski coils (up to 100 kA) and shunts (2 kA - 180 kA)
- voltage dividers
- computerised system for data acquisition and processing [4][5]

4. Experiments on low voltage fuses

To verify the behaviour at electric arc action and thermal factor were performed tests according to IEC 60269-1 standard on low voltage fuses. According to the program below, were performed breaking tests on 500 V/250 A fuses. [6]

A) Tests program

Tests program is the following:

Test duty 1

- One current calibration test at I_k = 120 kA
- Three breaking tests at parameters: U_r = 550 V; I_1 = 60 kA; cos φ = 0.15; $\varphi = 40^0 - 65^0$ (one test) and $\varphi = 65^0 - 90^0$ (two tests)

Test duty 2

- One current calibration test at I_k = 16.9 kA
- Three breaking tests at parameters: U_r = 550 V; I_2 = 16,9 kA ; cos φ = 0.25 ; $\varphi = 0 - 20^0$

Test duty 3

- One current calibration test at I_k = 13.4 kA
- One breaking test at parameters: U_r = 550 V; I_3 = 13.4 kA; cos φ = 0.4

Test duty 4

- One current calibration test at I_k = 0.90 kA
- One breaking test at parameters: U_r = 550 V; I_4 = 900 A; cos φ = 0.4

Test duty 5

- One current calibration test at I_k = 0.50 kA
- One breaking test at parameters: U_r = 550 V; I_4 = 500 A; cos φ = 0.4

Verification of overcurrent discrimination test

- One current calibration test at I_k = 8.6 kA
- Two tests at parameters: U = 320 V; I_D =8.6 kA; $\varphi = 0^0 - 20^0$
- One current calibration test at I_k = 11.8 kA
- Two tests at parameters: U = 320 V; I_D =11.8 kA; $\varphi = 0^0 - 20^0$

B) The elements and parameters of testing circuit

The aspect of fuse in the test circuit is presented in Figure 3. [6]

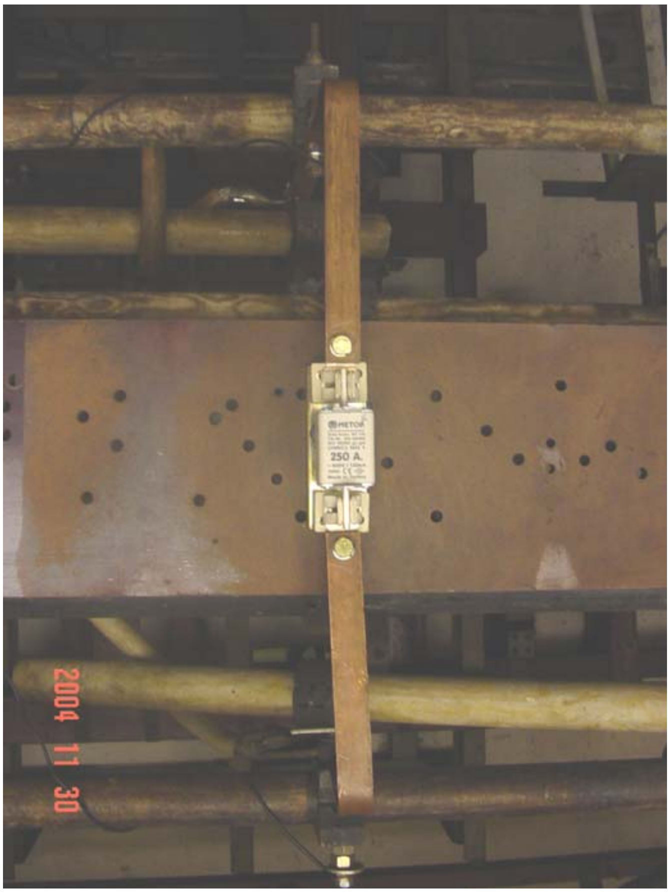

Figure 3 - The aspect of fuse in the test circuit

C) Data obtained at tests

The results obtained by processing the oscillograms presented in Table 3. For each test duty was selected an oscillogram presented in Figures 4-8.

