

Test Document

Report No.: HBA 09608 P

Copy No.: 0

Contents: 17 Sheets

Test object: Metal oxide surge arrester, nominal discharge current 20 kA

Type:	3EP2 ...-3..4.-....	3EP3 ...-3..4.-....
	3EQ3 ...-3..4.-....	3EQ4 ...-3..4.-....
	3ES2 ...-3..41-....	3ES5 ...-3..43-....

Manufacturer: Siemens AG, PTD H 515

Client: Siemens AG, PTD H 513

Date of test: July 2005

Testing station: Siemens AG, Arrester Test Laboratory, PTD H 512

Applied test specifications:

IEC 60099-4 Ed. 2 (2004)

IEC 60060-1 (1989)

Tests Performed:

Type test:

Verification of the power frequency voltage versus time characteristic

Test Result:

The test object has passed the test stated above without any objection. The results obtained and the performance proved of the test object complies with the requirements of the specifications mentioned above.

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High Voltage Surge arresters



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High Voltage Surge arresters

Berlin, July 11, 2005

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3 Technical data of the arresters

Type	Maximum rated voltage	Maximum continuous operating voltage
3EP2 ...-3..4.-....	468 kV	374 kV
3EP3 ...-3..4.-....	468 kV	374 kV
3EQ3 ...-3..4.-....	468 kV	374 kV
3EQ4 ...-3..4.-....	444 kV	355 kV
3ES2 ...-3..41-....	156 kV	124 kV
3ES5 ...-3..43-....	156 kV	124 kV

General data

Nominal discharge current	20 kA
Long duration current impulse capability	1200 A / 2 ms
Line discharge class	4
Thermal energy discharge capability	10.0 kJ / kV _{rated voltage}
Single impulse energy discharge capability (> 4 ms)	5.6 kJ / kV _{rated voltage}
High current impulse capability	100 kA

4 Verification of the power frequency voltage versus time characteristic

The verification of the power frequency voltage versus time characteristic was performed on three arrester sections of 11.32 kV rated voltage (arrester section, see sheet-no. 5) with a thermal and electrical behaviour corresponding to the behaviour of the complete arrester (test circuits see sheet-nos. 8 to 9). Sheet-nos. 5 and 6 in addition show in comparison the cooling curves of both the complete arresters type 3EP2, 3EP3, 3EQ4, 3EQ3, 3ES2 and 3ES5 as well as the thermal model used for the test.

Before the test the residual voltages at nominal discharge current 20 kA, 8/20 μ s, 500 A, 30/60 μ s and the reference voltage at 5 mA were measured.

The minimum ratio of $U_{ref} / U_r = 1.00$ was used to calculate the sample's rated voltage (U_r). The continuous operating voltage (U_c) was calculated with the ratio $U_r / U_c = 1.25$ ($U_c = 9.06$ kV).

After preheating to 60 °C the test samples were subjected to two long duration current impulses of line discharge class 4 with a minimum required impulse energy of 54.9 kJ each (see 4.1.2). Time between the impulses was 60 s. About 60 ms after the second impulse a power-frequency voltage (temporary overvoltage TOV) was applied to the samples with a voltage value and a time duration according to the power frequency voltage versus time characteristic on sheet-no. 7. Three points of the power frequency voltage versus time curve were verified. After the respective time duration of TOV the samples were subsequently connected to a power transformer supplying 9.06 kV, i.e. U_c . U_c was applied for at least 30 min.

To prove thermal stability the power dissipation, the resistive component of the leakage current as well as the temperature were measured and registered continuously during U_c - application.

After the test the residual voltage at nominal discharge current 20 kA, 8/20 μ s was measured again.

According to IEC 60099-4 Ed. 2 (2004), clause 8.5.2 an accelerated aging test was performed on three single MO-blocks surrounding medium N_2 for the arresters type 3EP2, 3EP3, 3EQ4, 3EQ3 and on three single MO-blocks surrounding medium SF_6 for the arresters type 3ES2, 3ES5. Test conditions were: constant block temperature 115 °C, constant test voltage equal to $1.2 \cdot U_c$. During the test running for more than 1000 h power dissipation was measured. No increase of power dissipation was observed during the test time (see sheet-nos. 6 and 7). That means no correction of above test voltages was necessary.

4.1.1 Calculation of rated voltage

$$U_r = U_{ref} / 1.00$$

4.1.2 Calculation of impulse energy for line discharge class 4

$$W = U_{res,500A \min} \cdot (U_L - U_{res,500A \min}) \cdot 1 / Z \cdot T$$

According to line discharge class 4:

