Maschinenfabrik Reinhausen GmbH
Testcenter
Falkensteinstraße 8
93059 Regensburg

PTTP/Wag
17.07.2025

Type test report

No. VI 6E 009e

Type test for types:	On-load tap-changers VACUTAP® VI with - three phase design - delta (D) application - number of contacts: 10, 12 or 14 - highest voltage for equipment: 123/76 kV - maximum rated through-current: 400 A - maximum rated step voltage: 1500 V - reversing, coarse or without change-over selector
Test standards:	IEC 60214-1:2014, sub-clause 5.2.8: “Dielectric tests” IEEE C57.131-2024, sub-clause 5.2.8 “Dielectric tests”
Classification:	Class II in compliance with IEC 60214-1:2014, sub clause 5.2.8.3 Cat. 2 in compliance with IEEE C57.131-2024, sub-clause 5.2.8.3
Test samples:	1: VACUTAP® VI III 400 D – 76 – 14 27 1W/G 2: VACUTAP® VI III 400 D – 40 – 14 27 1W/G 3: VACUTAP® VI III 400 Y – 123 – 14 27 1W/G
Manufacturer:	Maschinenfabrik Reinhausen GmbH
Date of test:	February 2025 to March 2025
Tests performed:	
Full wave lightning impulse (LI) tests:	Impulse 1.2 / 50 µs. Three applications with positive and negative polarity each.
Chopped wave lightning impulse (LIC) tests:	Impulse 1.2 / 50 / 3 µs. Three applications with positive and negative polarity each.
Switching impulse (SI) test:	Impulse 250 / 2500 µs. Three applications with positive and negative polarity each.
Applied voltage test:	Single phase alternating voltage 50 Hz / 60 s.
Measurement of partial discharges (PD):	In compliance with IEC 60214-1:2014, sub-clause 5.2.8.9.
Test results:	The requirements of IEC 60214-1:2014 sub-clause 5.2.8 “Dielectric tests” and IEEE C57.131-2024, sub-clause 5.2.8 “Dielectric tests” were met.

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

Maschinenfabrik Reinhausen GmbH
- TAP-CHANGER TESTING -

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1. General

Applicant:

Name of applicant:	Maschinenfabrik Reinhausen GmbH
Street:	Falkensteinstraße 8
Post-code – Location:	93059 – Regensburg, Germany

Place of test:

Name of laboratory:	Maschinenfabrik Reinhausen GmbH, Testcenter
Street:	Falkensteinstraße 8
Post-code – Location:	93059 – Regensburg, Germany

2. Data of test samples

Test sample 1

Type designation:	VACUTAP® VI III 400 D – 76 – 14 27 1W/G
Type characteristics:	On-load tap-changer
Serial numbers:	2773199
IBASE:	1016777019
Year of manufacture:	2024
Manufacturer:	Maschinenfabrik Reinhausen GmbH

Test sample 2

Type designation:	VACUTAP® VI III 400 D – 40 – 14 27 1W/G
Type characteristics:	On-load tap-changer
Serial numbers:	2773198
IBASE:	1016777019
Year of manufacture:	2024
Manufacturer:	Maschinenfabrik Reinhausen GmbH

Test sample 3

Type designation:	VACUTAP® VI III 400 Y – 123 – 14 27 1W/G
Type characteristics:	On-load tap-changer
Serial numbers:	2773200
IBASE:	1016777019
Year of manufacture:	2024
Manufacturer:	Maschinenfabrik Reinhausen GmbH

3. Test specification

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8 “Dielectric tests”
	IEEE C57.131-2024, sub-clause 5.2.8 “Dielectric tests”

4. Specification of insulation distances

Specification of the insulating distances of the tap selector and change-over selector and the corresponding voltage stress of the transformer windings:

