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Type test report no. VR 4E 002e

Transition impedance test

Product Approval
CTTP/Wag
31.05.2017

Type test for types: Diverter switches VACUTAP® VRM with
- maximum rated through-current 700 A, 1000 A or 1300 A / 2600 A[1],
- maximum rated step voltage 4500 V.

Test specification: IEC 60214-1:2014, sub-clause 5.2.5: "Transition impedance test".

Test samples:
1: Resistor value: 1.51 Ω / Cross-section: 12.0 mm²
2: Resistor value: 2.50 Ω / Cross-section: 8.0 mm²

Test samples mounted in diverter switch:
VACUTAP® VRM III 1300 Y – 72.5, S/N: 1734908.

Manufacturer: Maschinenfabrik Reinhausen GmbH, Regensburg, Germany.

Date of test: August 2016 to September 2016.

Place of test: Maschinenfabrik Reinhausen GmbH, Regensburg, Germany.

Tests performed: Power pulse currents in acc. with IEC 60214-1:2014, Annex C.

Test series 1: With each test sample 34 current pulses were carried out in intervals of 2.2 s equivalent to one-half of a cycle of operation of an on-load tap-changer with 18 contacts and change-over selector.
The values of current and current duration corresponded to the loading of a diverter switch with 1.5 times the maximum rated through-current at relevant rated step voltage.

Test series 2: With each test sample one current pulse was performed corresponding to the loading of a diverter switch with twice the maximum rated through-current at relevant rated step voltage.

Test results: The requirements of IEC 60214-1:2014 were met, i.e.:
- The temperature rise of the tested transition resistors did not exceed 350 K at the end of the test. Parts adjacent to the transition resistors were not affected.
- The test samples withstood the stresses at twice the maximum rated through-current and the relevant rated step voltage without any wear on the mechanical parts or deterioration of the insulation material. The measured values of the transition resistors before and after the test were within the permissible tolerance of ± 10 %.

[1] Single phase design with two current paths of identical design (2 x 1300 A) for applications with enforced current splitting.

This report contains 10 pages.

i. V. Dr. Thomas Strof
[valid without signature]

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1. Test specification

The type test was performed in accordance with IEC 60214-1:2014 “Tap-changers - Part 1: Performance requirements and test methods”, sub-clause 5.2.5 “Transition impedance test” and Annex C.

2. Data of test samples

Test sample no.	**1**
Transition resistor variant:	86
Dimension of meander:	6.0 mm x 1.0 mm
Cross section:	12.0 mm²
Resistor value	1.51 Ω

Test sample no.	**2**
Transition resistor variant:	69
Dimension of meander:	4.0 mm x 1.0 mm
Cross section:	8.0 mm²
Resistor value	2.50 Ω

Test samples mounted in diverter switch:

Type designation:	VACUTAP® VRM III 1300 Y – 72.5
Type characteristics:	Diverter switch
Serial number:	1734908
Year of manufacture:	2016
Manufacturer:	Maschinenfabrik Reinhausen GmbH, Regensburg, Germany.

3. Scope of application

Various transition resistors, depending on rated through-current and the relevant rated step voltage of the custom-designed operation point, are used for diverter switches type VACUTAP® VRM. The basic design of the transition resistors is alike, i.e. equivalent material of resistors, fixations, identical resistor connecting leads and same position in diverter switch. The only differences are the cross-sections and the number of single meanders connected in series or in parallel.

In order to cover all transition resistor variants according to the step capacity diagram of VACUTAP® VRM, the maximum thermal stresses of the transition resistors with the highest expectable heating values were calculated. Based on these calculations, the transition impedance test was performed on following test samples, in accordance with IEC 60214-1:2014, Annex C, with 34 current pulses equivalent to one-half cycle of operation of an on-load tap-changer with 18 contacts and change-over selector:

- Test sample 1 (1.51 Ω): Designated for VACUTAP® VRM to operate in the loading point with maximum rated through-current and relevant rated step voltage.
- Test sample 2 (2.50 Ω): Designated for VACUTAP® VRM; variant with the highest calculated thermal stress per operation among all transition resistors for VACUTAP® VRM.

Hence, testing the chosen test samples covers the complete application range of all transition resistors used for diverter switches type VACUTAP® VRM.

Therefore this type test report is valid for diverter switches type VACUTAP® VR with following characteristics:

-	Diverter switch design variant:	VRM
-	Maximum rated through-current:	700 A, 1000 A or 1300 A / 2600 A[1]
-	Maximum rated step-voltage:	4500 V

[1] Single phase design with two current paths of identical design (2 x 1300 A) for applications with enforced current splitting.

4. Test conditions / Test arrangement

Setup:	The test was performed with power pulse currents in accordance with IEC 60214-1:2014, Annex C. The transition resistors were mounted in diverter switch type VACUTAP® VRM III 1300 Y – 72.5 as follows: - Sector S1A: Test sample 2 - Sector S2B: Test sample 1
Oil compartment oil filling:	Transformer oil according to the requirements of IEC 60296.
Oil cooling:	No oil cooling.
Condition of test samples:	New, as manufactured.
Test circuit:	See figure 1.
Measurement:	
- Through-current:	By means of current transformers.
- Step voltage:	By means of voltage transformers.
- Temperature of resistor:	By means of thermocouples NiCr-Ni with ∅ 0.2 mm.
- Temperature of oil:	By means of thermocouples NiCr-Ni with ∅ 0.2 mm; 25 mm below the lowest point of the transition resistor.
Measuring points (exemplary):	See pictures 1 and 2.
Switching sequence:	See figure 2.
Recording:	By transient recorder.

