

SIEMENS

Test Document

Report-No.: HBA 09154 P

Content: 24 Sheets

Apparatus tested : Metal oxide surge arresters, nominal discharge current 20 kA.

Type: 3EP2 ...-3..4.-....
3EP3 ...-3..4.-....
3EQ3 ...-3..4.-....
3EQ4 ...-3..4.-....

Date of Test : May 31 to July 14, 1999

Testing Station : Siemens AG, Arrester Test Field

Applied Test Specifications :

IEC 60099-4, Edition 1.1, 1998-08

Test performed :

Long duration current impulse withstand test (part of type test)
Switching surge operating duty test (part of type test)

Test Result :

The test objects have passed the tests stated above without any objection.
The results obtained and the performance proved of the test objects comply with the requirements of the specifications mentioned above.

Siemens Aktiengesellschaft
PTD H 4

sign Dr. Steinfeld

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Berlin, March 21st, 2002

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Index

	Sheet-no.
Test Document	1
Index	2
Technical data of the arresters	3
Long duration current impulse withstand test	4
Test result	5
Oscillograms	6
Technical data of test circuits	
Reference voltage measurement	7
Residual voltage tests	8
Long duration current impulse withstand test	9
Switching surge operating duty test	10
Test result	10
Arrester cross section (thermal model)	19
Cooling curves	19
Result of accelerated aging test	20
Technical data of test circuits	
Conditioning test	21
High current impulse test	22
Switching surge operating duty test	23

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

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 kJ / kV _{rated voltage}
Single impulse energy discharge capability (> 4 ms)	5,6 kJ / kV _{rated voltage}
High current impulse capability	100 kA

Long duration current impulse withstand test

The long duration current impulse withstand test was performed on three arrester sections of 11,81 kV rated voltage (2 MO-blocks in series, test circuits see sheet nos. 7 to 9).

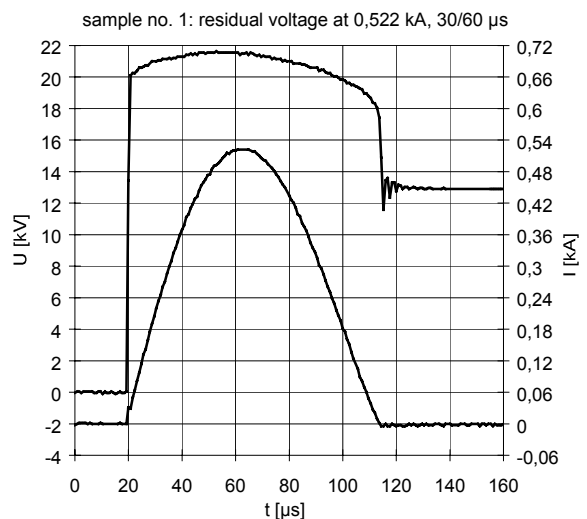
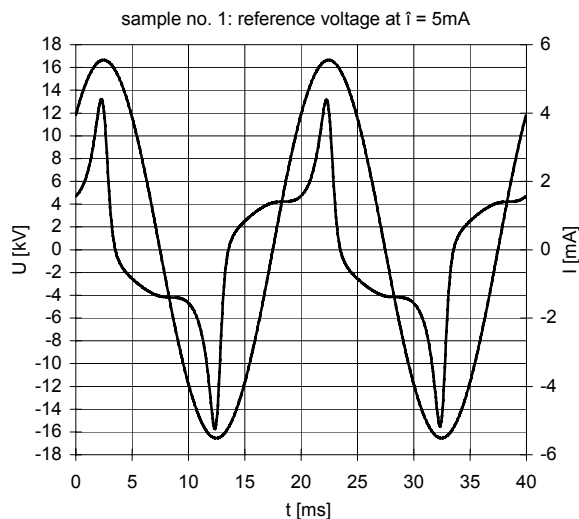
The test consists of 18 discharge operations divided into 6 groups of 3 operations. Time between the operations was 1 min, time between the groups such that the samples cooled down to ambient temperature.

Calculation of the test sample's rated voltage and the required impulse energy for line discharge class 4:

1. Measurement of reference voltage at a current peak value of 5 mA and switching impulse residual voltage at 500 A, 30/60 μ s

sample no.	$U_{\text{ref},5\text{mA}}$ [kV]	$U_{\text{res},500\text{A}}^*)$ [kV]
1	11,81	21,46
2	11,79	21,40
3	11,76	21,37

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



2. Calculation of rated voltage

$$U_r = U_{\text{ref}} / 1,00$$

3. Impulse energy for line discharge class 4

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

according to LD-class 4:

$$\begin{aligned} U_L &= 2,6 \cdot U_r \\ Z &= 0,8 \cdot U_r \\ T &= 2800 \mu\text{s} \end{aligned}$$

$$\begin{aligned} W &= 21,37 \text{ kV} \cdot (2,6 \cdot 11,81 \text{ kV} / 1,00 - 21,37 \text{ kV}) \cdot 1 / (0,8 \cdot 11,81 \Omega / 1,00) \cdot 2800 \mu\text{s} \\ &= 59,1 \text{ kJ} \end{aligned}$$

Before and after the test the residual voltage was measured at nominal discharge current.

Test result:

Long duration current impulse withstand test:

sample no.	1st impulse			18th impulse		
	I [A]	U _{res} [kV]	W [kJ]	I [A]	U _{res} [kV]	W [kJ]
1	958	21,8	65,0	895	22,1	61,0
2	910	21,7	61,4	899	22,2	61,8
3	904	21,6	61,1	893	22,2	61,5

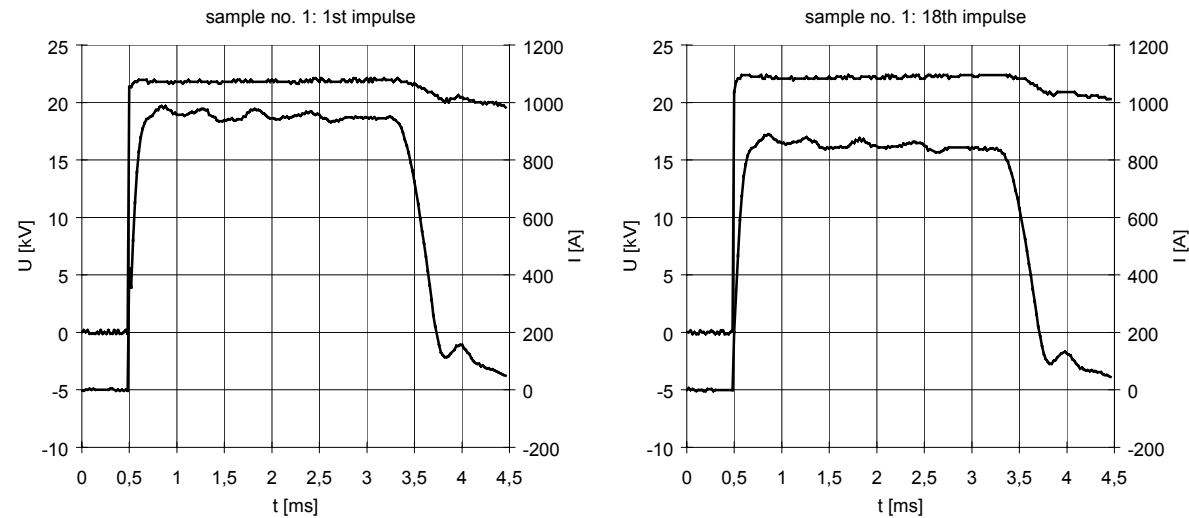
Residual voltage measurement:

sample no.	U _{res,20kA} [kV] ^{*)}		change [%]
	before the test	after the test	
1	28,95	28,89	-0,2
2	28,99	28,87	-0,4
3	29,03	28,93	-0,3

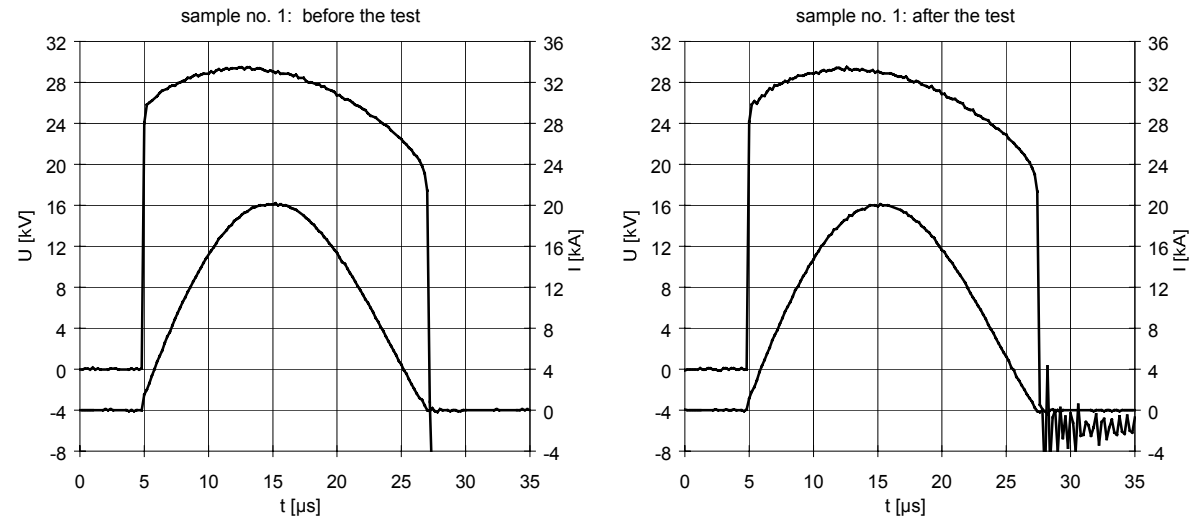
^{*)} $U_{\text{res}} = U_{\text{res,Osc}} - U_{\text{shunt}}$

Visual examination of the MO-blocks revealed no evidence of puncture, flashover or cracking and the change of residual voltage was within 5 %.