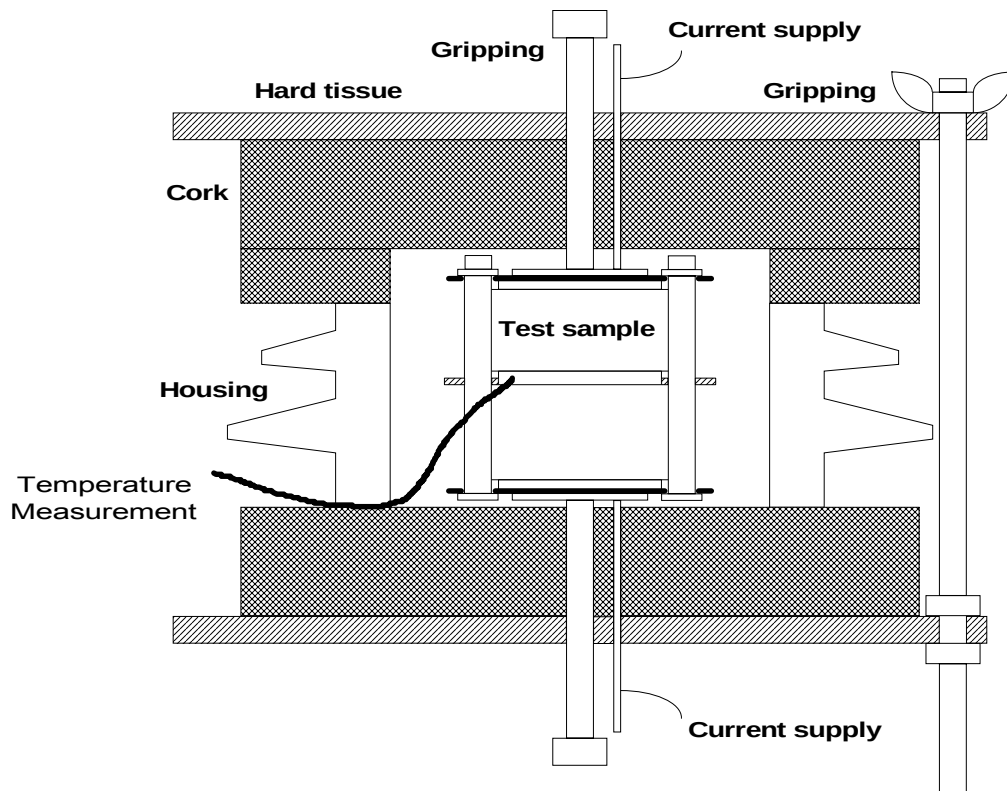
$$U_L = 2.6 \cdot U_r$$

$$Z = 0.8 \cdot U_r$$

$$T = 2800 \mu s$$

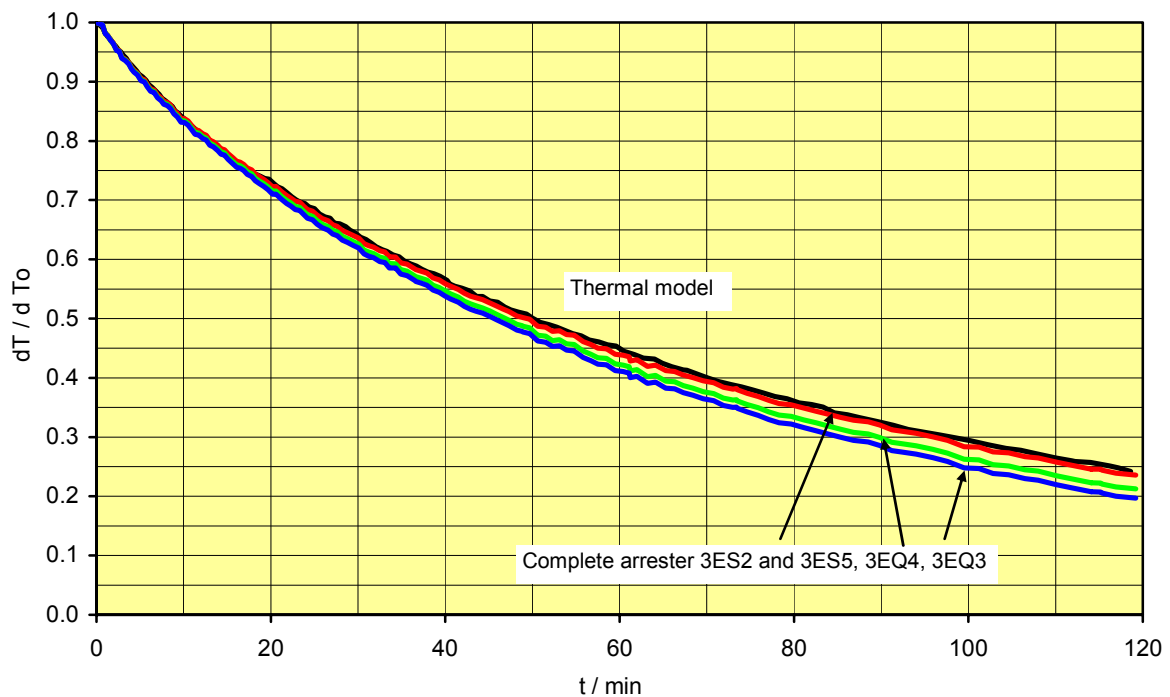
$$W = 20.96 \text{ kV} \cdot (2.6 \cdot 11.32 \text{ kV} / 1.00 - 20.96 \text{ kV}) \cdot 1 / (0.8 \cdot 11.32 \Omega / 1.00) \cdot 2800 \mu s \\ = 54.9 \text{ kJ}$$