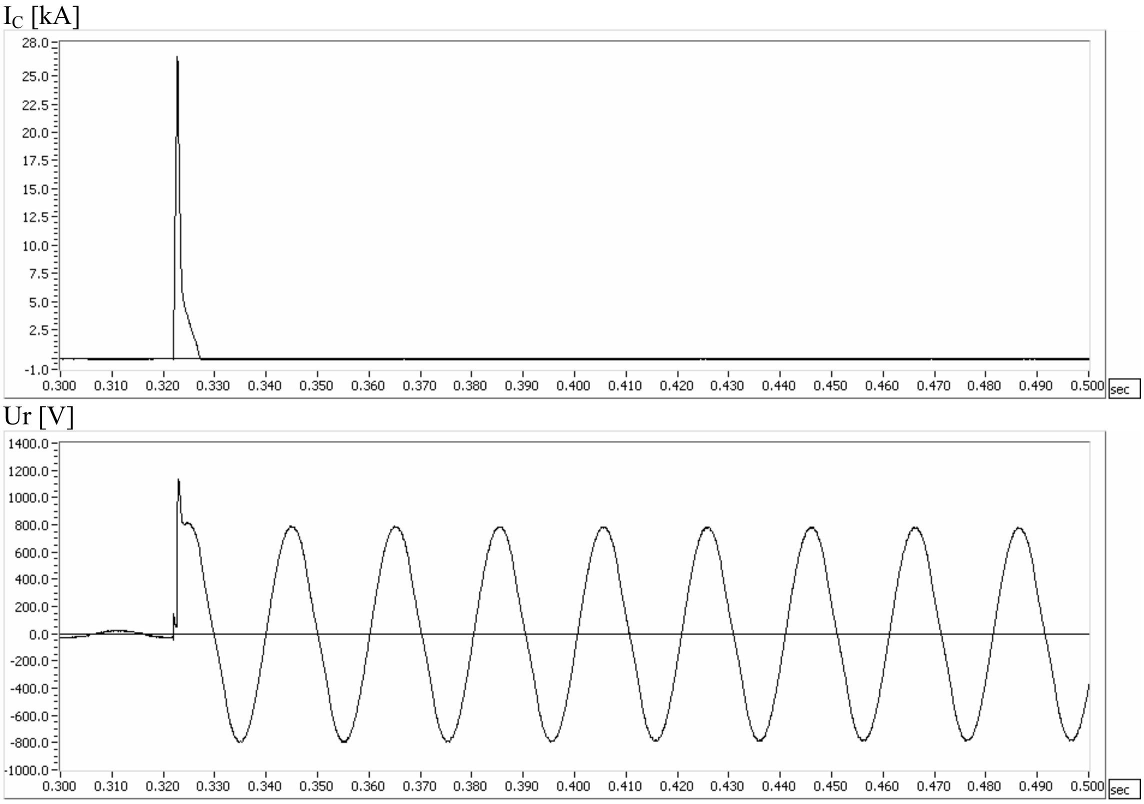

Figure 4 – Oscillogram from test duty I_1

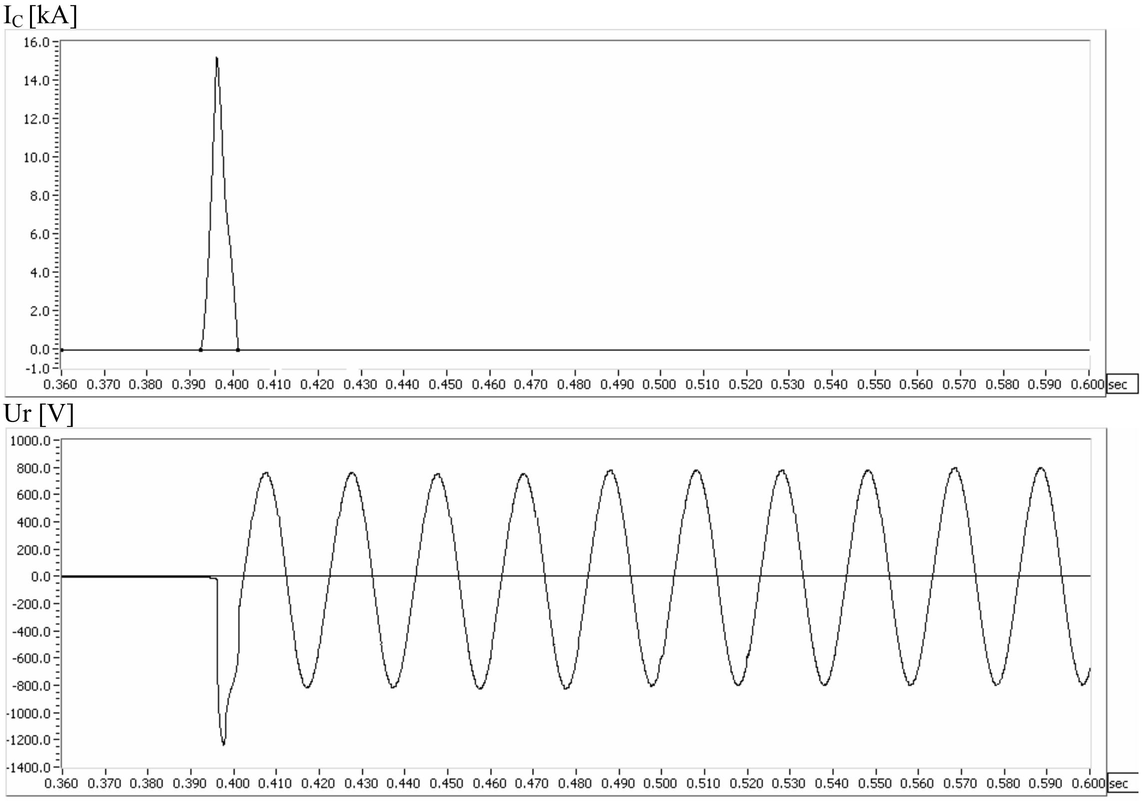

Figure 5 – Oscillogram from test duty I_2

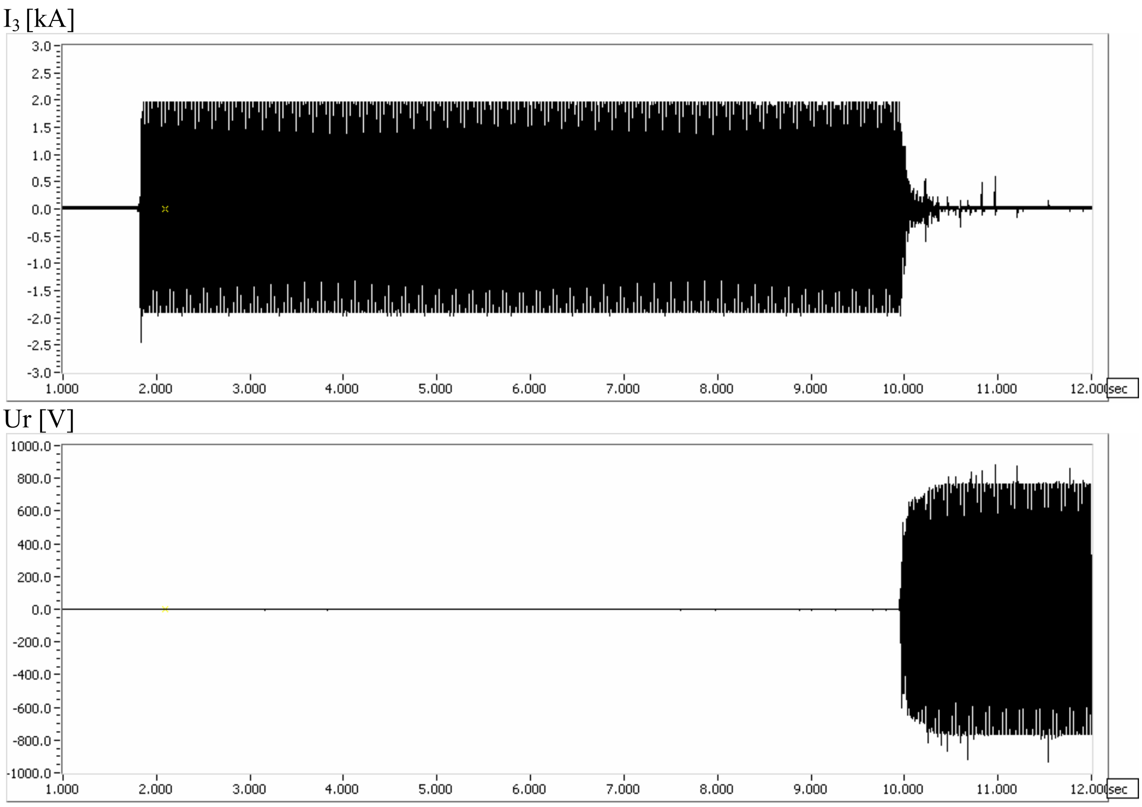

Figure 6 – Oscillogram from test duty I_3

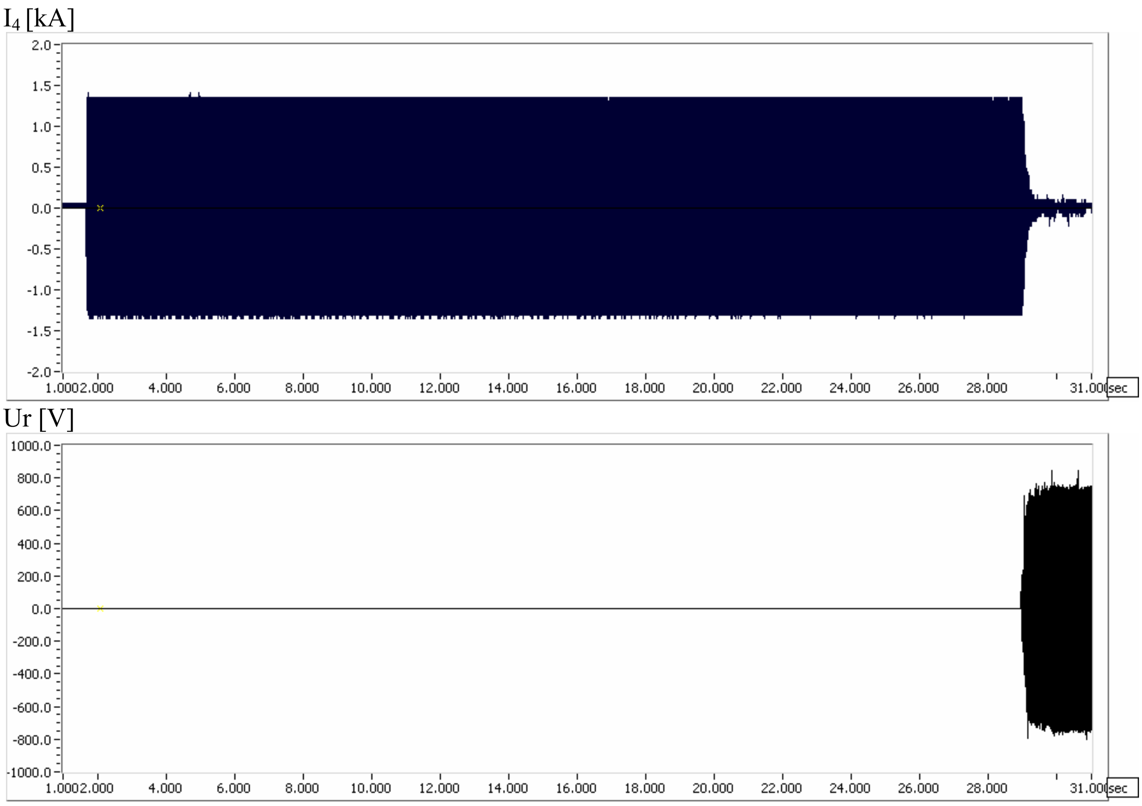

Figure 7 – Oscillogram from test duty I_4

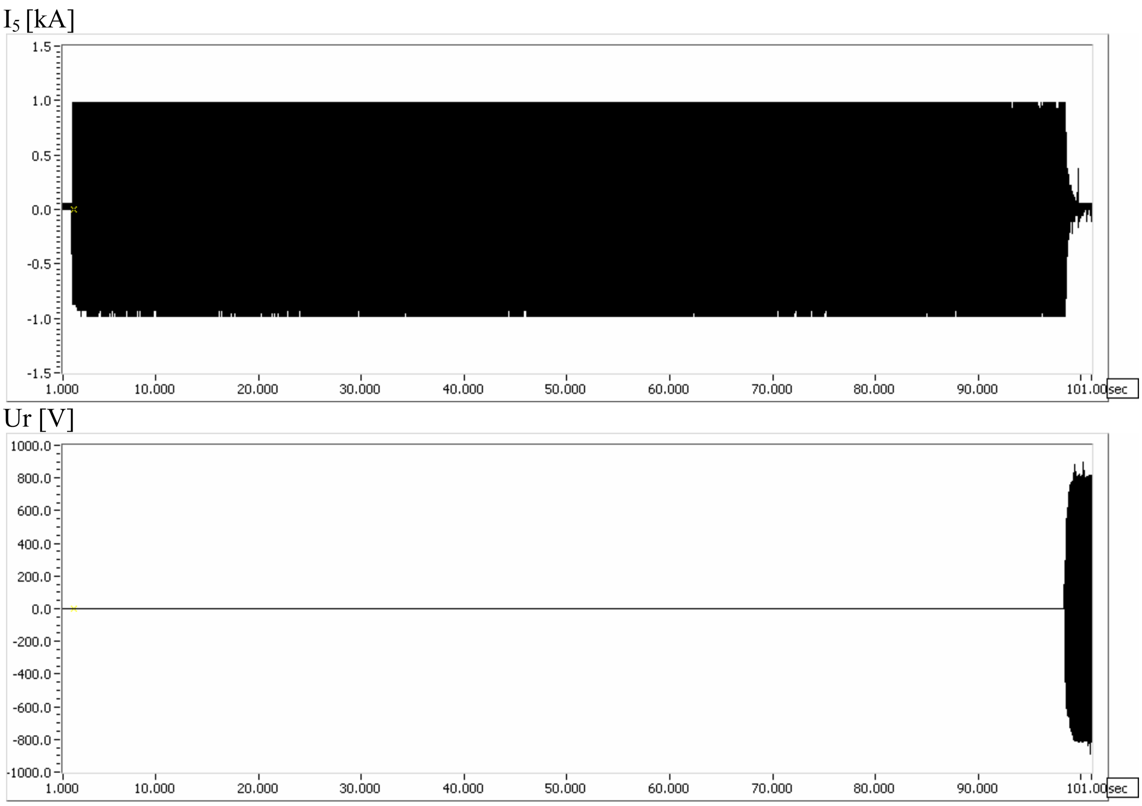

Figure 8 – Oscillogram from test duty I_5

Table 3 - Main results obtained at tests on fuses

Test No.	Test duty.	Recovery voltage	Current	Time			I^2t			Over-voltage	Making after voltage zero /
		Ur	I_C/I_D	Pre-arcing	Arcing	Total	Pre-arcing	Arcing	Total	Uc	Angle of arcing initiation
		[V]	[kA]	[ms]	[ms]	[ms]	$[10^3xA^2s]$	$[10^3xA^2s]$	$[10^3xA^2s]$	[V]	[°]
1.	I_1	550	26.7	0.85	4.5	5.35	198	273	471	1126	-/54
2.	I_1	550	28.1	0.75	3.9	4.65	204	279	494	1216	-/66.6
3.	I_1	550	27.9	0.75	4.1	4.85	215	273	488	1199	-/68