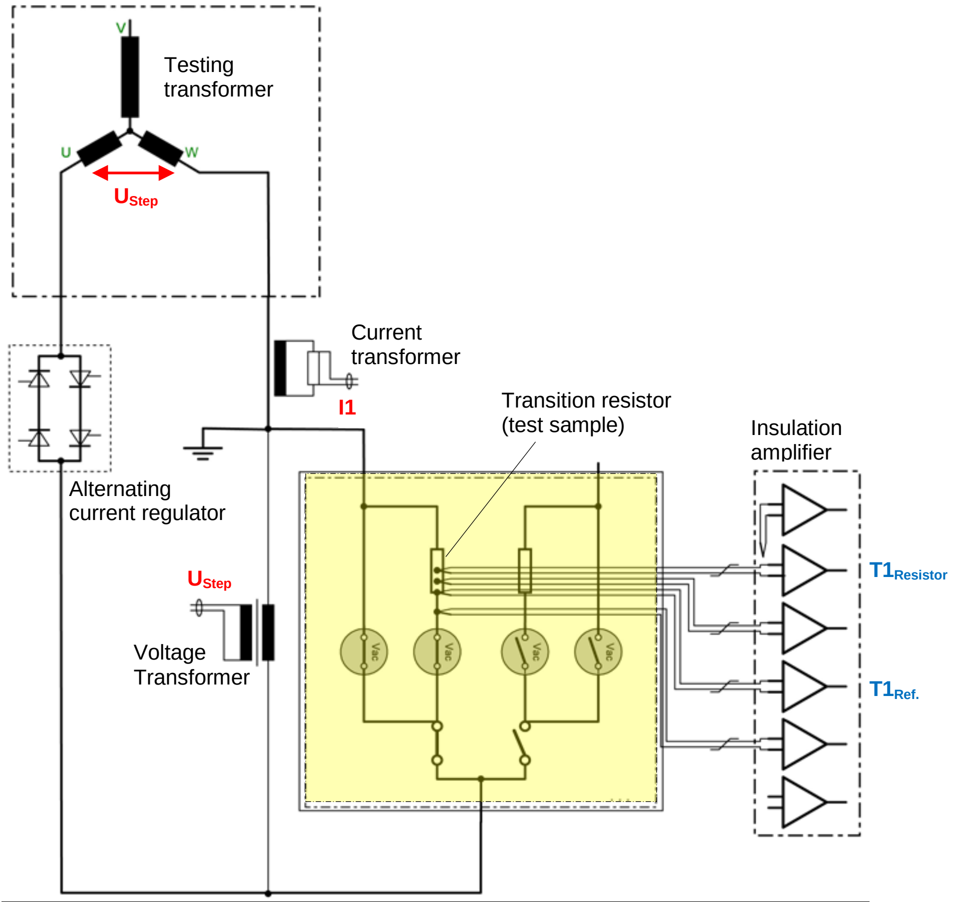
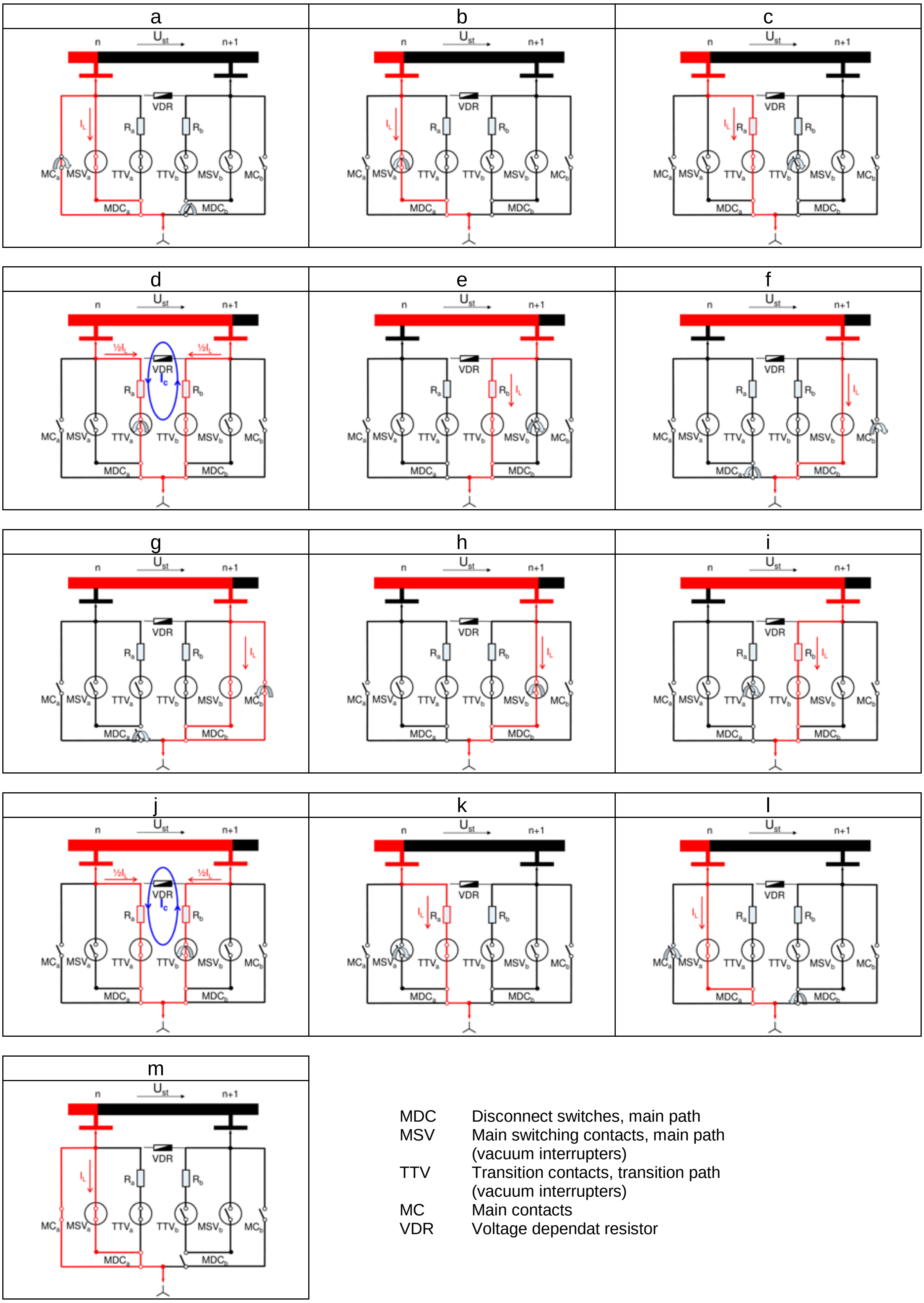