4.2 Arrester section (thermal model)



4.3 Cooling curves (comparison: arrester - thermal model)

4.3.1 Arresters type 3ES2, 3ES5, 3EQ4 and 3EQ3



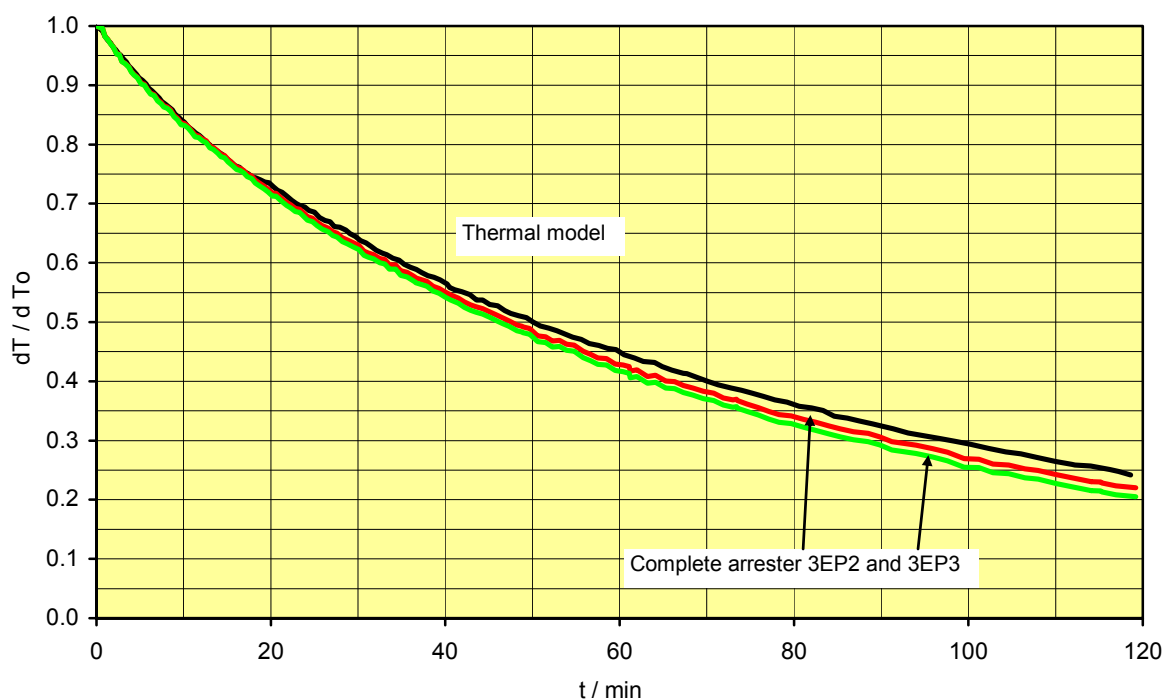
$$T_0 = 120 \text{ }^{\circ}\text{C}$$

$$dT_0 = T_0 - T_{\text{ambient}} = 100 \text{ }^{\circ}\text{C}$$

$$T_{\text{ambient}} = 20 \text{ }^{\circ}\text{C}$$

$$dT = T - T_{\text{ambient}}$$

4.3.2 Arresters type 3EP2 and 3EP3



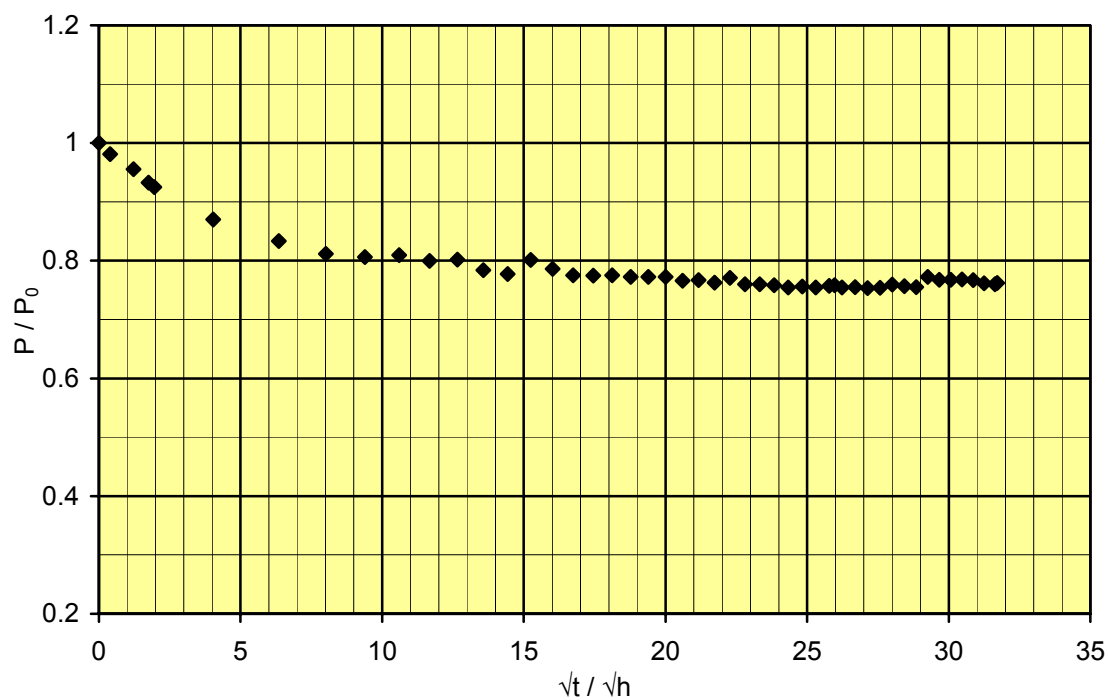
$$T_0 = 120\text{ }^{\circ}\text{C}$$

$$dT_0 = T_0 - T_{\text{ambient}} = 100\text{ }^{\circ}\text{C}$$

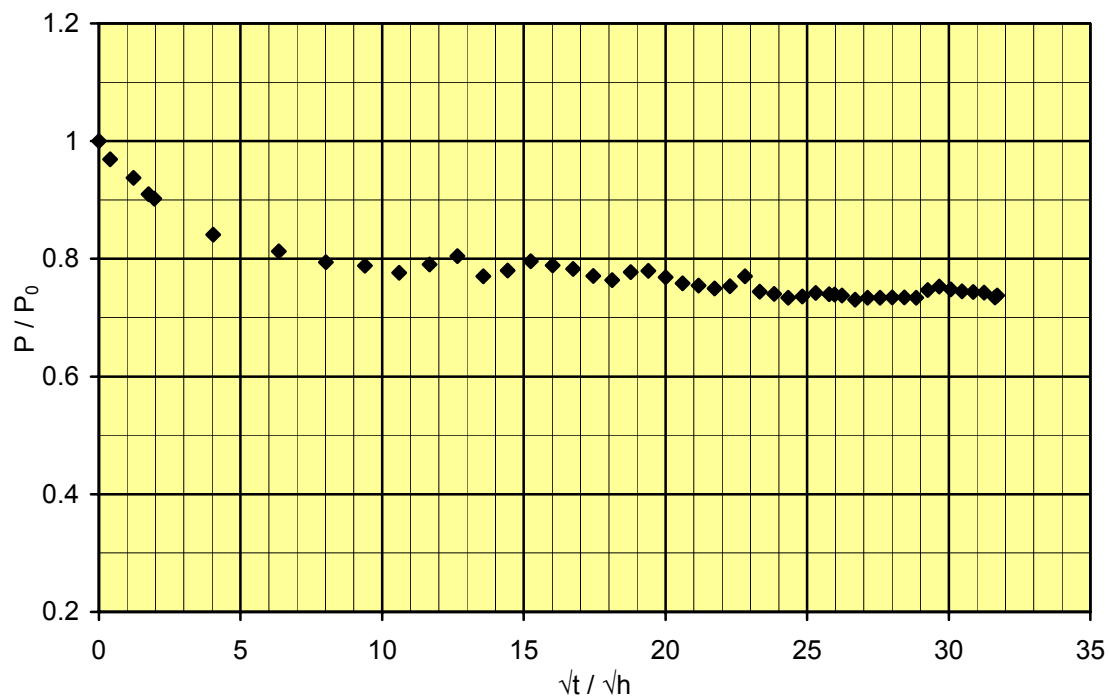
$$T_{\text{ambient}} = 20\text{ }^{\circ}\text{C}$$

$$dT = T - T_{\text{ambient}}$$

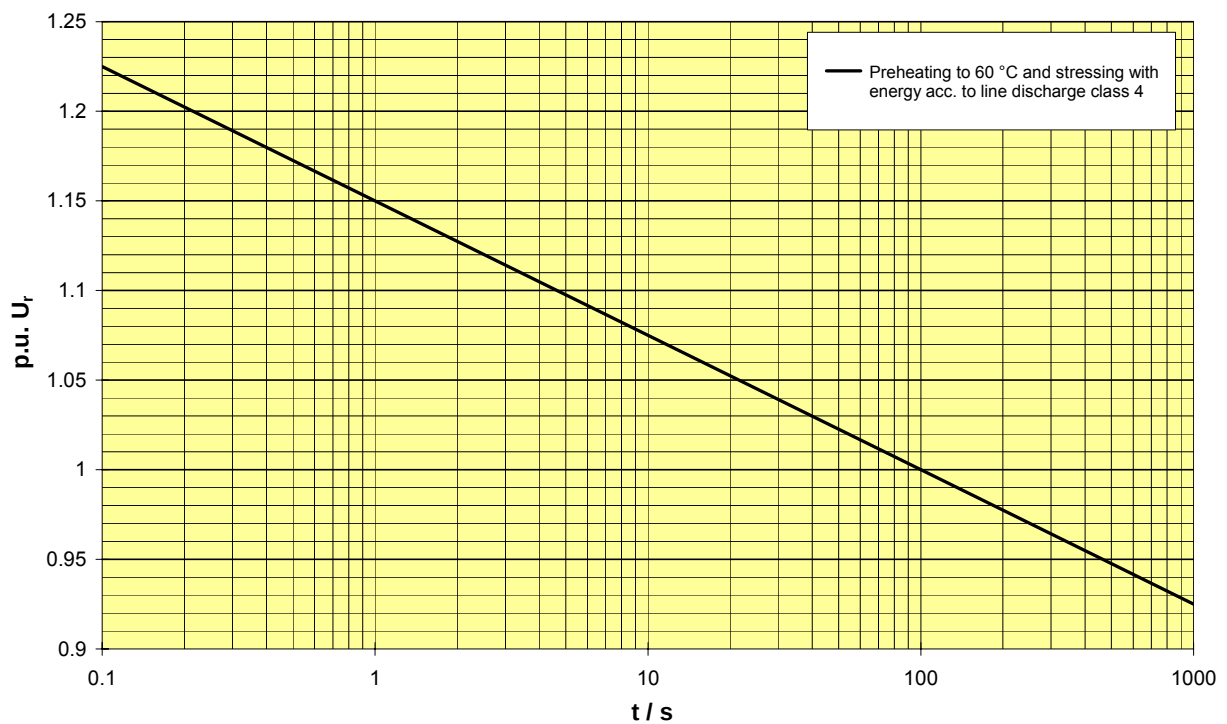
4.4 Result of accelerated aging test (one MO-block), surrounding medium N_2