Symbol	Definition of the insulation distances of the transformer windings
a1	Between fine tap selector contacts of the winding of one tap position (connected or not).
a	Between beginning and end of a tap winding and, for a coarse winding model, also between beginning and end of a coarse winding. Note for coarse tap selector connection in (-) position of the change-over selector: When stressed with impulse voltage, the permissible withstand voltage "a" between the end of a coarse winding connected with the K tap selector contact and the tap selector contact at the end of the tap winding of the same phase must be adhered to.
b	Between the tap selector contacts of different phases and between change-over selector contacts of different phases, which are connected with the beginning/end of a tapped winding or with a tap selector contact. The permissible voltages between the contacts for tap-changers for delta connections depend on the positions of the change-over selector and tap selector. The different permissible withstand voltages b1, b2 or b3 must therefore be noted for an insulation distance: b1 = between selected contacts for different phases b2 = from the selected contact of one phase to non-selected contacts of other phases b3 = between non-selected contacts for different phases.
f	Between tap selector contacts and (+) change-over selector contacts to ground. Different values apply for the delta connection version: f1 = between take-off lead and ground and in (+) position of change-over selector between (+) change-over selector contacts and ground. f2 = between non-selected tap selector contacts and in (-) position of change-over selector between (+) contacts and ground.

Additionally, for coarse tap selector connection in (+) position of the change-over selector:

c1	From one (-) change-over selector contact to take-off lead of the same phase.
c2	Between (-) change-over selector contacts of different phases and from one (-) change-over selector contact to one (+) change-over selector contact of another phase. Different values apply for the delta connection version: c21 = between a (-) change-over selector contact and a (+) change-over selector contact of another phase. c22 = between (-) change-over selector contacts of different phases.