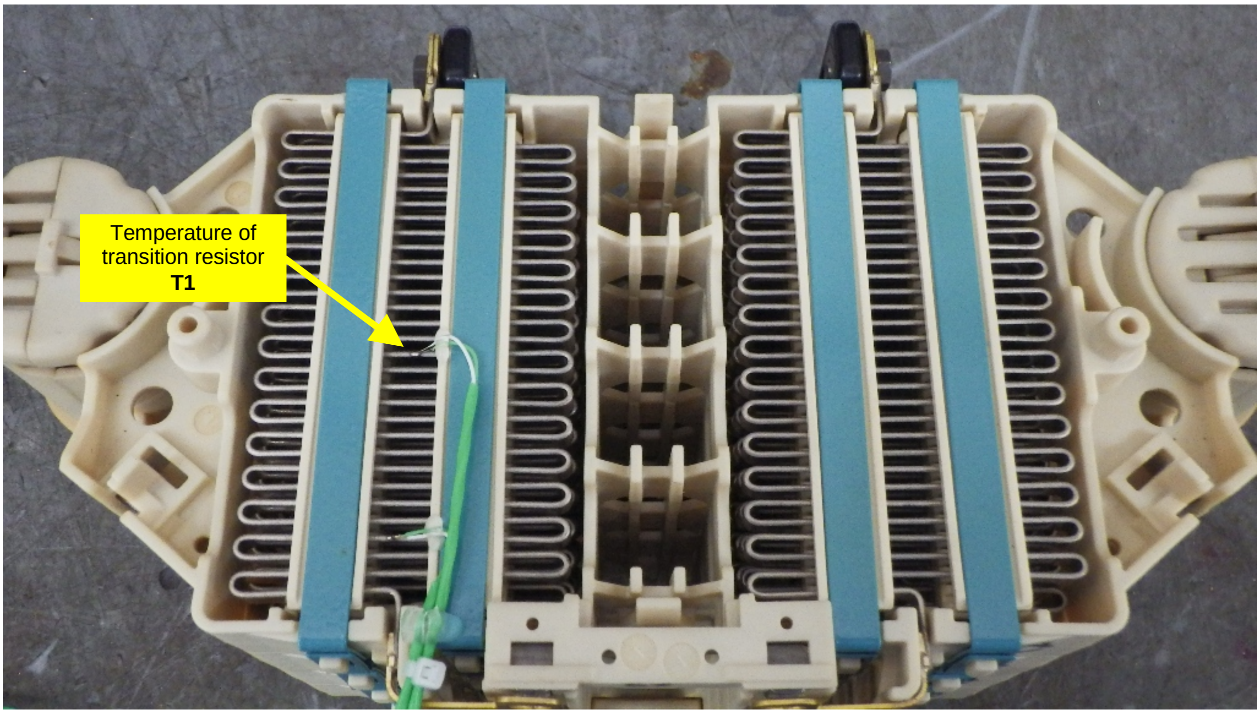