4.5 Result of accelerated aging test (one MO-block), surrounding medium SF₆



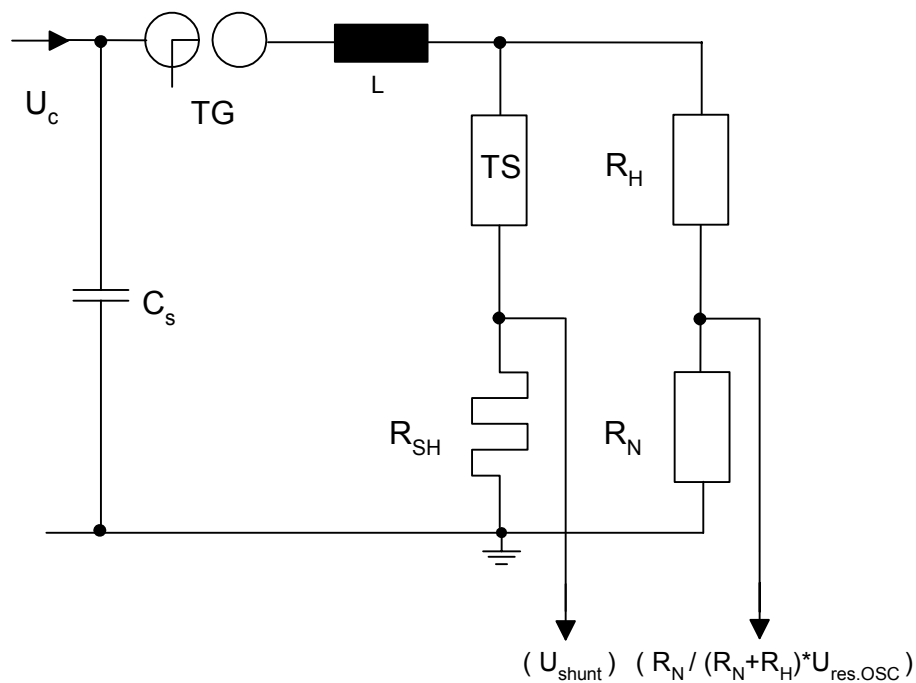
4.6 Power frequency voltage versus time characteristic (p.u. U_r)



4.7 Technical data of test circuits

4.7.1 Lightning impulse and Switching impulse residual voltage measurement

Surge circuit: Discharge current	kA	20	0.5
Surge capacitance	μF	3.7	1.85
Inductance	μH	12	401
Wave shape	μs	8/20	30/60



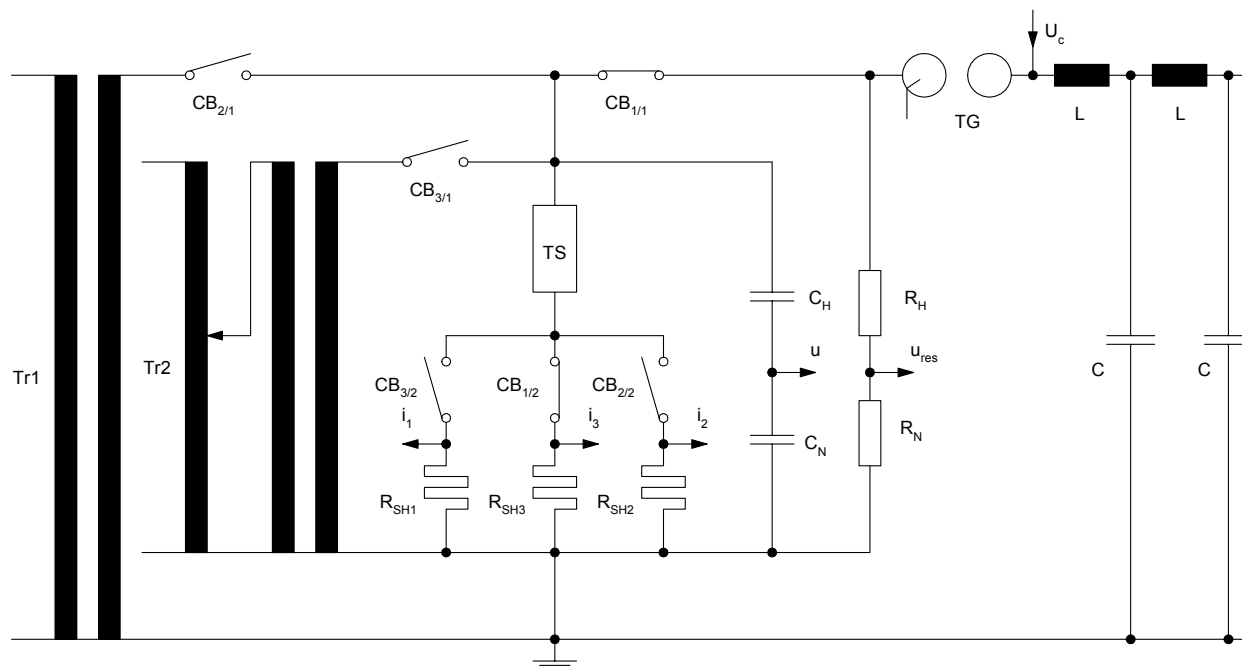
TG ... Trigger spark gap
 TS ... Test sample
 C ... Surge capacitor
 L ... Inductance
 U_c ... Charge voltage