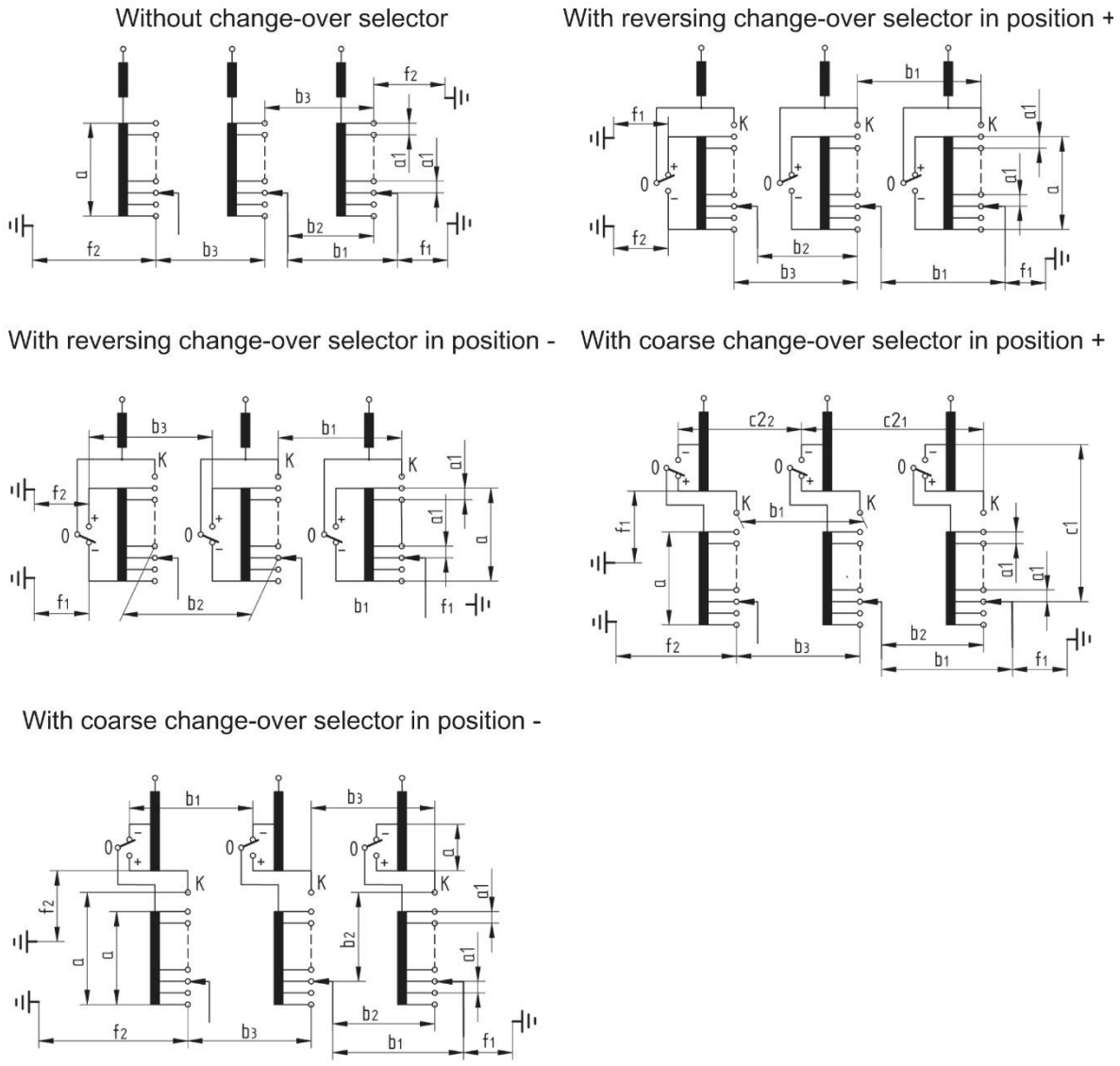


Figure 1: Insulating distances of the transformer windings.

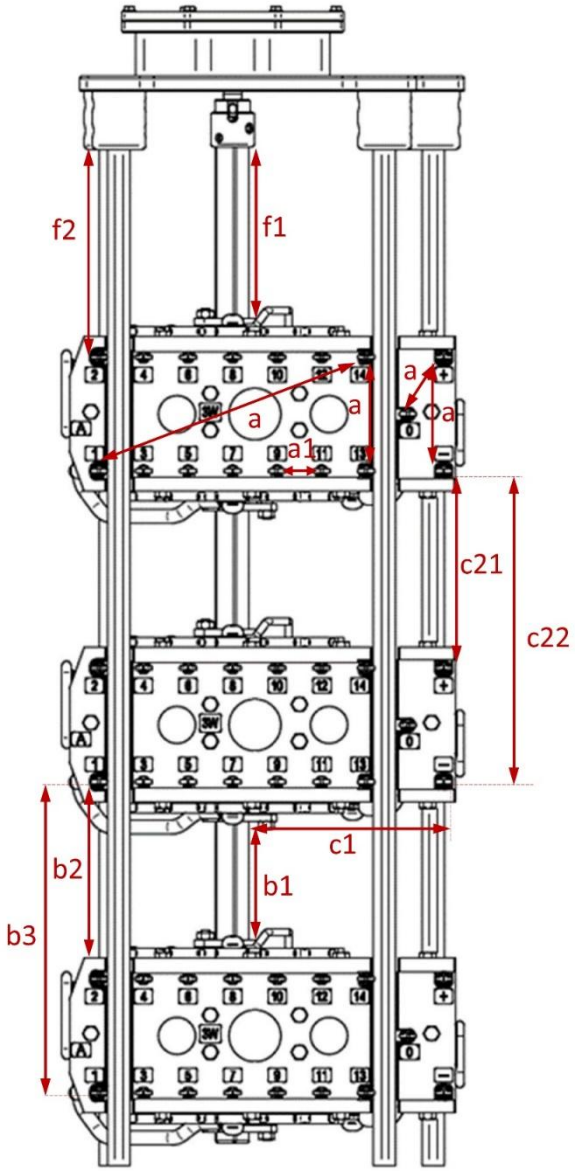


Figure 2: Insulating distances on the on-load tap changer.