4.	I_2	550	14.9	3.5	4.8	8.3	211	310	521	1239	10.8/-
5.	I_2	550	15.2	3.7	4.7	8.4	225	356	581	1239	9.9/-
6.	I_2	550	15.1	3.7	4.65	8.35	223	355	578	1236	9/-
7.	I_3	550	1.34	-	-	8220	-	-	-	-	-
8.	I_4	550	0.92	-	-	27400	-	-	-	-	-
9.	I_5	550	0.6	-	-	96400	-	-	-	-	-
10.	I_{Dmin}	320	8.1	4.2	2.95	7.15	102.5	60.3	163	454	16.2/
11.	I_{Dmin}	320	8.0	4.5	2.75	7.25	102.1	60.1	162.2	890	17.1/-
12.	I_{Dmax}	320	12.9	4.7	2.7	7.4	205.2	141.1	346.3	967	4.5/-
13.	I_{Dmax}	320	13.1	4.75	2.85	7.6	208.3	154.6	362.9	955	7.2/-

I_C – cut-off current; I_D – discrimination current; Ur – recovery voltage (was maintained 15 s at all tests)

D) Appreciation criteria for fuses behaviour at tests

According to IEC [2] there are fulfilled the following acceptance criteria:

- Fuses did not break during the tests.
- The arc voltage occurring during test of fuse in test duty I_1 and I_2 did not exceeded 2500 V.