Voltage measurement: u
 Ohmic divider: $R_H = 6051 \, \Omega$, $R_N = 60.29 \, \Omega$
 Oscilloscope Tektronix type TDS 520 / PC

Current measurement: i
 Shunt $R_{SH} = 205.2 \, \text{m}\Omega$ ($\leq 3 \, \text{kA}$); $22 \, \text{m}\Omega$ (20 kA)
 Oscilloscope Tektronix type TDS 520 / PC

Test sample: arrester section

4.7.2 Verification of the power frequency voltage versus time characteristic



Tr₁.....Transformer ($P_N = 7500$ kVA), Tr₂.....Transformer ($P_N = 10$ kVA)

TS.....Test sample

TG.....Trigger spark gap

CB.....Circuit breaker

C.....Surge capacitor

L.....Inductance

U_c.....Charge voltage

Section capacitance: 7.4 μ F

Section inductance: 0.41 mH

Number of sections: 28

Power-frequency voltage measurement: u

Capacitive divider: $C_H = 256$ pF, $C_N = 256$ nF

Oscilloscope Tektronix type TDS 5032B / PC

Leakage current measurement TOV sample 2 and sample 3: i_2

Shunt $R_{SH2} = 50$ Ω

Oscilloscope Tektronix type TDS 5032B / PC

Leakage current measurement for U_c and TOV sample 1: i_1

Shunt $R_{SH1} = 204$ Ω

Oscilloscope Tektronix type TDS 5032B / PC

Measurement of power dissipation:

Computer calculation from voltage and current

Temperature measurement

FISO Fiber Thermometer

Residual voltage measurement: u_{res}

Ohmic divider: $R_H = 5039$ Ω , $R_N = 33.7$ Ω

Oscilloscope Tektronix type TDS 340A / PC

Long duration current measurement: i_3

Shunt $R_{SH3} = 61.6$ m Ω

Oscilloscope Tektronix type TDS 340A / PC

Test procedure:

1. Long duration current impulse
2. CB₁ opens and CB₃ closes (sample no. 1)
or CB₁ opens and CB₂ closes (sample nos. 2, 3)
3. After U_{TOV} transformer Tr₂ voltage regulation down to U_c (sample no. 1) or
CB₂ opens and CB₃ closes after U_{TOV} applying U_c (sample nos. 2, 3)

Test sample: arrester section

4.8 Test result

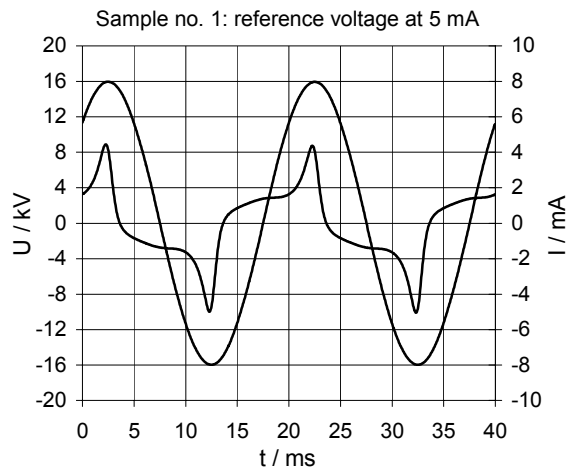
On all three test samples power dissipation, resistive component of the leakage current and temperature permanently decreased during 30 min. application of U_c .

Visual inspection of the MO-blocks after the test revealed no evidence of puncture, flashover or cracking. Change of the residual voltages of all three test samples was far below the allowed 5 %.

The oscillograms of the complete test procedure are shown as an example for test sample no. 1 on sheet nos. 10 to 14. The oscillograms of TOV are shown for all three samples on sheet no. 13. The records of the power dissipation, resistive component of the leakage current and temperature during 30 min. application of U_c are shown for all three samples on sheet nos. 15 to 17.

4.8.1 Measurement of reference voltage at 5 mA

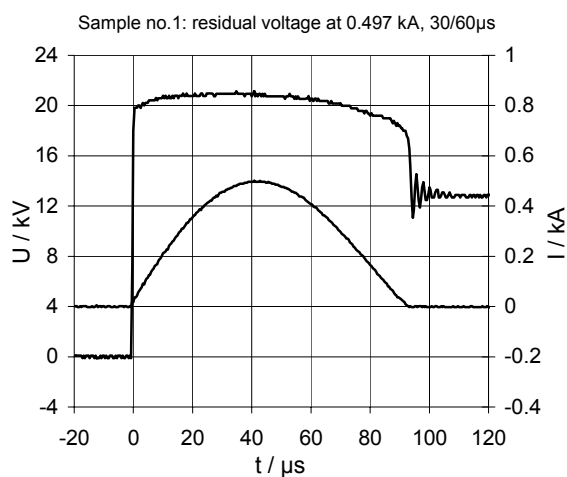
Sample no.	$U_{\text{ref},5\text{mA}}$ / kV
1	11.29
2	11.28
3	11.32



4.8.2 Measurement of switching impulse residual voltage at 500 A, 30/60 μ s

Sample no.	$U_{\text{res},500\text{A}}^{*)}$ / kV
1	20.97
2	20.90
3	20.96

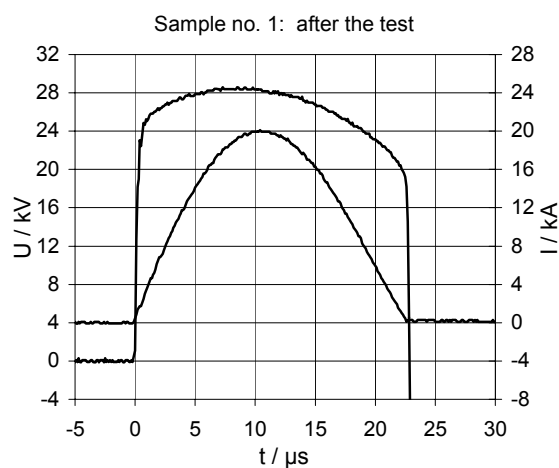
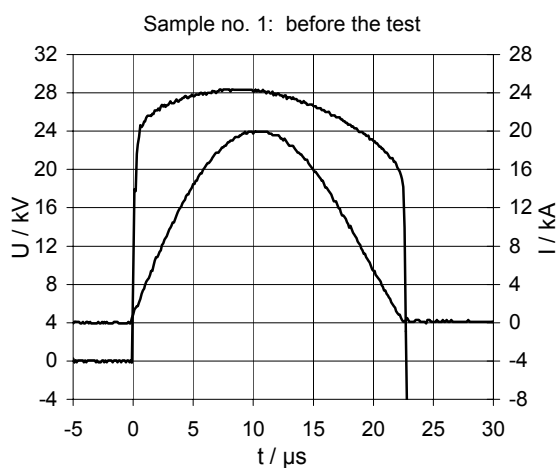
$$^{*)} U_{\text{res}} = U_{\text{res,Osc}} - U_{\text{shunt}}$$