Note: In case of several insulating distances of the same design all distances were tested, figure 2 shows only examples of these distances.

5. Scope of application

On-load tap-changers of type VACUTAP® VI with delta (D) application and highest voltage for equipment Um = 123/76 kV are available with reversing change-over selector, coarse change-over selector or without change-over selector.

On-load tap-changers of type VACUTAP® VI are designed with 14 tap selector contacts. Optionally, customers can reduce the number of tap selector contacts to 12 or 10 by using bridges. The bridges required for this are supplied by the manufacturer (Maschinenfabrik Reinhausen GmbH).
Without built-in bridges the dielectric stress of the insulating distances between neighboring fine tap selector contacts (insulation distance “a1”) is twice as high as with built-in bridges. Thus, the basic configuration with 14 contacts (without bridges) is considered as worst case and configurations with 10 or 12 tap selector contacts (with built-in bridges) are covered by the performed tests. Other insulation distances are not affected by mounted bridges between the tap selector contacts.

The design of insulating distances “a”, “a1” and “c1” is identical for all on-load tap-changers type VACUTAP® VI. Hence, these insulating distances were exemplary tested on type VACUTAP® VI III 400 D – 40 – 14 27 1W/G (test sample 2).
The design of insulating distances “b1”, “b2”, “b3”, “c21” and “c22” is identical for all on-load tap-changers type VACUTAP® VI with delta (D) application and Um = 76 kV. Hence, these insulating distances were exemplary tested on type VACUTAP® VI III 400 D – 76 – 14 27 1W/G (test sample 1).
The design of insulating distances “f1” and “f2” is identical for all on-load tap-changers type VACUTAP® VI with star-point (Y) application and Um = 123 kV. Hence, these insulating distances were exemplary tested on type VACUTAP® VI III 400 Y – 123 – 14 27 1W/G (test sample 3).
Thus, all on-load tap-changers of type VACUTAP® VI with delta (D) application and Um = 123/76 kV are covered by the performed tests.

To cover VACUTAP® VI variants with reversing change-over selector and coarse change-over selector, the dielectric test was performed in two test sequences.
First, the test samples were configured and tested with reversing change-over selector. Thereafter, the change-over selectors of the test samples were configured as coarse change-over selector for further tests. The VACUTAP® VI variant without change-over selector was not tested explicit, because this variant is less critical and covered by the performed tests.

Therefore, this type test report is valid for on-load tap-changers of type VACUTAP® VI with following characteristics:

- Number of phases: 3
- Application: delta (D)
- Number of contacts: 10, 12 or 14
- Highest voltage for equipment: 123/76 kV
- Maximum rated through-current: 400 A
- Maximum rated step voltage: 1500 V
- Change-over selector: without change-over selector, coarse change-over selector or reversing change-over selector

6. Test setup

6.1 General

Test arrangements:	The dielectric tests were performed on permanently installed measuring chains for applied voltage tests and impulse voltage tests (see chapters 6.2 and 6.3).
Treatment of the test sample before testing:	Vacuum drying procedure.
Test tank oil filling:	Clean transformer oil according to IEC 60296 was filled in a Plexiglas test tank (volume 29,000 liters).
Breakdown strength of transformer oil:	69.8 – 83.4 kV / 2.5mm.