Oscillograms of long duration current impulse withstand test, sample no. 1:



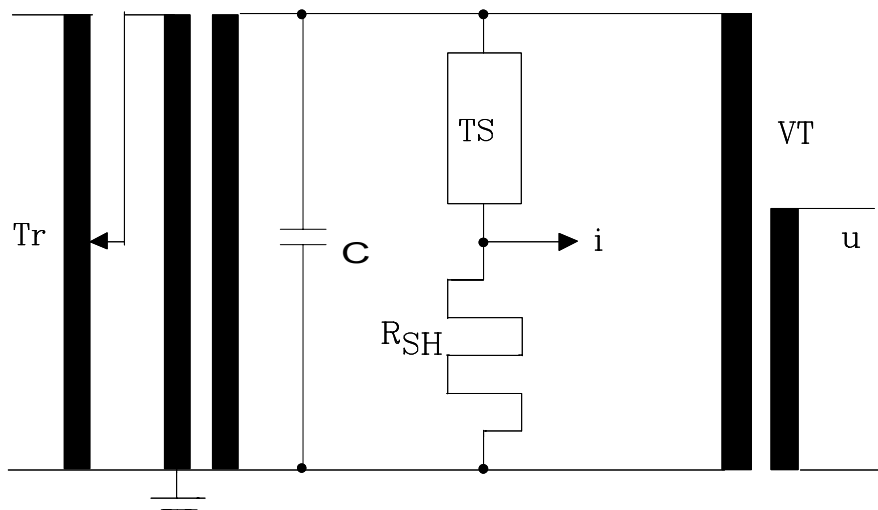
Oscillograms of the residual voltage at 20 kA, 8/20 μ s, sample no. 1:



Technical data of test circuit

Reference voltage measurement

Transformer:	Rated voltage	kV	15
	Rated power	kVA	7,5



C ... Damping capacitor
Tr ... Transformer
TS ... Test sample

Voltage measurement: u

Voltage transformer (VT): 20000:100
Peak Voltmeter Haefely Typ 64M
Oscilloscope Tektronix type TDS 320 / PC-Laptop

Leakage current measurement: i

Shunt $R_{SH} = 1000 \Omega$
Oscilloscope Tektronix type TDS 320 / PC-Laptop

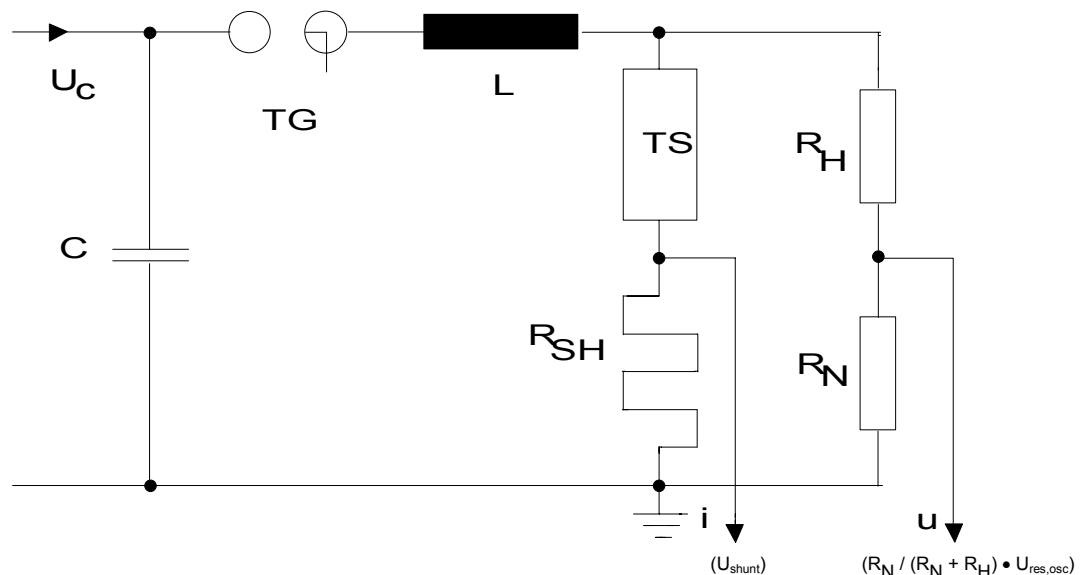
Test sample: arrester section

Technical data of test circuit

Lightning impulse residual voltage test

Switching impulse residual voltage test

Surge circuit:	Discharge current	kA	20	0,500
	Surge capacitance	μF	3,7	1,85
	Inductance	μH	11	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: $R_H = 6242,7 \Omega$; $R_N = 60,21 \Omega$

Oscilloscope Tektronix type TDS 520 / PC

Current measurement: i

Shunt $R_{SH} = 205,2 \text{ m}\Omega$ (0,500 kA); $21,99 \text{ m}\Omega$ (20 kA)

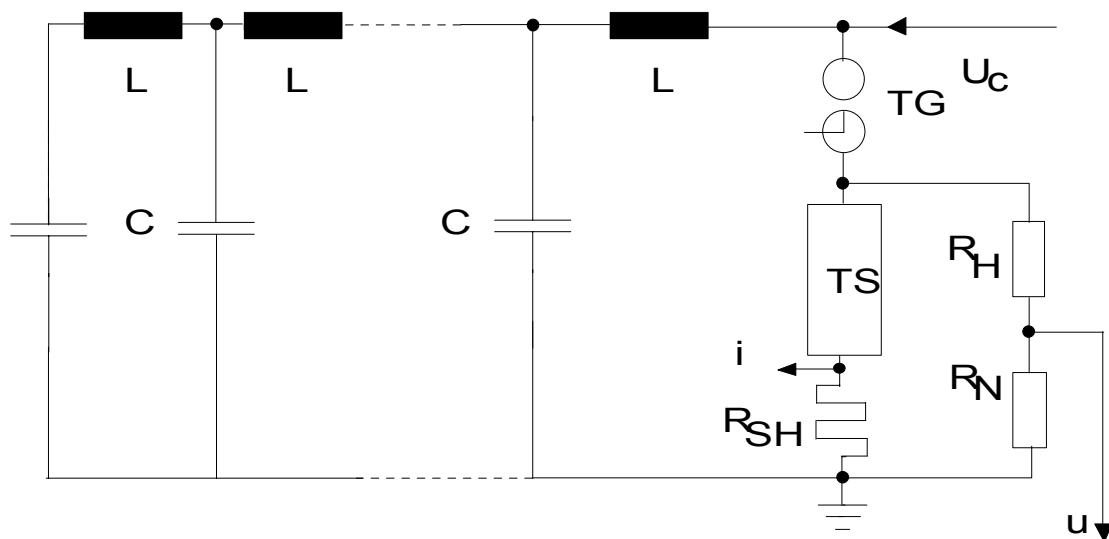
Oscilloscope Tektronix type TDS 520 / PC

Test sample: arrester section

Technical data of test circuit

Long duration current impulse withstand test

Surge circuit:	Section capacitance	μF	7,4
	Section inductance	mH	0,41
	Number of sections		28



TG ... Trigger spark gap
 TS ... Test sample
 C ... Section capacitor
 L ... Section inductance
 U_c ... Charge voltage

Voltage measurement: u

Ohmic divider: R_H = 4956 Ω ; R_N = 33,69 Ω
 Oscilloscope Tektronix type TDS 340A / PC

Current measurement: i

Shunt R_{SH} = 61,6 m Ω
 Oscilloscope Tektronix type TDS 340A / PC

Test sample: arrester section

Switching surge operating duty test

The test was performed on three arrester sections of 11,71 kV rated voltage each consisting of two MO-blocks in series (test circuits see sheet-nos. 21 to 24).

Before the test the reference voltage at a current peak value of 5 mA and the residual voltages at nominal discharge current 20 kA, 8/20 μ s and 500 A, 30/60 μ s 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 $U_r / U_c = 1,25$ ($U_c = 9,37$ kV).