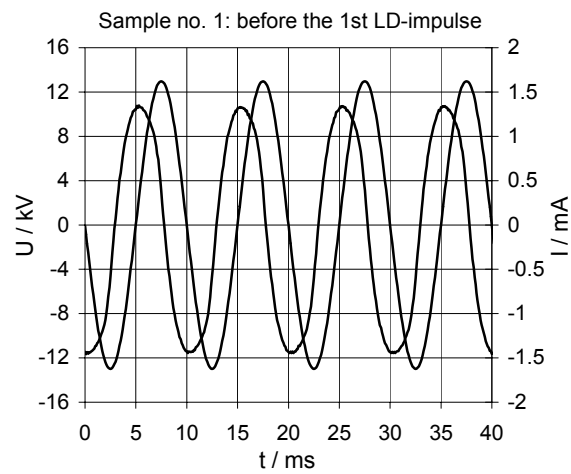
4.8.3 Residual voltage measurement at 20 kA, 8/20 μ s

Sample no.	$U_{\text{res},20\text{kA}} / \text{kV}^{*)}$		change / %
	before the test	after the test	
1	28.34	28.43	+0.3
2	28.31	28.58	+0.9
3	28.35	28,48	+0.5

$$^{*)} U_{\text{res}} = U_{\text{res,Osc}} - U_{\text{shunt}}$$

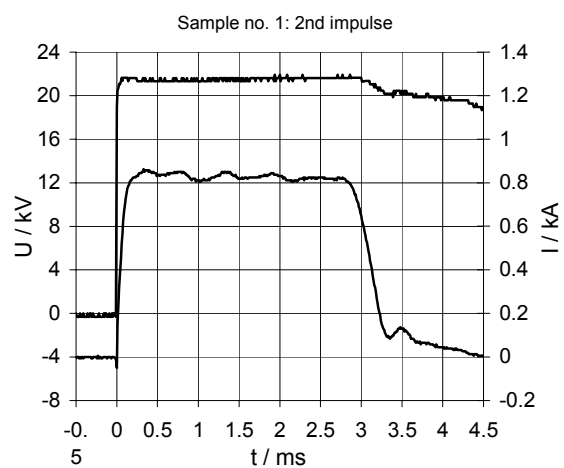
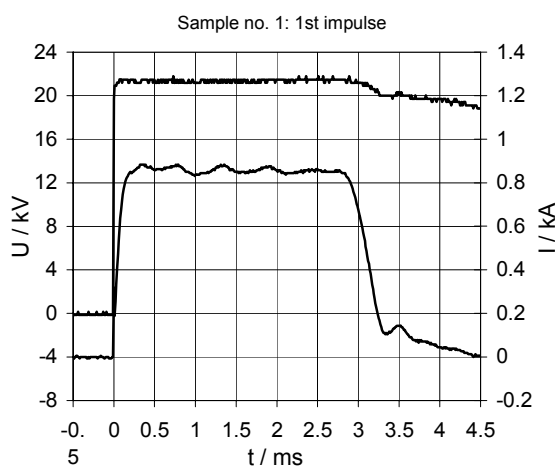


4.8.4 Leakage current at $U_c = 9.06 \text{ kV}$ and 60°C before the 1st long duration current impulse



4.8.5 Two long duration current impulses with a time interval between the impulses of 60 s

sample no.	1st impulse			2nd impulse			W_{total} / kJ
	I / A	U_{res} / kV	W / kJ	I / A	U_{res} / kV	W / kJ	
1	858	21.16	57.3	829	21.51	55.8	113.1
2	833	21.42	56.0	810	21.63	55.1	111.1
3	847	21.27	56.7	822	21.53	55.5	112.2

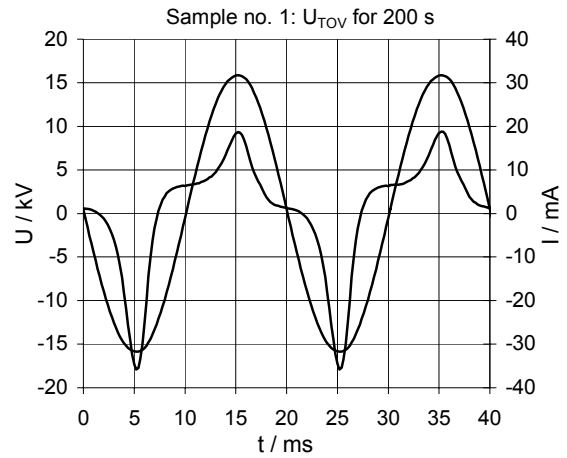


4.8.6 60 ms after the 2nd impulse TOV – application

Sample no.1

$U_{TOV} = 11.09 \text{ kV}$

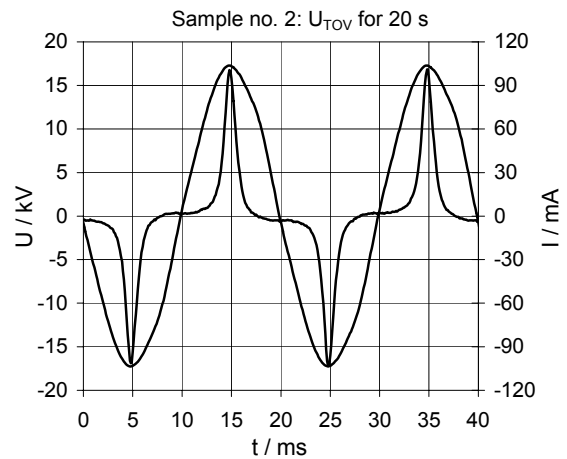
(this is 0.980 times U_r)
corresponding test time acc. to the
u-t-characteristic: $t_{TOV} \approx 190 \text{ s}$
applied test duration: $t_{TOV} = 200 \text{ s}$



Sample no. 2

$U_{TOV} = 12.14 \text{ kV}$

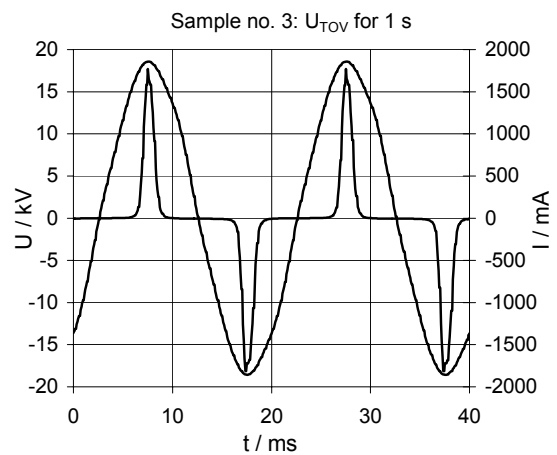
(this is 1.072 times U_r)
corresponding test time acc. to the
u-t-characteristic: $t_{TOV} \approx 10.5 \text{ s}$
applied test duration: $t_{TOV} = 20 \text{ s}$