Figure 1: Schematic test circuit.

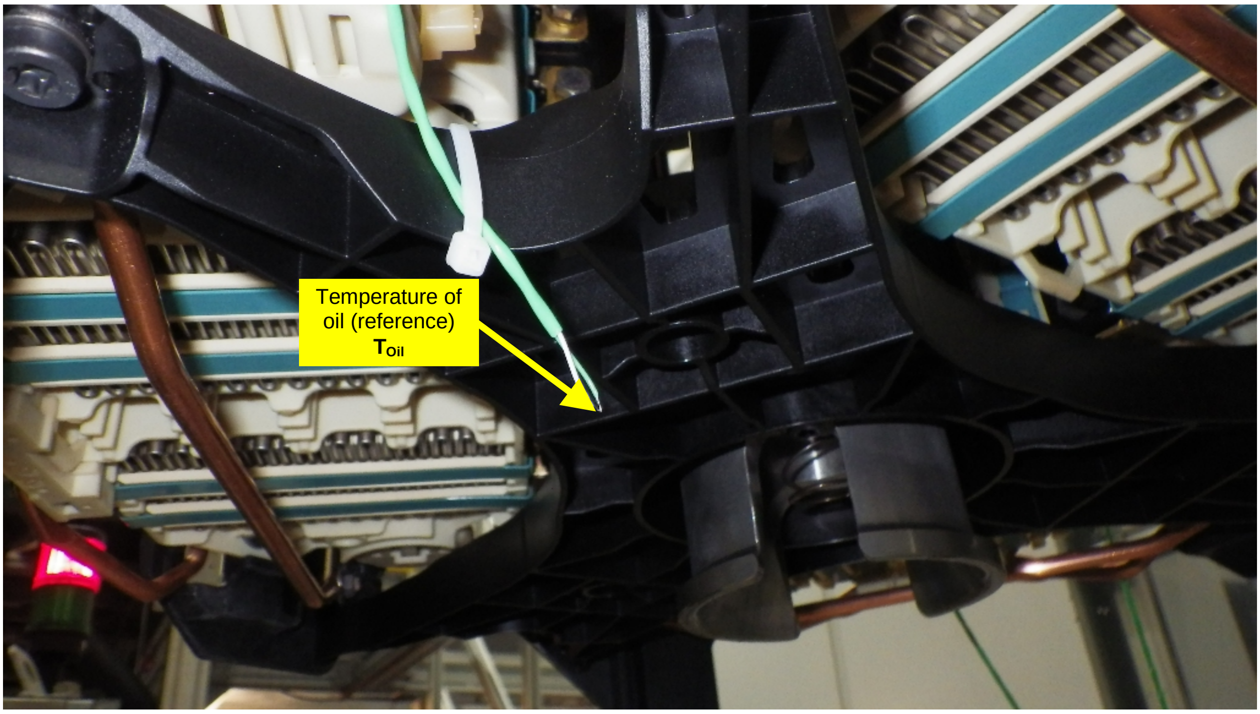


MDC	Disconnect switches, main path
MSV	Main switching contacts, main path (vacuum interrupters)
TTV	Transition contacts, transition path (vacuum interrupters)
MC	Main contacts
VDR	Voltage dependat resistor

<u>Figure 2:</u> Switching sequence of diverter switch type VACUTAP® VRM.



Picture 1: Measuring point of transition resistor temperature (exemplary).



Picture 2: Measuring point of oil temperature (exemplary).

5. Tests performed

The test samples were loaded with power pulse currents in acc. with IEC 60214-1:2014, Annex C.

In test series 1 the resistor load was equivalent to the resistor loading during switching operations at 1.5 times maximum rated through-current and at relevant rated step voltage.
In test series 2 the resistor load was equivalent to the resistor loading during switching operations at 2.0 times maximum rated through-current and at relevant rated step voltage.

5.1 Resistor loading during tap-change operation in normal service

During one tap-change operation the transition resistor is loaded with through-current and circulating current (see switching sequence figure 2). The highest load of the transition resistor occurs during a “heavy” switching operation (vectorial addition of circulating current and part of through-current). During the following operation the same transition resistor is loaded by a “light” switching operation (vectorial subtraction of circulating current and part of through-current).

In order to cover all available transition resistor variants according to the step capacity diagram of VACUTAP® VRM, the maximum thermal stresses of the transition resistors with the highest expectable heating values were calculated. Based on these calculations, following variants were exemplary tested:

- Test sample 1 (1.51 Ω): Designated for VACUTAP® VRM to operate in the loading point with maximum rated through-current and relevant rated step voltage.
- Test sample 2 (2.50 Ω): Designated for VACUTAP® VRM; variant with the highest calculated thermal stress per operation among all transition resistors for VACUTAP® VRM.

Table 1 shows the required calculated values as integral [I_r^2 x t_r] per operation when loaded with 1.5 times the rated through-current at relevant rated step voltage:

	Test sample 1 (1.51 Ω)	Test sample 2 (2.50 Ω)
Integral [I_r^2 x t_r] Heavy switching direction	137801 A²s	64878 A²s
Integral [I_r^2 x t_r] Light switching direction	72847 A²s	25279 A²s

Table 1: Required calculated values as integral [I_r^2 x t_r] when loaded with 1.5 times the rated through-current at relevant rated step voltage.