- There were not observed permanent arcing, flashovers or ejection of flames which may be dangerous for surrounding.
- The resistance between fuse contacts measured after each test was greater than 100 kΩ.
- The operating I^2t values did not exceed the values indicated by manufacturer and specified in IEC (see Table 3):
  $250 \cdot 10^3\ A^2s < I^2t < 760 \cdot 10^3\ A^2s$
- The pre-arcing I^2t values for test duty I_2 were calculated according with IEC method.
- The discrimination of the fuse was verified by means of time-current characteristics and the pre-arcing and operating I^2t values.

5. Contributions within this paper:

- Elaboration of test circuit with flexibility for whole range of low voltage test, from small to high currents
- Design of load adjustment circuit, realized in two constructive variants – for overload and short-circuit currents
- Interpretation of fuses behavior given by the effects of overload and short-circuit currents passing through them
- High speed acquisition and processing computerized system, which gives immediately after test current and voltage parameters and other special characteristics (like $\int i(t)^2dt$ energy, breaking angles etc)

6. Conclusions

- The realised circuit allows the achievement of tests both for switchgears and controlgeas and for low voltage fuses.
- Experiments performed on low voltage fuses of 550 V/250 A shown a good behaviour for short-circuit and overload currents passing, without long arc durations and without great arc energies
- The values of I^2t and breaking behaviour are in normal ranges, within those previewed by IEC standards.
- Overvoltages during the tests did not exceed the values stated in IEC standards.
- Isolation resistances after tests are good.

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