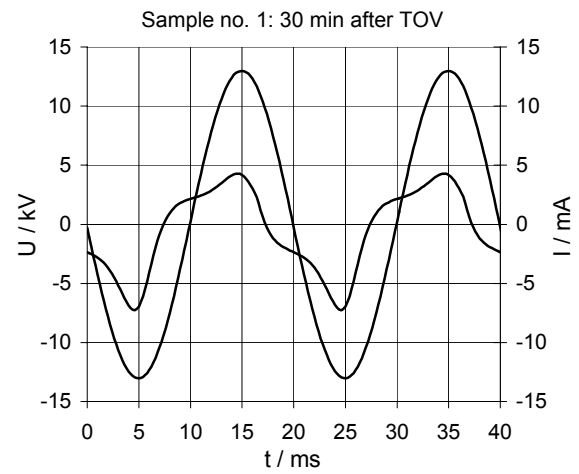
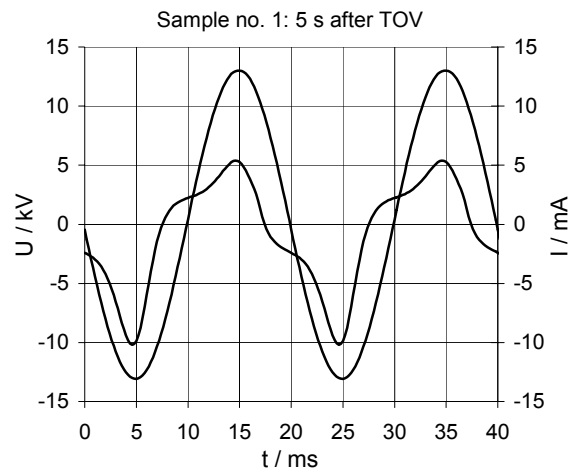
Sample no. 3

$U_{TOV} = 13.13 \text{ kV}$

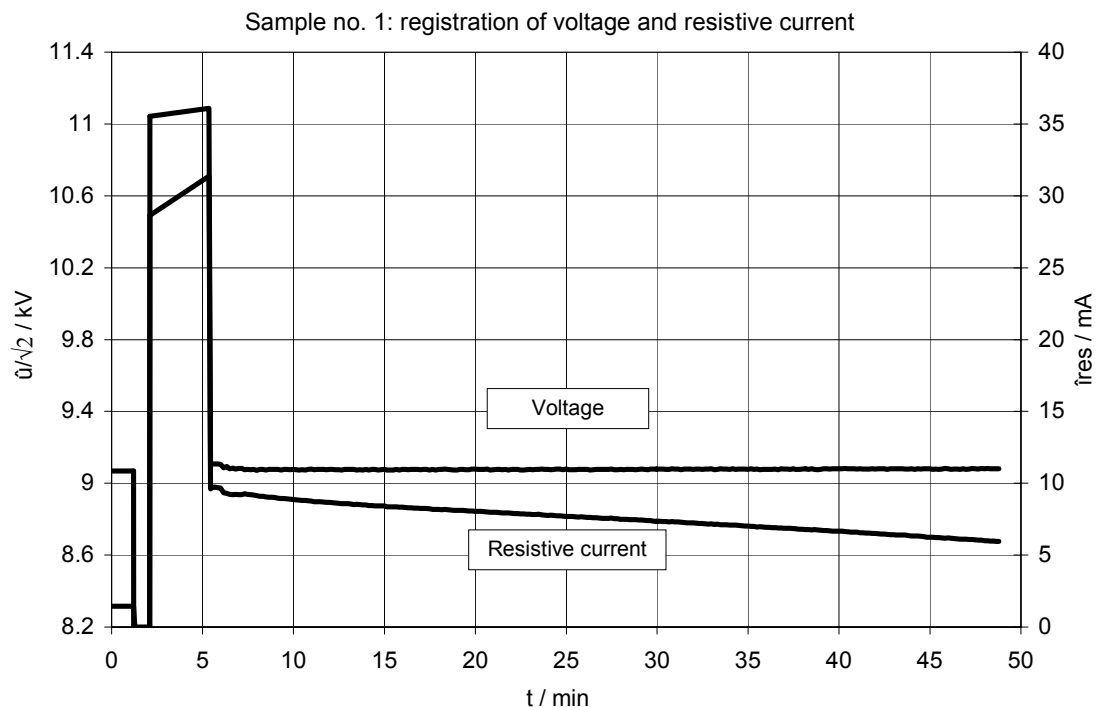
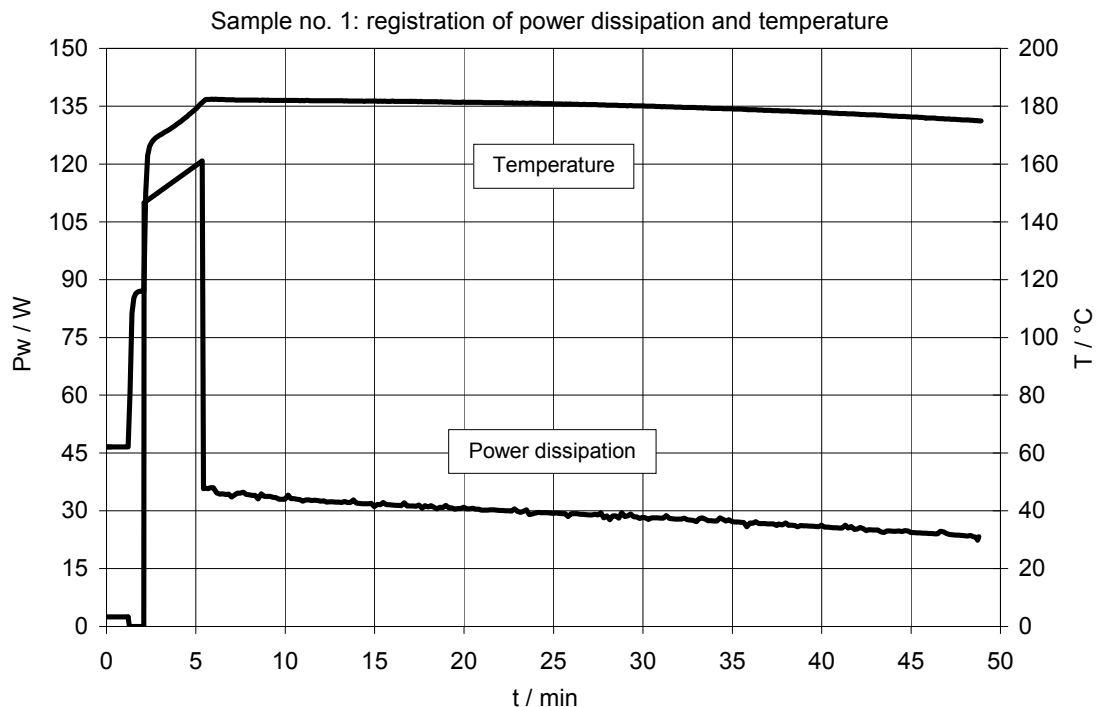
(this is 1.160 times U_r)
corresponding test time acc. to the
u-t-characteristic: $t_{TOV} \approx 0.75 \text{ s}$
applied test duration: $t_{TOV} = 1 \text{ s}$