6.2 Test circuit for applied voltage test

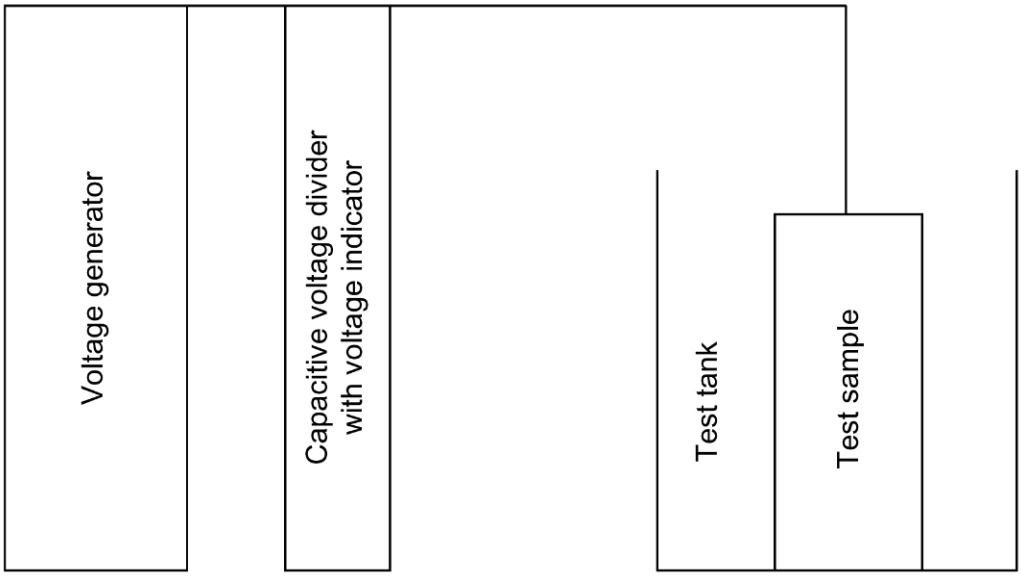


Figure 3: Test circuit for applied voltage test.

6.3 Test circuit for lightning impulse voltage tests (full / chopped wave) and switching impulse test

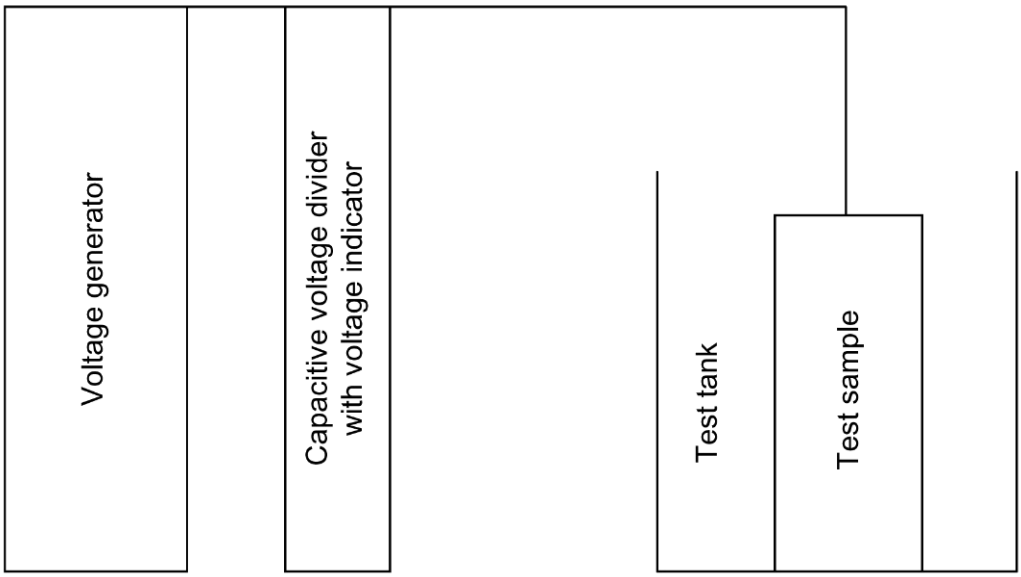


Figure 4: Test circuit for lightning impulse voltage tests (full / chopped wave) and switching impulse test.