Table 2 shows the required calculated values as integral [I_r^2 x t_r] per operation when loaded with 2.0 times the rated through-current at relevant rated step voltage.

	Test sample 1 (1.51 Ω)	Test sample 2 (2.50 Ω)
Integral [I_r^2 x t_r] Heavy switching direction	229905 A²s	98713 A²s

Table 2: Required calculated values as integral [I_r^2 x t_r] when loaded with 2.0 times the rated through-current at relevant rated step voltage.

I_r Resistor current
t_r Duration of current flow

5.2 Resistor loading during test series 1 (34 current pulses equivalent to 1.5 times the maximum rated through-current at relevant rated step voltage)

Each test sample was loaded with 34 current pulses in time intervals equivalent to 1.5 times the rated through-current and relevant rated step voltage. The resistor current (I_r) and the duration of current flow (t_r) of each current pulse as well as the corresponding integral *[I_r^2 x t_r]* are documented in table 3.

Current pulse no.	Test sample 1 (1.51 Ω)			Test sample 2 (2.50 Ω)		
	I_r (r.m.s)	t_r	I_r^2 x t_r	I_r (r.m.s)	t_r	I_r^2 x t_r
1	1493 A	35.2 ms	76719 A²s	1168 A	22.4 ms	27768 A²s
2	1470 A	65.7 ms	143081 A²s	1151 A	49.1 ms	66746 A²s
3	1477 A	35.4 ms	75923 A²s	1159 A	22.1 ms	27109 A²s
4	1465 A	65.7 ms	141886 A²s	1145 A	49.3 ms	66184 A²s
5	1476 A	35.3 ms	75183 A²s	1156 A	22.6 ms	27377 A²s
6	1465 A	65.7 ms	141601 A²s	1145 A	49.0 ms	66013 A²s
7	1475 A	35.2 ms	74955 A²s	1156 A	22.6 ms	27377 A²s
8	1465 A	65.9 ms	142512 A²s	1145 A	49.5 ms	66209 A²s
9	1475 A	35.3 ms	75467 A²s	1156 A	22.3 ms	27133 A²s
10	1464 A	65.8 ms	141942 A²s	1145 A	49.2 ms	66087 A²s
11	1475 A	35.4 ms	75467 A²s	1156 A	22.2 ms	27035 A²s
12	1464 A	65.9 ms	142284 A²s	1143 A	49.5 ms	66013 A²s
13	1474 A	35.4 ms	75581 A²s	1155 A	22.4 ms	27133 A²s
14	1463 A	65.9 ms	142056 A²s	1144 A	49.5 ms	66038 A²s
15	1473 A	35.3 ms	75297 A²s	1155 A	22.2 ms	26962 A²s
16	1465 A	65.8 ms	142113 A²s	1144 A	49.2 ms	65916 A²s
17	1474 A	35.3 ms	75354 A²s	1155 A	22.1 ms	26962 A²s
18	1463 A	65.9 ms	142227 A²s	1143 A	49.3 ms	65916 A²s
19	1473 A	35.2 ms	74671 A²s	1154 A	22.2 ms	26987 A²s
20	1463 A	65.7 ms	141089 A²s	1143 A	49.3 ms	65867 A²s
21	1473 A	35.1 ms	74329 A²s	1154 A	22.4 ms	27035 A²s
22	1463 A	65.7 ms	141146 A²s	1142 A	49.3 ms	65818 A²s
23	1473 A	35.2 ms	74728 A²s	1153 A	22.6 ms	27182 A²s
24	1464 A	65.9 ms	142113 A²s	1143 A	49.1 ms	65818 A²s
25	1474 A	35.2 ms	74557 A²s	1154 A	22.2 ms	26962 A²s
26	1462 A	65.9 ms	141886 A²s	1142 A	49.1 ms	65623 A²s
27	1472 A	35.3 ms	74898 A²s	1154 A	22.2 ms	26938 A²s
28	1462 A	66.0 ms	142398 A²s	1142 A	49.1 ms	65623 A²s
29	1473 A	35.3 ms	74898 A²s	1153 A	22.4 ms	27035 A²s
30	1463 A	65.8 ms	141772 A²s	1142 A	49.3 ms	65720 A²s
31	1473 A	35.3 ms	75012 A²s	1153 A	22.6 ms	27255 A²s
32	1462 A	65.7 ms	141430 A²s	1143 A	49.5 ms	65916 A²s
33	1472 A	35.4 ms	75297 A²s	1154 A	22.6 ms	27231 A²s
34	1462 A	65.8 ms	141430 A²s	1142 A	49.5 ms	65794 A²s
Mean values out of 34 current pulses:						
"light"	1475 A	35.3 ms	75196 A²s	1156 A	22.4 ms	27146 A²s
"heavy"	1464 A	65.8 ms	141939 A²s	1144 A	49.3 ms	65959 A²s

Table 3: Tested series 1 (Current pulse no. 1 … 34).