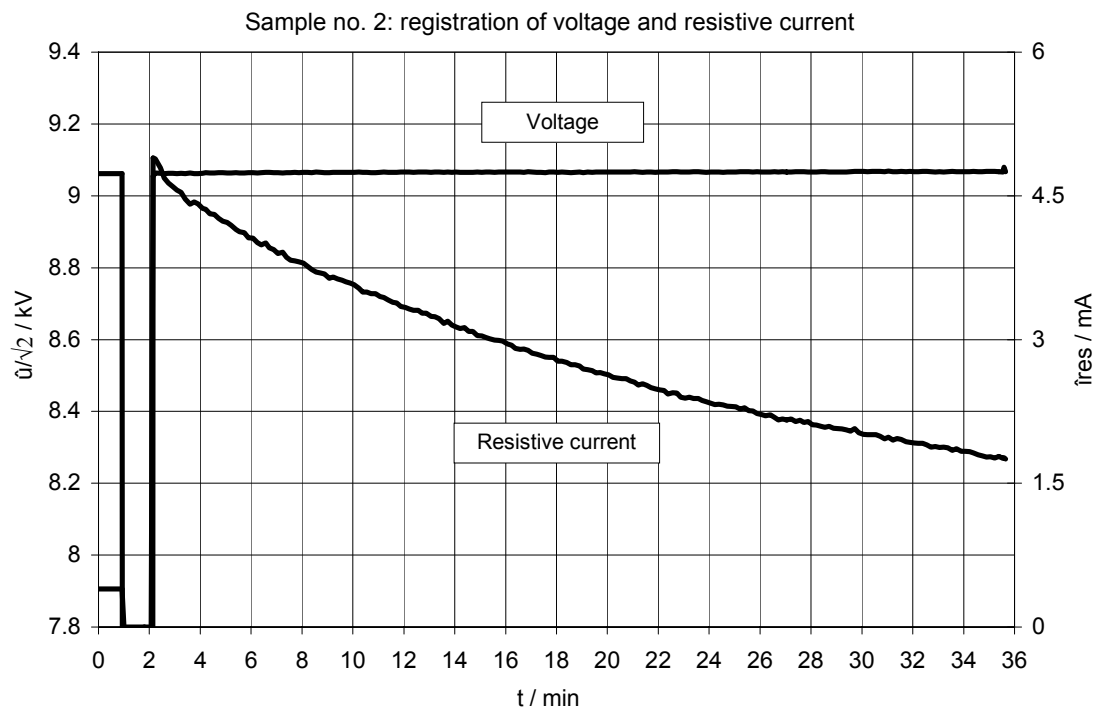
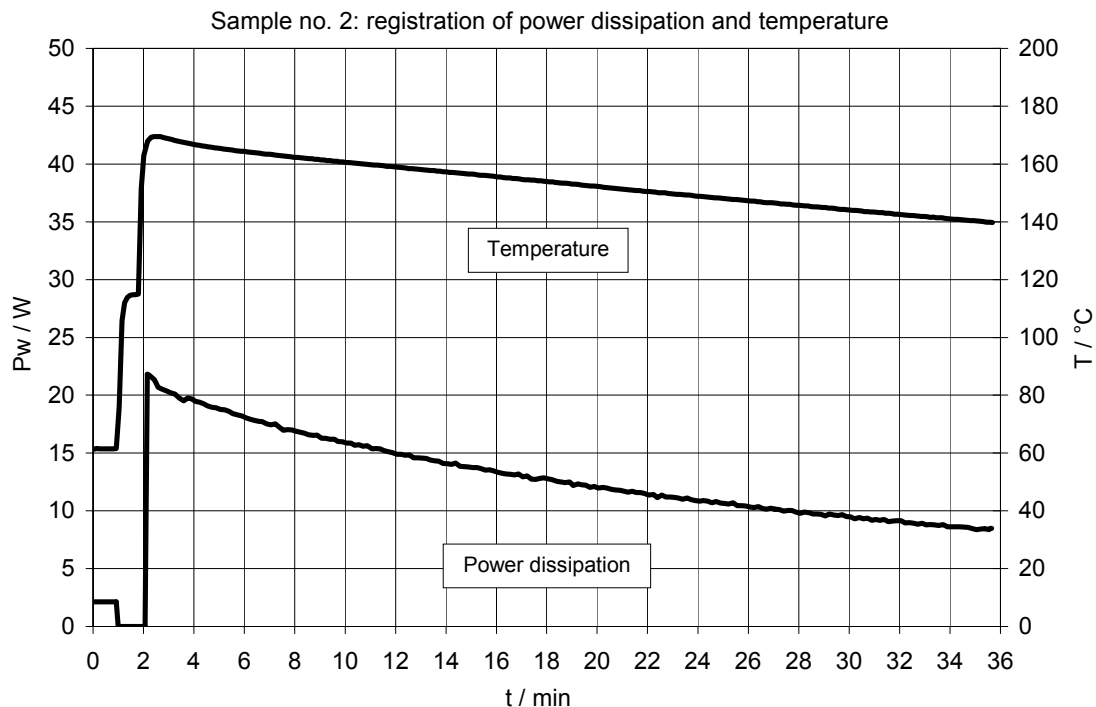
4.8.7 Leakage current measurement at U_c 5 s and 30 min after TOV



4.8.8 Registration of power dissipation, temperature, voltage ($\hat{u}/\sqrt{2}$) and resistive current (peak value) during U_{TOV} and 30 min U_c – application of sample no. 1



4.8.9 Registration of power dissipation, temperature, voltage ($\hat{u}/\sqrt{2}$) and resistive current (peak value) during 30 min U_c – application of sample no. 2



4.8.10 Registration of power dissipation, temperature, voltage ($\hat{u}/\sqrt{2}$) and resistive current (peak value) during 30 min U_c – application of sample no. 3