First the samples were exposed to a conditioning test consisting of 20 impulses of the nominal discharge current while the test samples were energized at 11,24 kV (that is 1,2 times the continuous operating voltage) and two high current impulses of 100 kA peak value.

After the conditioning test the samples were preheated to 60 °C. The samples were subjected to two long duration current impulses of class 4 with a minimum required impulse energy of 58,8 kJ^{*)} each. Time between the impulses was 60 s. About 60 ms after the second impulse a power transformer was connected to the samples for 10 s with a voltage $U_r = 11,71$ kV. After 10 s the samples were subsequently connected to a voltage transformer supplying $U_c = 9,37$ kV. The continuous operating voltage was applied for at least 30 min.

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

Except the conditioning test the test samples were inside a porcelain housing (arrester cross section, see sheet-no. 19) during the test, with a thermal and electrical behaviour corresponding to the behaviour of the complete arrester. Sheet-nos. 19 and 20 in addition show in comparison the cooling curves of both the complete arresters type 3EP2, 3EP3, 3EQ3 and 3EQ4 as well as the thermal model used for the test.

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

According to IEC 60099-4 (1998), clause 7.5.2 an accelerated aging test was performed on three single MO-blocks. Test conditions were: constant block temperature 115 °C, constant test voltage equal to U_c , surrounding medium N₂. 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-no. 20). That means no correction of above test voltages (U_r , U_c) was necessary.

*) Calculation procedure see: Long duration current impulse withstand test sheet-no. 5

$$W = 21,15 \text{ kV} \cdot (2,6 \cdot 11,71 \text{ kV} / 1,00 - 21,15 \text{ kV}) \cdot 1 / (0,8 \cdot 11,71 \Omega / 1,00) \cdot 2800 \mu\text{s} = 58,8 \text{ kJ}$$

Test result:

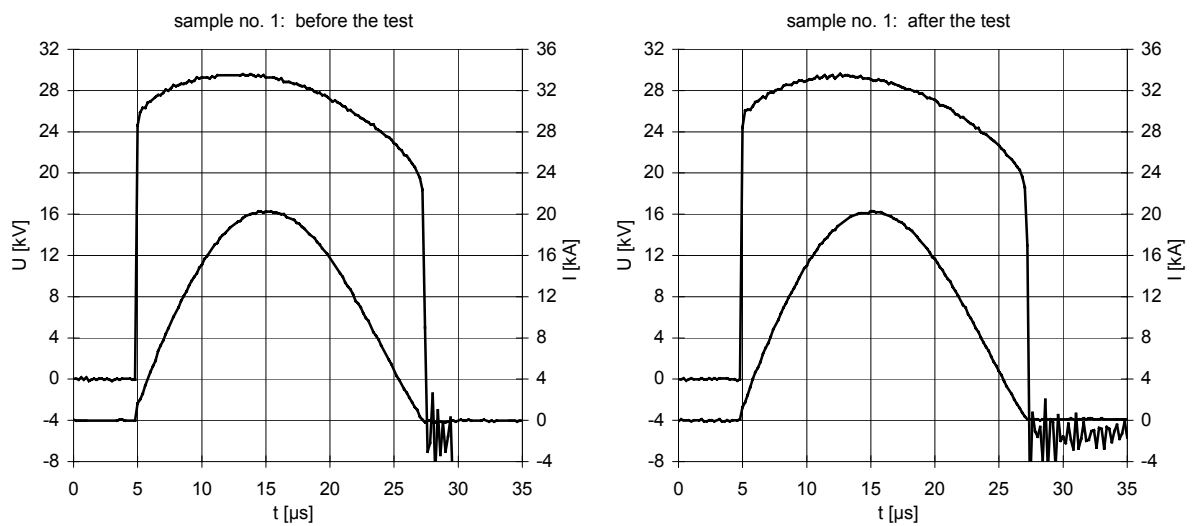
On all three test samples power dissipation, resistive component of the leakage current and temperature permanently decreased during 30 min. application of U_c . Visual inspection of the MO-blocks after the test revealed no evidence of puncture, flashover or cracking. Change of the residual voltages 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. 11 to 15. The records of 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. 16 to 18.

1. Residual voltage measurement at 20 kA, 8/20 μ s

sample no.	$U_{res,20kA}$ [kV] ^{*)}		change [%]
	before the test	after the test	
1	29,06	28,97	-0,3
2	28,75	28,91	0,6
3	28,88	29,09	0,7

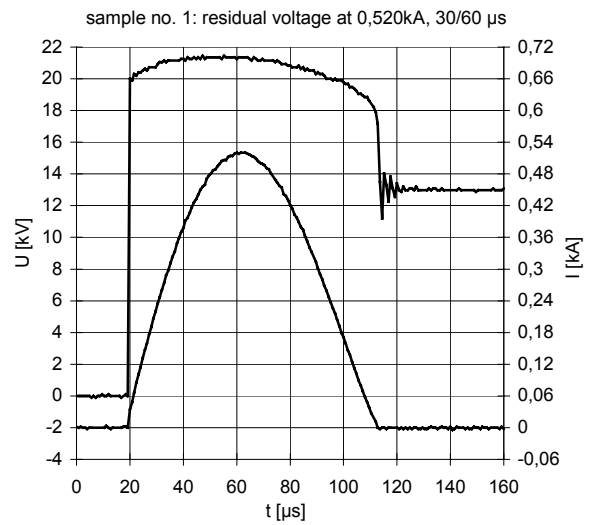
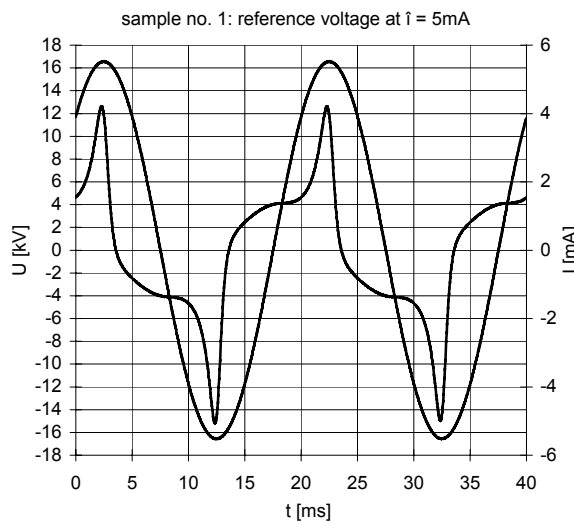
$$^{*)} U_{res} = U_{res,Osc} - U_{shunt}$$



2. Measurement of reference voltage at 5 mA and switching impulse residual voltage at 500 A, 30/60 μ s

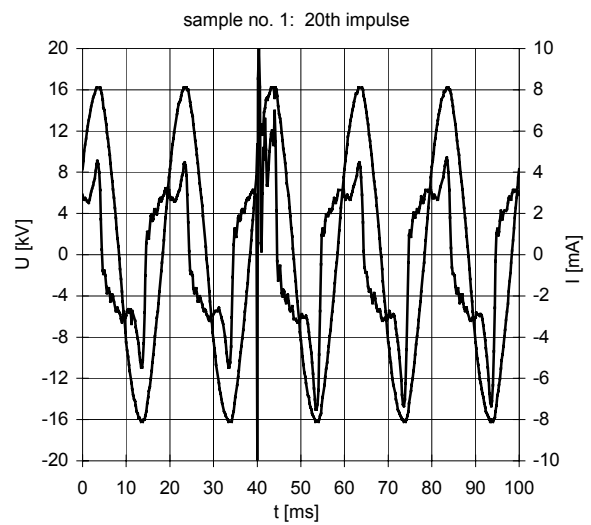
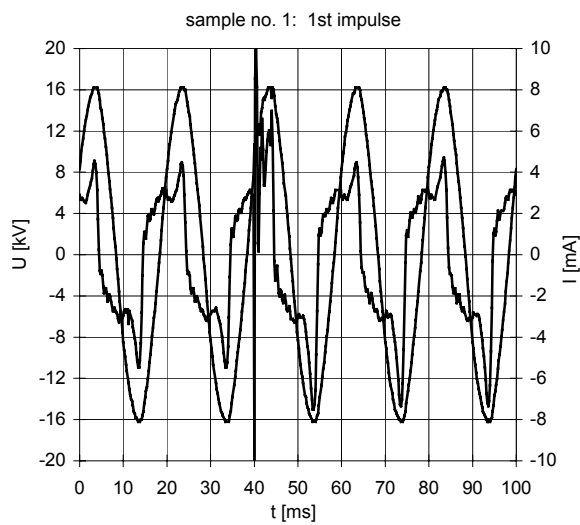
sample no.	$U_{ref,5mA}$ [kV]	$U_{res,500A}$ ^{*)} [kV] ^{*)}
1	11,70	21,24
2	11,65	21,15
3	11,71	21,22