6.4 Test circuit for partial discharge measurement

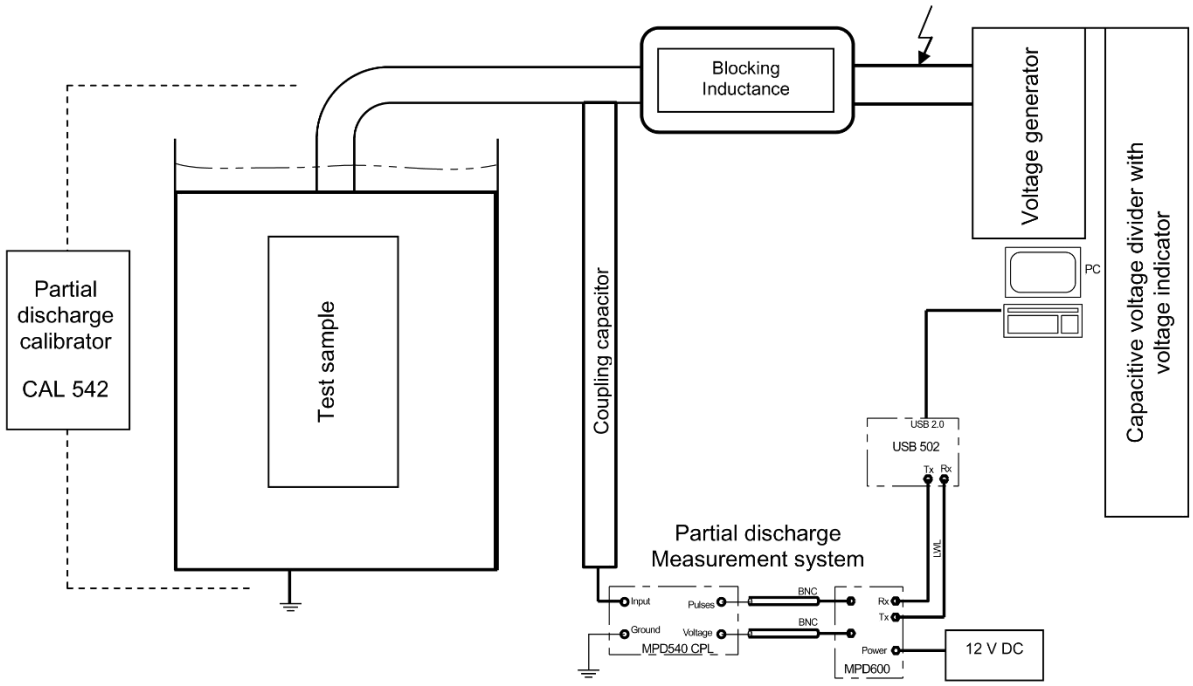


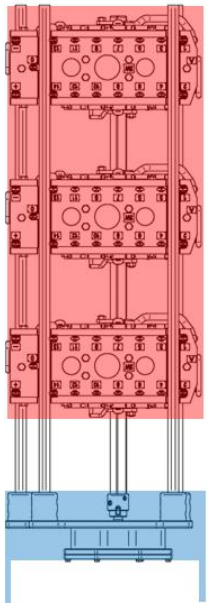
Figure 5: Test circuit for partial discharge measurement.

7. Tests performed

7.1 Full wave lightning impulse test (LI)

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8.5 IEEE C57.131-2024, sub-clause 5.2.8.5
Impulse voltage generator:	See chapter 6.3 (max. charging: 1800 kV)
Voltage waveform (T_1/T_2):	1.2 / 50 µs
Number of applications:	Three applications with positive and three with negative polarity