Table 3 shows that the mean values of integrals *[I_r^2 x t_r]* (heavy and light switching direction) of each test sample were above the required calculated values (see table 1).

Figures 5a and 5b show oscillograms of the performed tests with current pulses and the progression of temperature rises for each test sample. Figures 6a and 6b show the last current pulse no. 34 more detailed with extrapolation of the temperature rise.

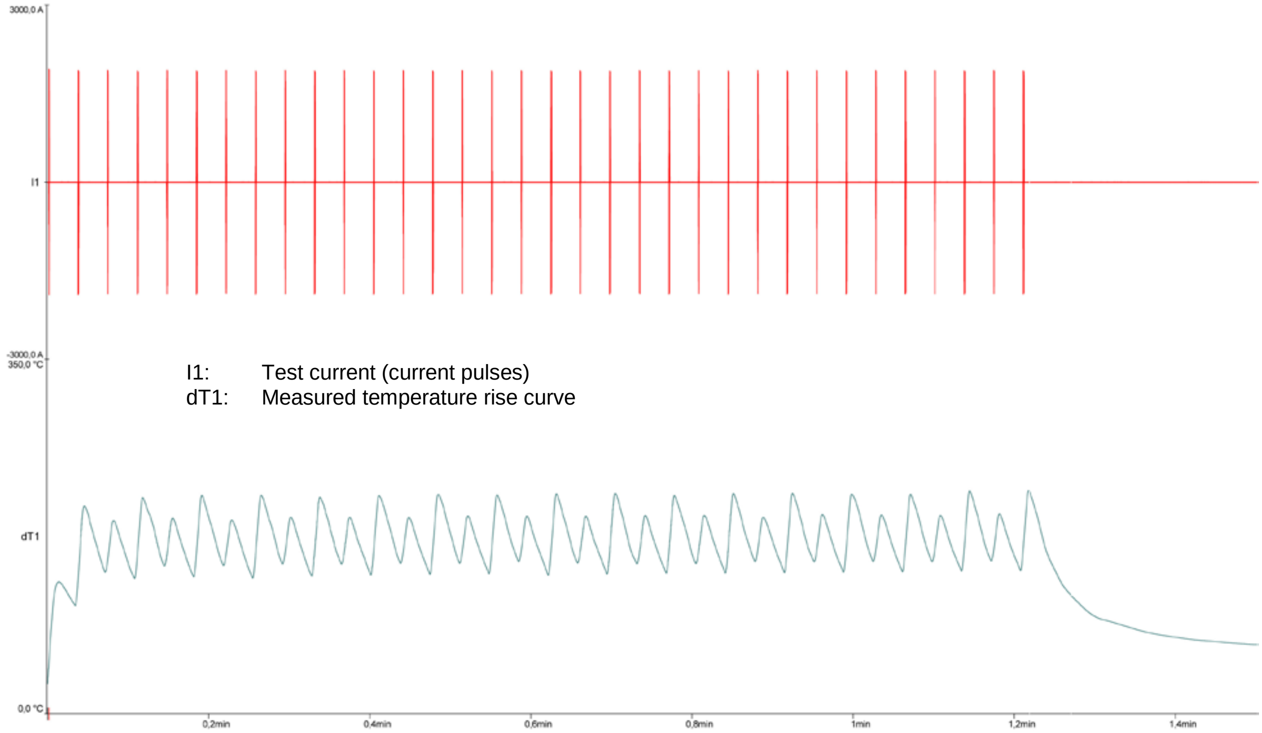


Figure 5a: Current pulses and temperature rise of test sample 1 (1.51 Ω).