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



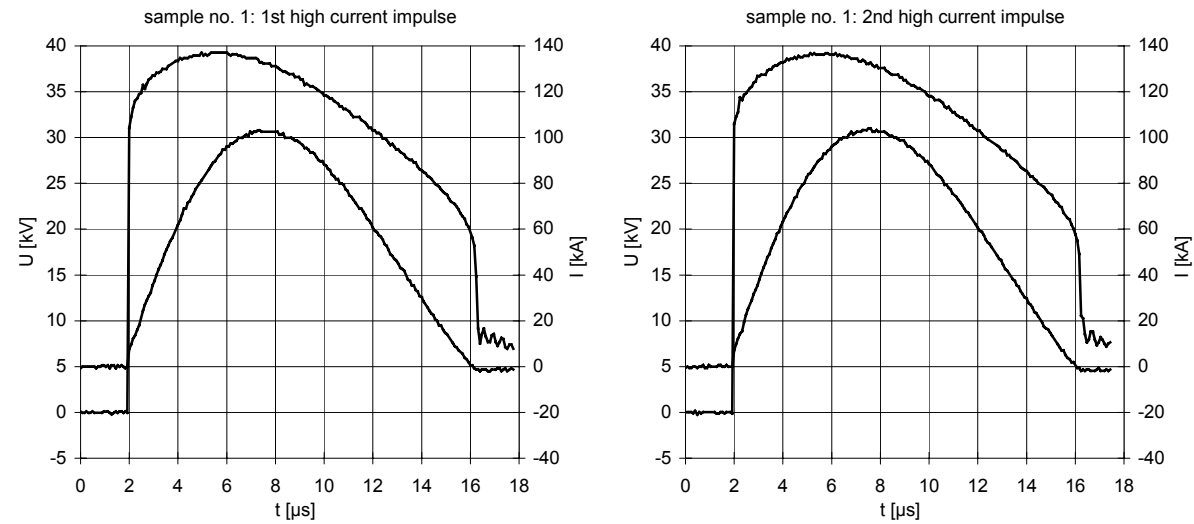
3. Conditioning test

3.1. 20 impulses 20 kA, 8/20 μs and simultaneously 11,24 kV, i.e. 1.2 times U_c

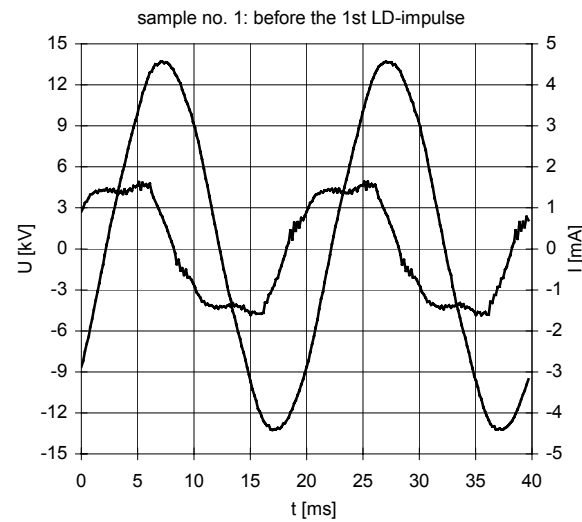


3.2 High current impulse test

sample no.	1st impulse		2nd impulse	
	I [kA]	U _{res} [kV]	I [kA]	U _{res} [kV]
1	103	38,9	103	38,8
2	103	38,8	104	38,7
3	103	38,9	103	38,8

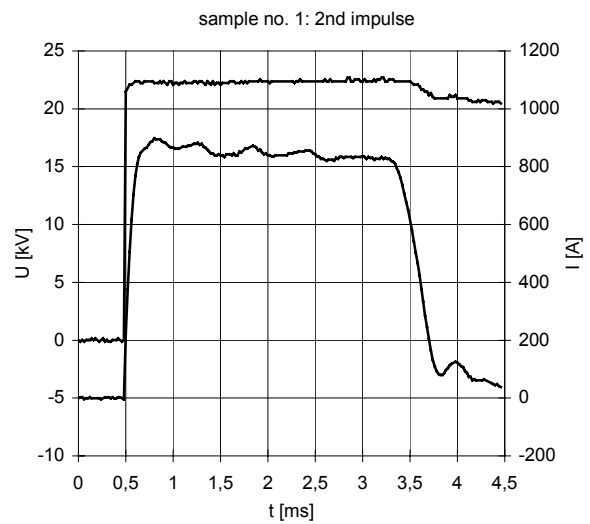
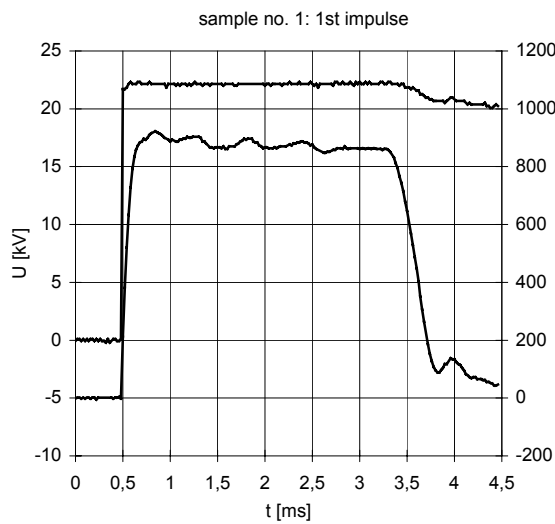


4. Leakage current at $U_c = 9,37$ kV and 60 °C before the 1st long duration current impulse

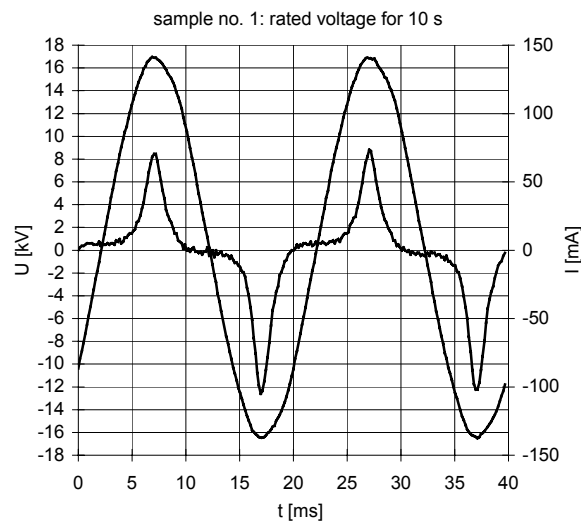


5. Two long duration current impulses with a time interval between the impulses of 60 s

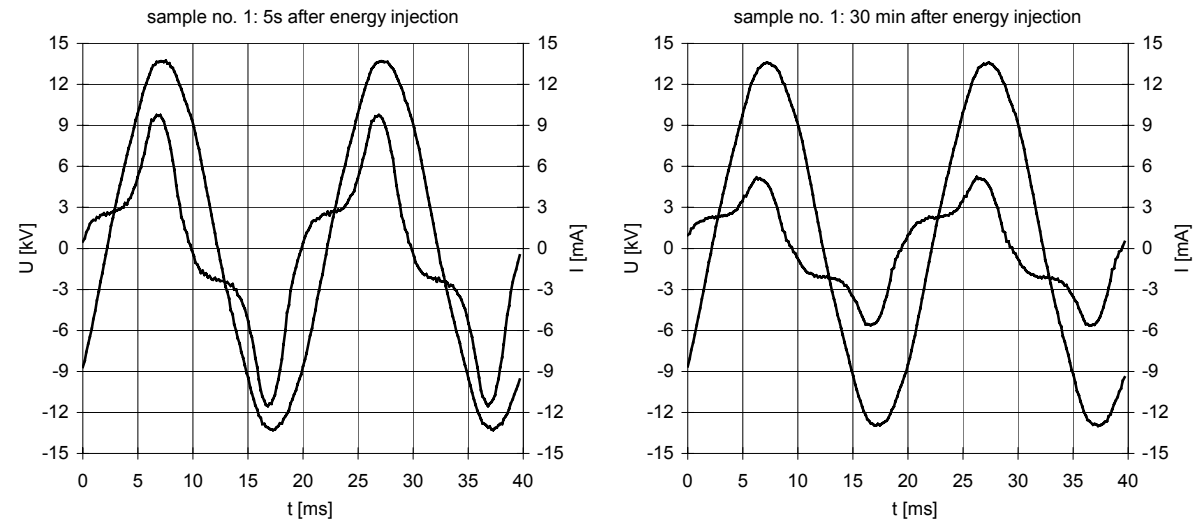
sample no.	1st impulse			2nd impulse			W_{total} [kJ]
	I [A]	U_{res} [kV]	W [kJ]	I [A]	U_{res} [kV]	W [kJ]	
1	880	22,1	60,3	852	22,3	58,8	119,1
2	884	22,0	60,4	857	22,3	59,0	119,4
3	882	22,0	60,4	851	22,3	58,9	119,3