7.1.1 Insulating distance “f1”

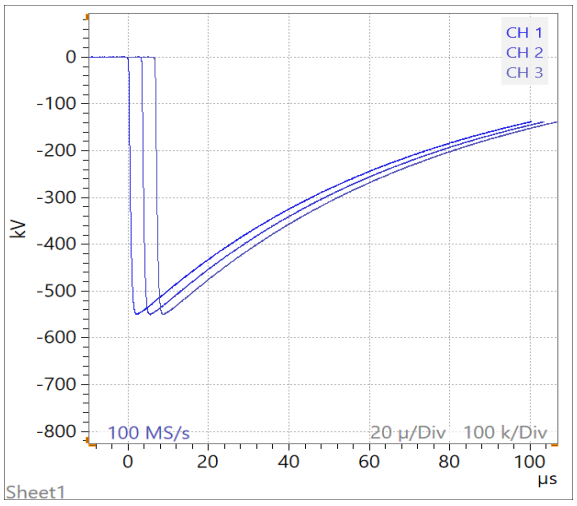


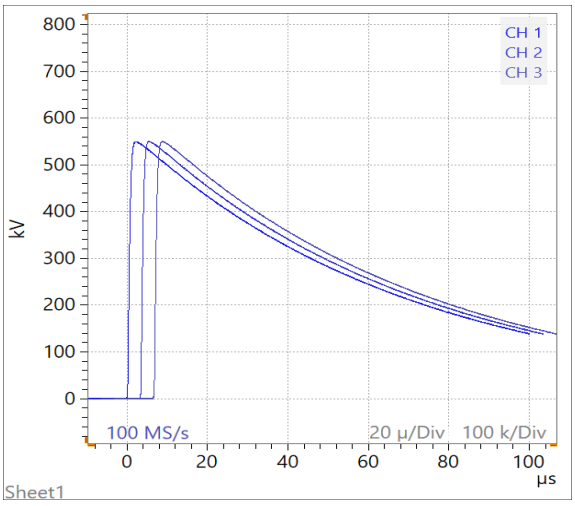
BLUE: Grounded
RED: 100% test voltage

Figure 6: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-550	-549.9	1.2	1.255	50	51.66	≤ 5	< 1
2		-550.1		1.254		51.65		< 1
3		-550.1		1.255		51.69		< 1
4	550	549.8		1.268		51.76		< 1
5		550.1		1.264		51.78		< 1
6		550.2		1.266		51.77		< 1

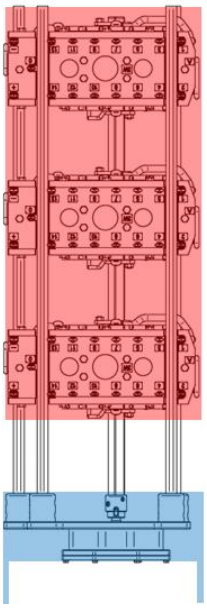
Table 1: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “f1”.





Figures 7a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “f1”.