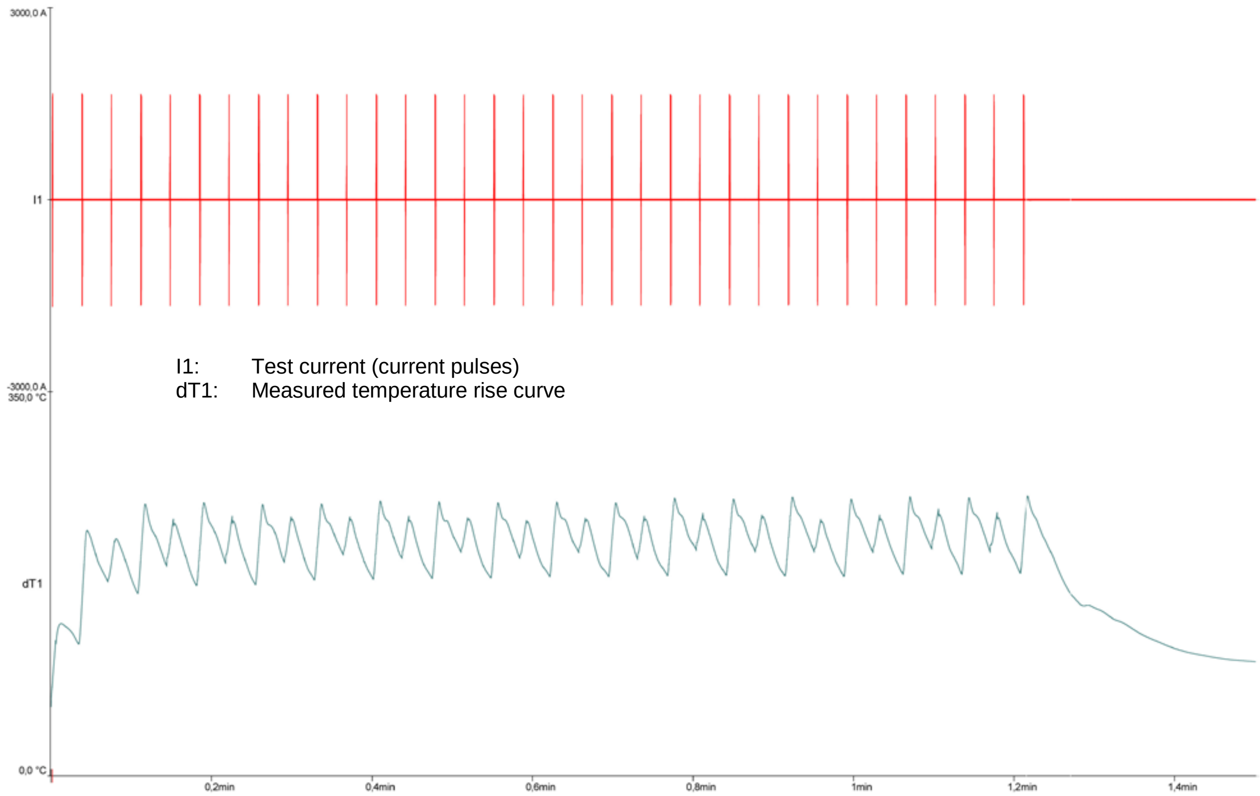


Figure 5b: Current pulses and temperature rise of test sample 2 (2.50 Ω).

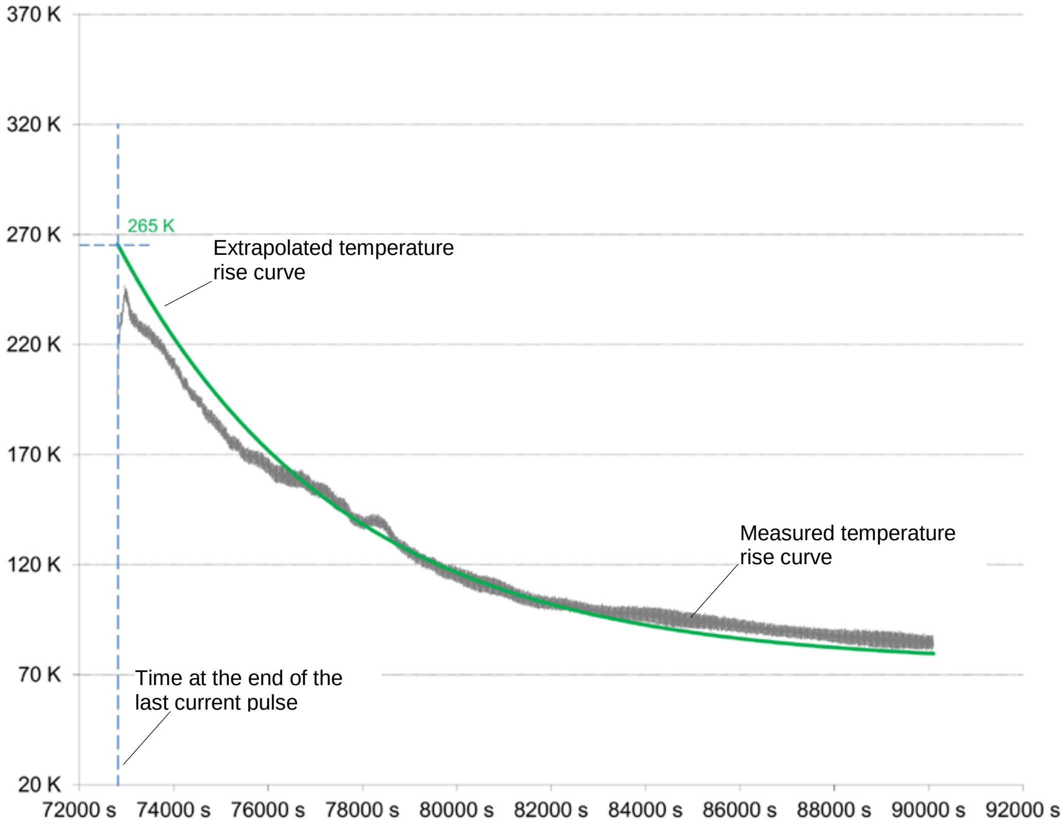


Figure 6a: Current pulse no. 34 performed on test sample 1 (1.51 Ω) with extrapolation.