6. 60 ms after the 2nd impulse $U_r = 11,71$ kV for 10 s

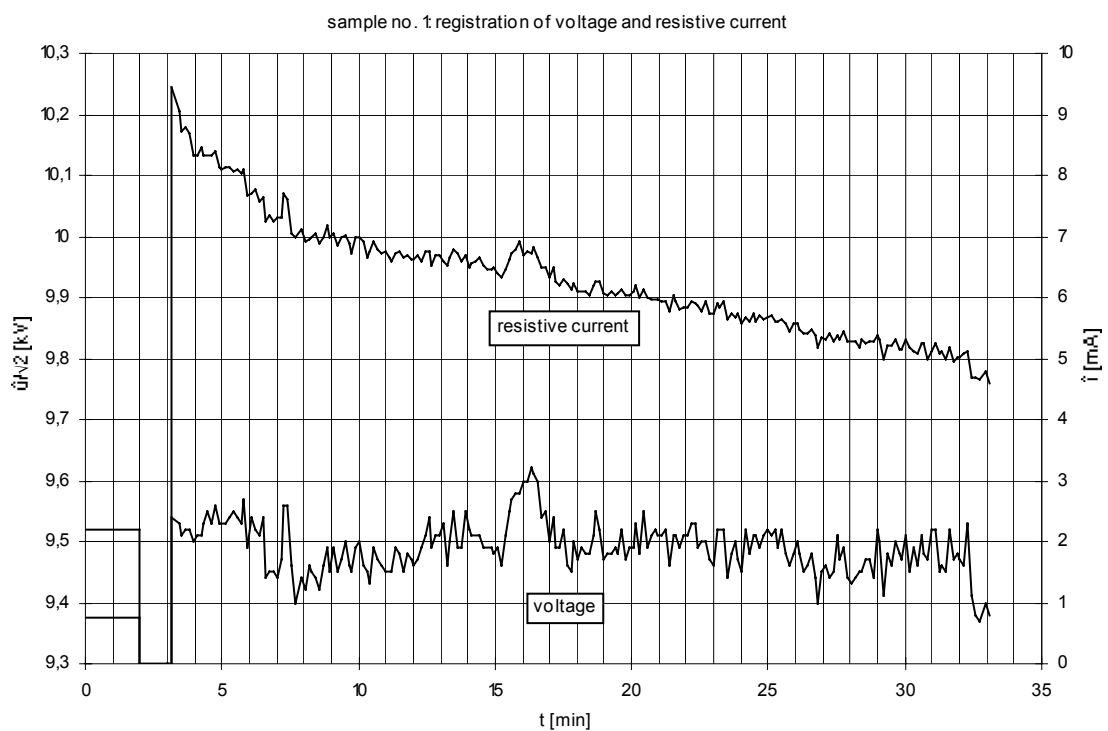
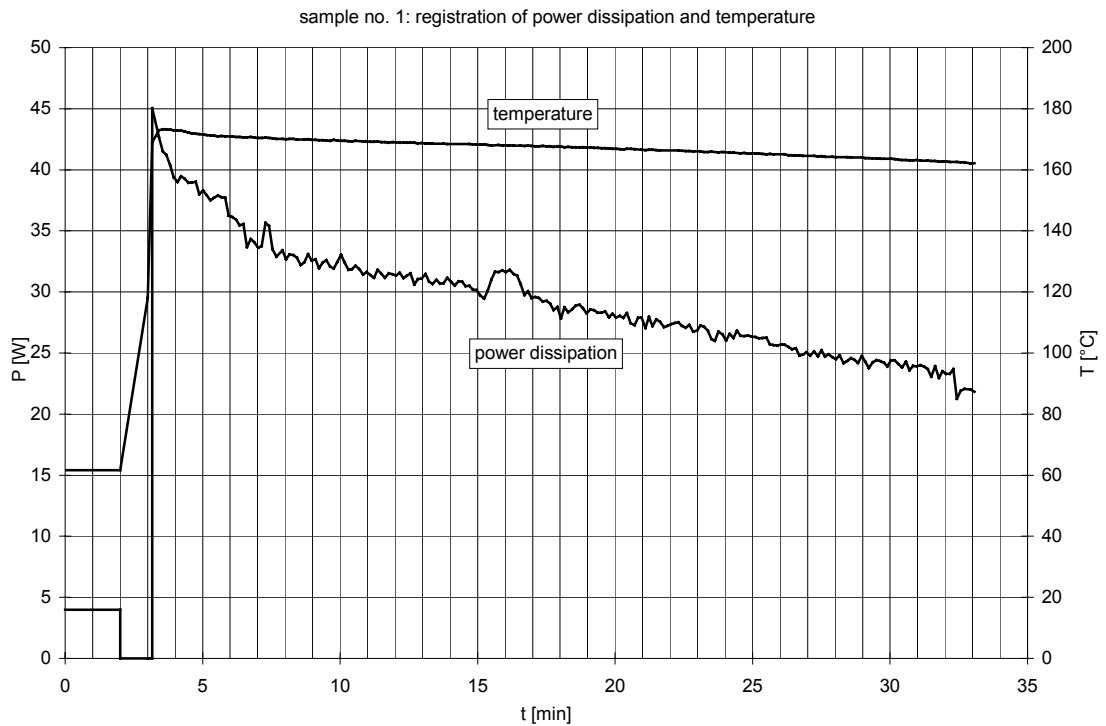


7. 5 s and 30 min after energy injection leakage current at U_c

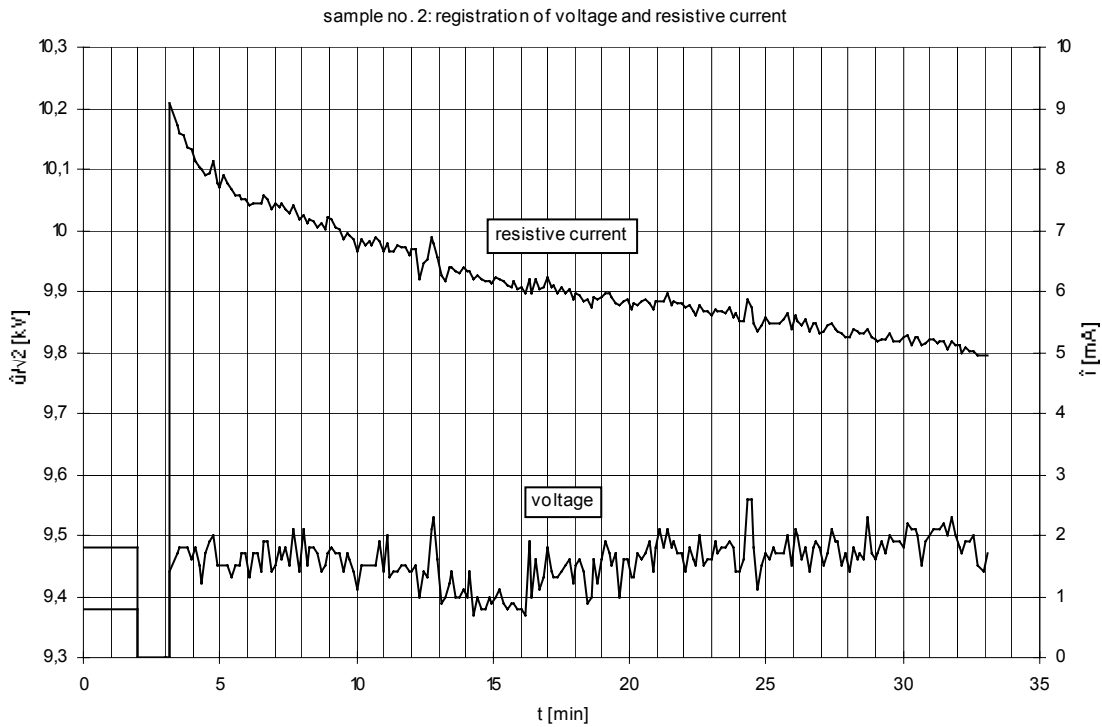
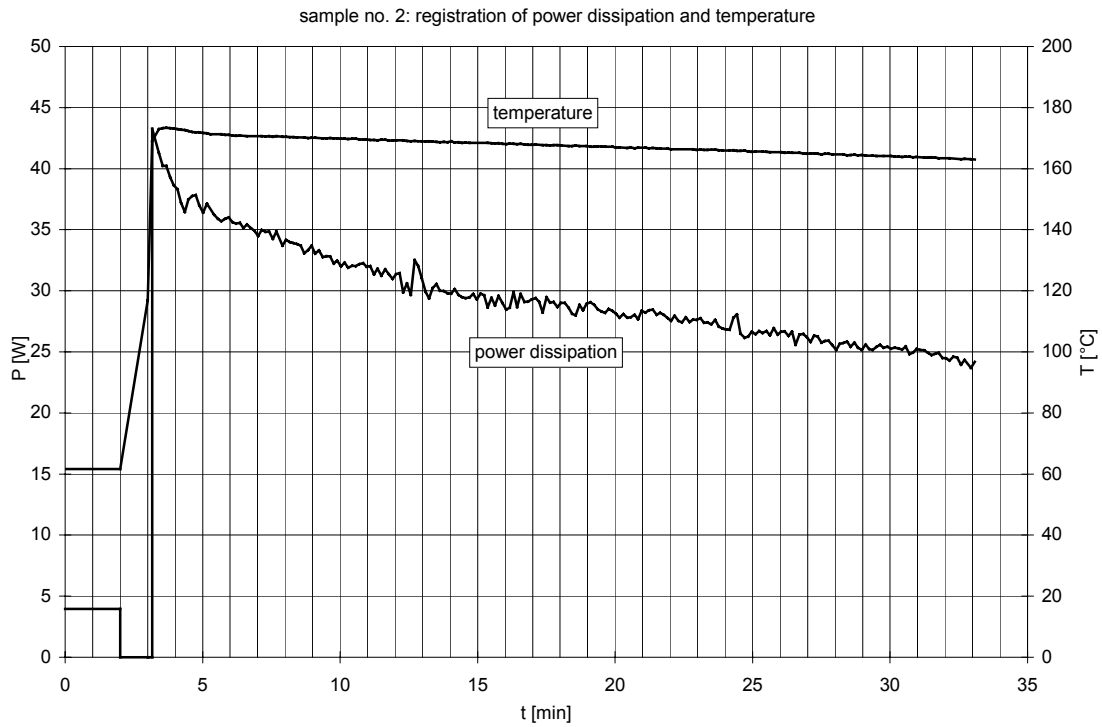