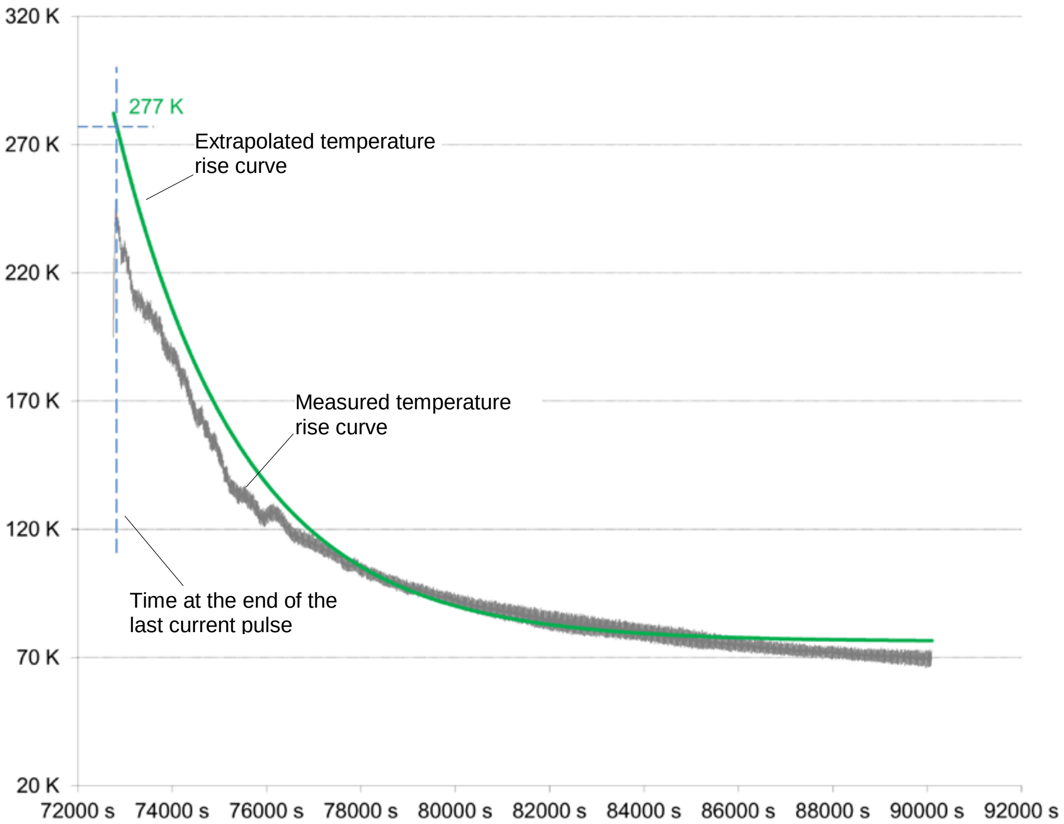


Figure 6b: Current pulse no. 34 performed on test sample 2 (2.50 Ω) with extrapolation.

Table 4 shows the maximum temperature rises at the moment of the end of current flow after the last current pulse no. 34 (determined by extrapolations, see figures 6a and 6b).

	Test sample 1 (1.51 Ω)	Test sample 2 (2.50 Ω)
Maximum temperature rise at the moment of the end of current flow after the last current pulse no. 34 (determined by extrapolations , see figures 6a and 6b)	265 K	277 K

Table 4: Temperature rises of the test samples after current pulse no. 34.

5.3 Resistor loading during test series 2 (single current pulse equivalent to 2.0 times the maximum rated through-current at relevant rated step voltage)

Each test sample was loaded with one (heavy) current pulse equivalent to 2.0 times the rated through-current and relevant rated step voltage. The resistor current (I_r) and the duration of current flow (t_r) of each current pulse as well as the corresponding integral $[I_r^2 \times t_r]$ are documented in table 5.

Current pulse no.	Test sample 1 (1.51 Ω)			Test sample 2 (2.50 Ω)		
	I_r (r.m.s)	t_r	$I_r^2 \times t_r$	I_r (r.m.s)	t_r	$I_r^2 \times t_r$
1	1263 A	108.3 ms	232680 A²s	1149 A	74.8 ms	106353 A²s

Table 5: Tested series 2.

Table 5 shows that the value of integral $[I_r^2 \times t_r]$ (heavy switching direction) of each test sample was above the required calculated value (see table 2).

The tests carried out, prove that the transition resistors withstand the stresses at 2.0 times the rated through-current and relevant rated step voltage without any wear on the mechanical parts or deterioration of the insulation material. Table 6 shows the measured resistance values of the test samples before and after the test.

	Test sample 1 (1.51 Ω)	Test sample 2 (2.50 Ω)
Value of the transition resistor before the test	1.50 Ω	2.50 Ω
Value of the transition resistor after the test	1.56 Ω	2.60 Ω

Table 6: Measurement of the value of the transition resistor before and after the test.

6. Test results

The requirements of IEC 60214-1:2014 “Tap-changers - Part 1: Performance requirements and test methods”. sub-clause 5.2.5: “Transition impedance test” were met.

- The temperature rise of the transition resistors was below the maximum permissible value of 350 K for liquid environment on-load tap-changers. Parts adjacent to the transition resistors were not affected.
- The test samples withstood the stresses at twice the maximum rated through-current and the relevant rated step voltage without any wear on the mechanical parts or deterioration of the insulation material. The measured values of the transition resistors before and after the test were within the permissible tolerance of ± 10 %.