8. Registration of power dissipation, temperature, voltage ($\hat{u}/\sqrt{2}$) and resistive current (peak value) during 30 min U_c - application

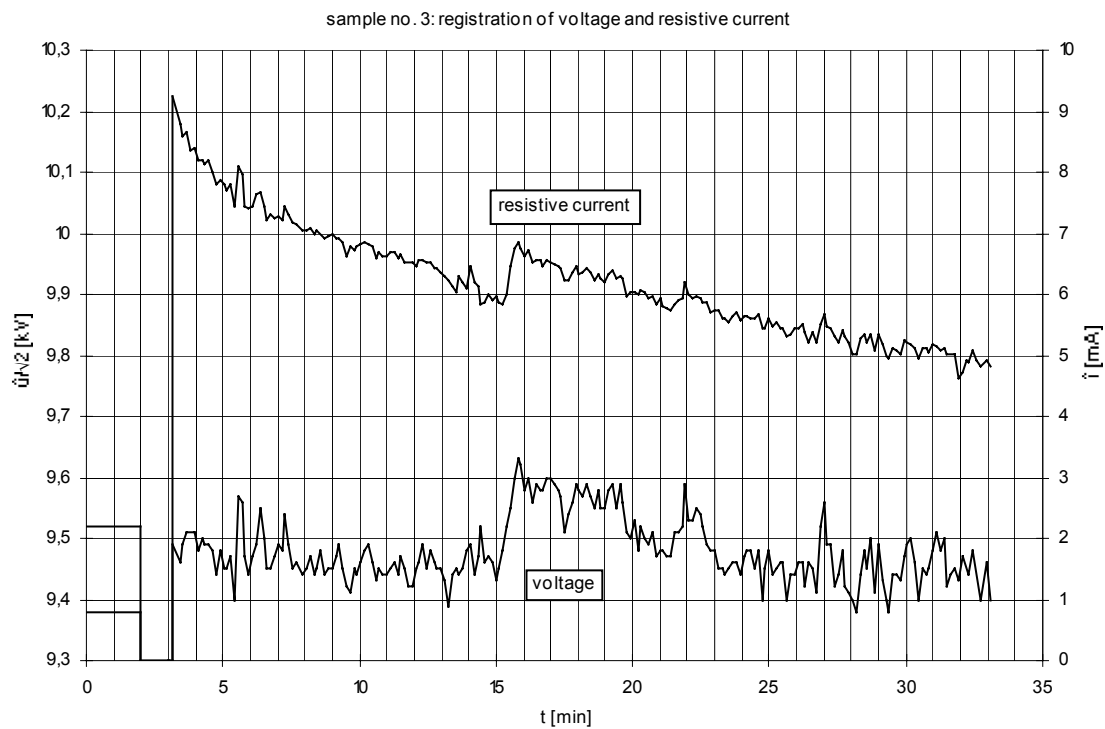
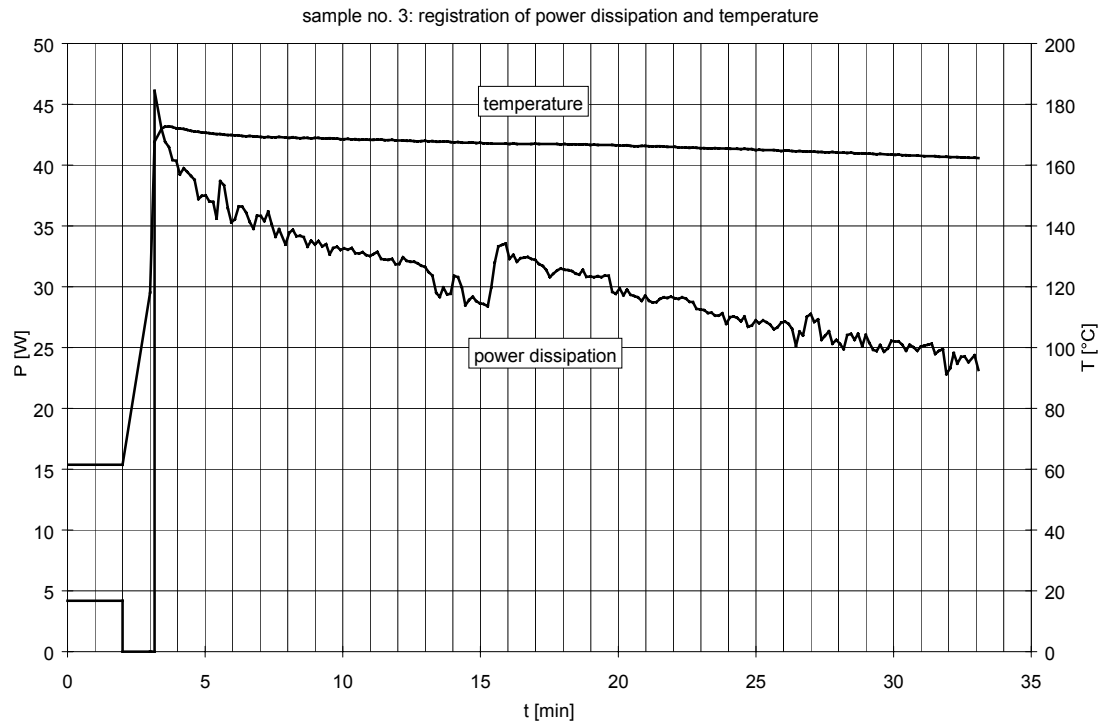
8.1. Result of sample no. 1:



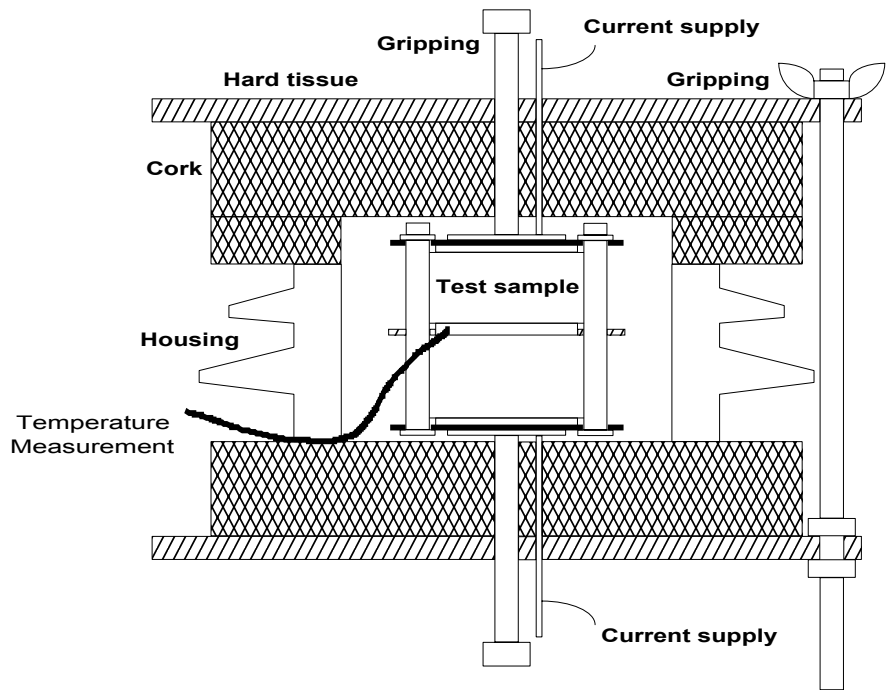
8.2. Result of sample no. 2:



8.3. Result of sample no. 3:

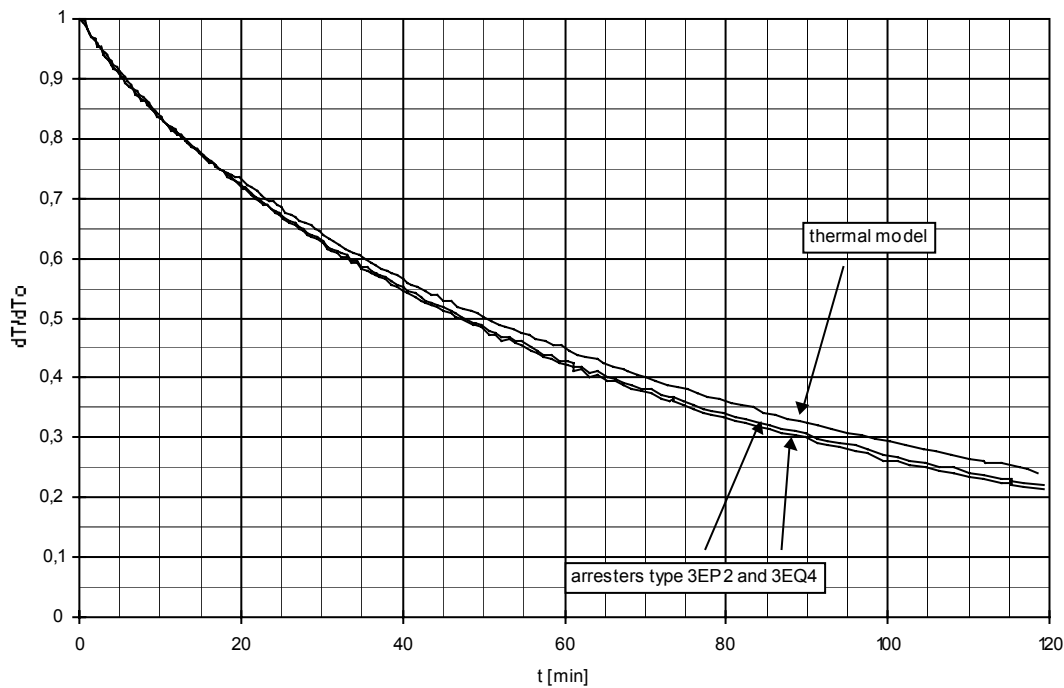


Arrester cross section (thermal model)

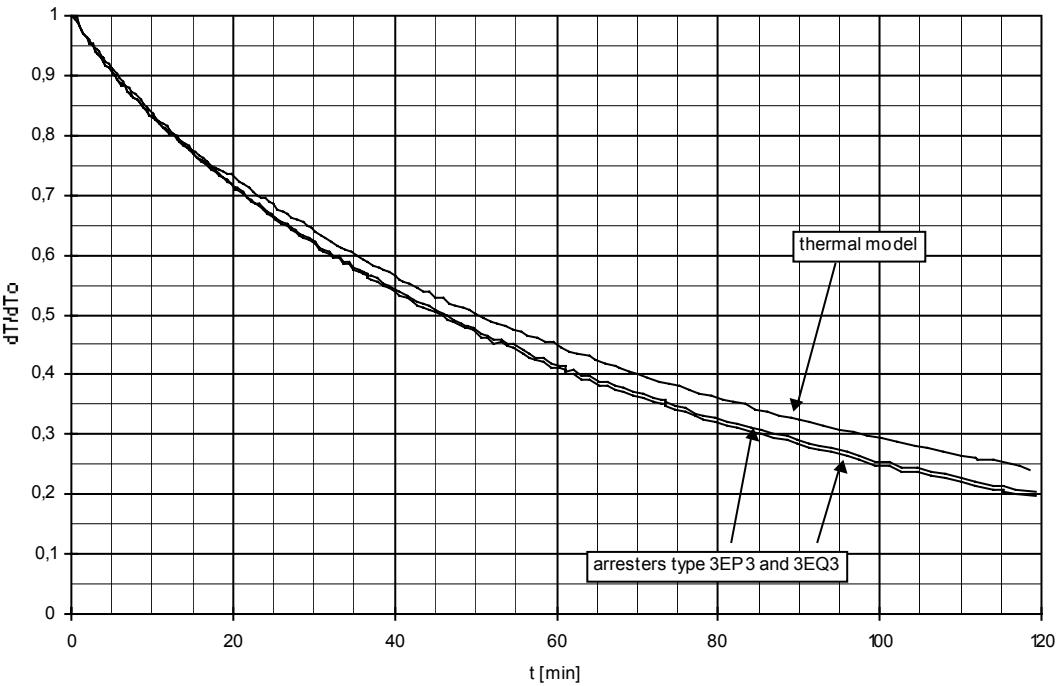


Cooling curves (comparison: arrester - thermal model)

arresters type 3EP2 and 3EQ4

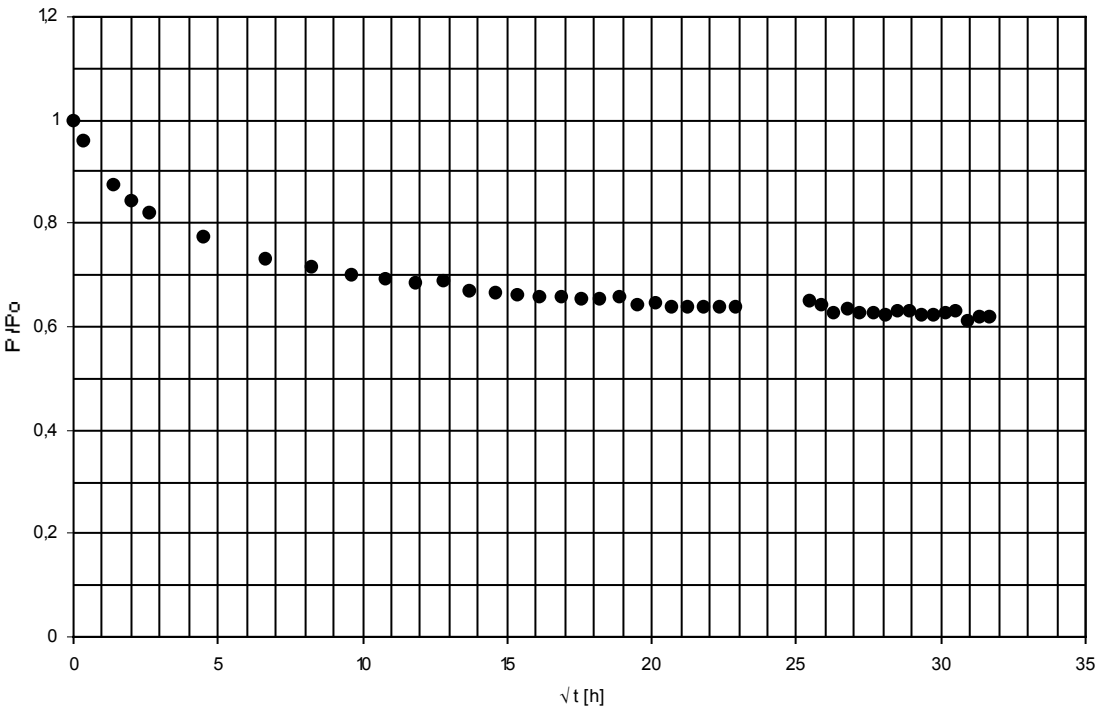


arresters type 3EP3 and 3EQ3



$T_0 = 120\text{ }^{\circ}\text{C}$
 $dT_0 = T_0 - T_{\text{ambient}} = 100\text{ }^{\circ}\text{C}$
 $T_{\text{ambient}} = 20\text{ }^{\circ}\text{C}$
 $dT = T - T_{\text{ambient}}$

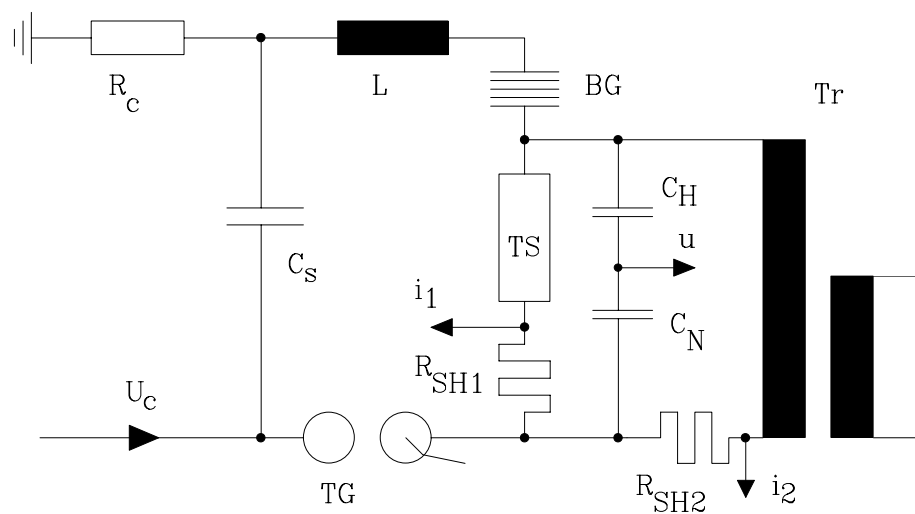
Result of accelerated aging test (one MO-block)



Technical data of test circuit

Conditioning test (Switching surge operating duty test)

Surge circuit:	Discharge current	kA	20
	Surge capacitance	μF	3,7
	Inductance	μH	11
	Wave shape	μs	8/20



TG ... Trigger spark gap
 TS ... Test sample
 C_s ... Surge capacitor
 Tr ... Transformer: 20 kV, 12 kVA

BG ... Blocking gap
 R_c ... Charge resistor
 U_c ... Charge voltage
 L ... Inductance

Voltage measurement: u

Capacitive divider: C_H = 256 pF; C_N = 256 nF
 Oscilloscope Tektronix type TDS 320 / PC

Leakage current measurement: i₂

Shunt R_{SH2} = 1000 Ω
 Oscilloscope Tektronix type TDS 320 / PC

Impulse current measurement: i₁

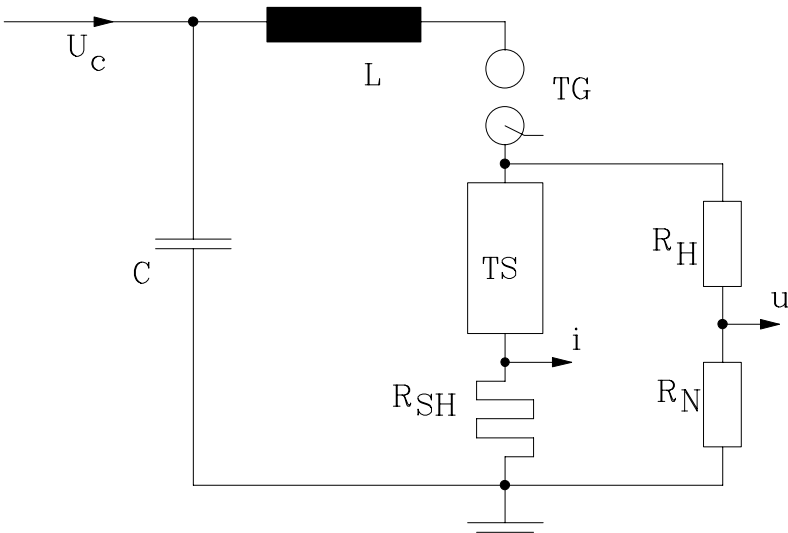
Shunt R_{SH1} = 21,99 m Ω
 Oscilloscope Tektronix type TDS 520 / PC

Test sample: arrester section

Technical data of test circuit

High current impulse test

Test circuit:	Discharge current	kA	100
	Surge capacitance	μF	13,5
	Inductance	μH	1
	Wave shape	μs	4/10



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

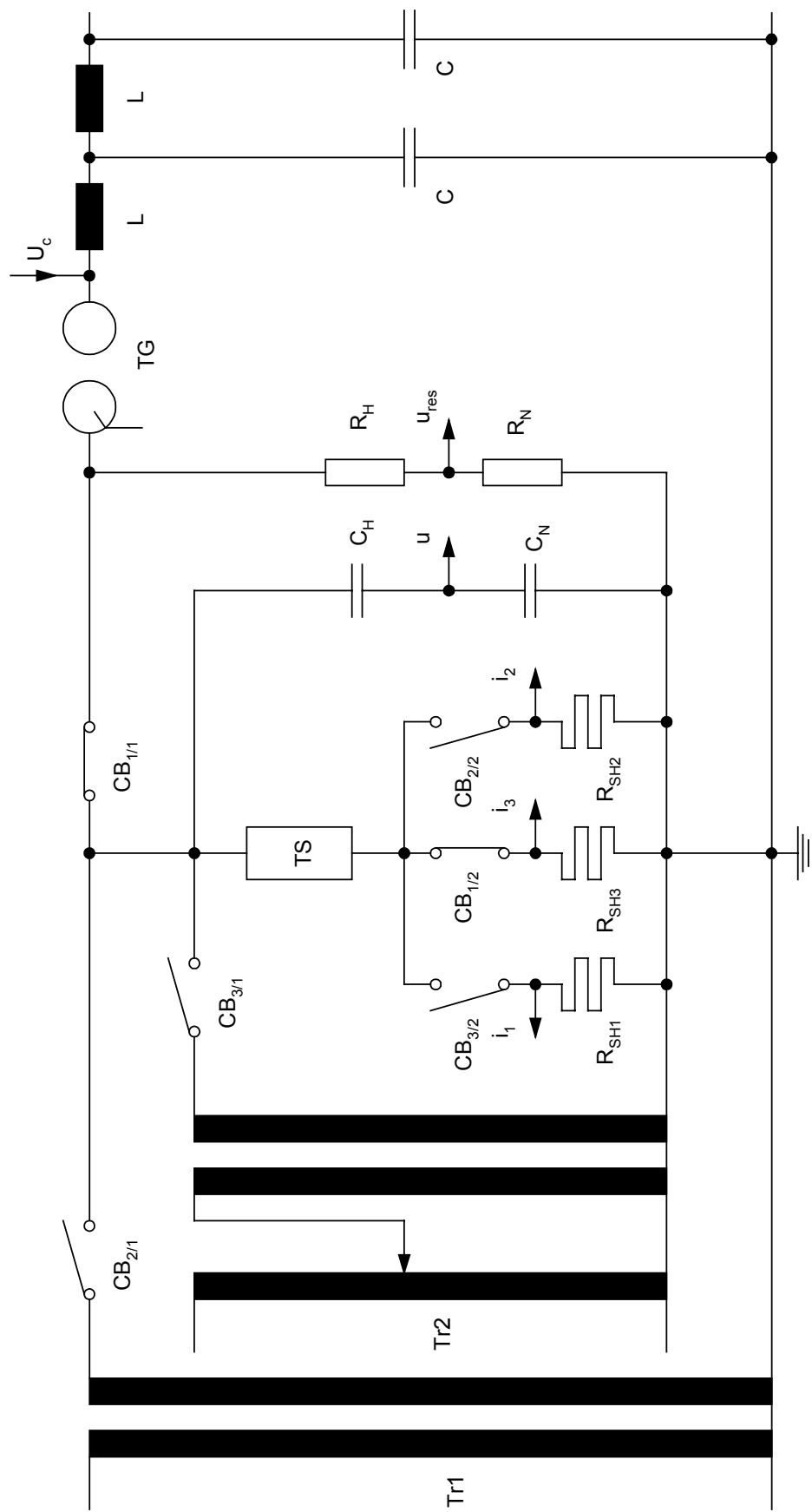
Voltage measurement: u

Ohmic divider: $R_H = 8736,7 \, \Omega$; $R_N = 60,21 \, \Omega$
Oscilloscope Tektronix type TDS 520 / PC

Current measurement: i

Shunt $R_{SH} = 3,1 \, \text{m}\Omega$
Oscilloscope Tektronix type TDS 520 / PC

Test sample: arrester section



Test circuit: Switching surge operating duty test

Technical data of test circuit

Switching surge operating duty test

Tr ... Transformer (Tr1: $P_N = 7500 \text{ kVA}$; Tr2: $P_N = 10 \text{ kVA}$)
TS ... Test sample
TG ... Trigger spark gap
CB ... Circuit breaker
C ... Section capacitor
L ... Section inductance
 U_c ... Charge voltage

Power-frequency voltage measurement: u

Capacitive divider: $C_H = 256 \text{ pF}$; $C_N = 256 \text{ nF}$
Oscilloscope Tektronix type TDS 410 / PC-Laptop

Leakage current measurement: i_1, i_2

Shunt $R_{SH1} = 1000 \Omega$, $R_{SH2} = 50 \Omega$
Oscilloscope Tektronix type TDS 410 / PC-Laptop

Measurement of power dissipation:
Computer calculation from voltage and current

Temperature measurement:
Takaoka, Fiber Thermometer 1110

Residual voltage measurement: u_{res}

Ohmic divider: $R_H = 4956 \Omega$; $R_N = 33,69 \Omega$
Oscilloscope Tektronix type 340A / PC-Laptop

Long duration current measurement: i_3

Shunt $R_{SH3} = 61,6 \text{ m}\Omega$
Oscilloscope Tektronix type 340A / PC-Laptop

Test procedure:

1. CB_1 closes during long duration current impulses
2. CB_1 opens immediately after the 2nd long duration impulse
 CB_2 closes for the preselected time
3. CB_3 closes subsequent after opening of CB_2

Test sample: arrester section