7.1.2 Insulating distance “f2”

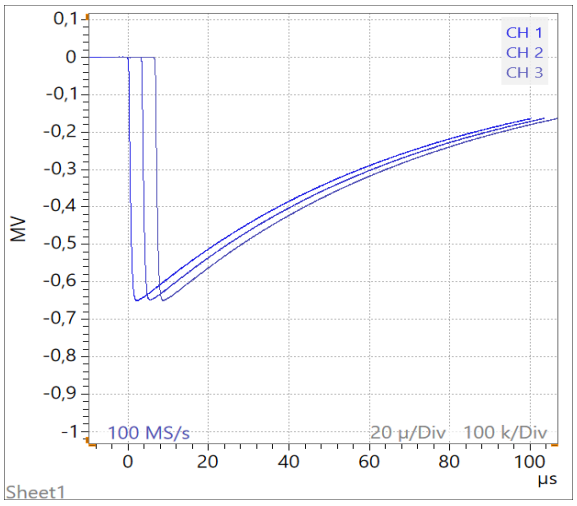


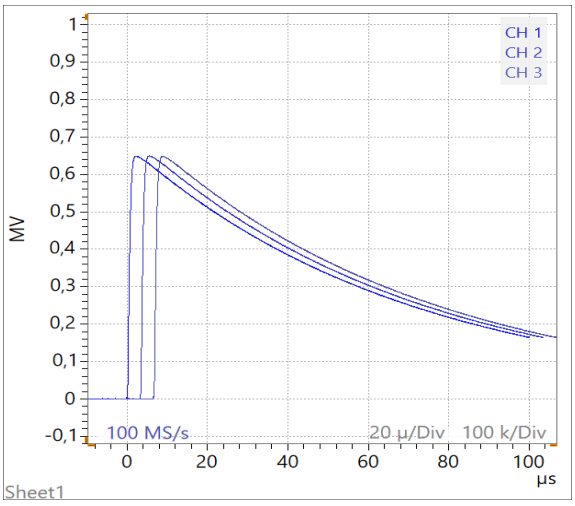
BLUE: Grounded
RED: 100% test voltage

Figure 8: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-650	-650.9	1.2	1.260	50	51.81	≤ 5	< 1
2		-649.0		1.259		51.83		< 1
3		-650.5		1.260		51.81		< 1
4	650	649.3		1.277		51.95		< 1
5		649.6		1.274		51.96		< 1
6		648.5		1.274		51.95		< 1

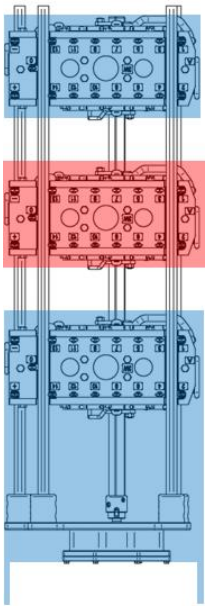
Table 2: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “f2”.





Figures 9a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “f2”.

7.1.3 Insulating distance “b1”

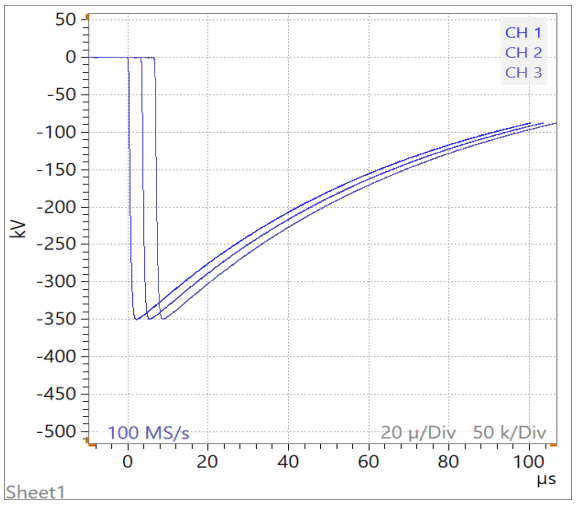


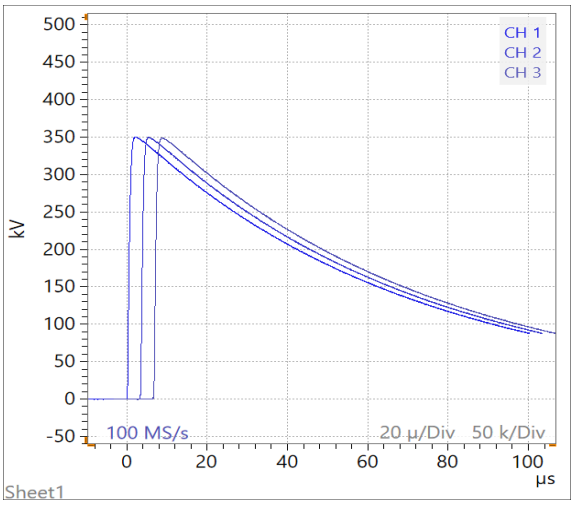
BLUE: Grounded
RED: 100% test voltage

Figure 10: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-350	-350.5	1.2	1.247	50	51.63	≤ 5	< 1
2		-350.0		1.247		51.59		< 1
3		-350.0		1.246		51.63		< 1
4	350	350.5		1.257		51.62		< 1
5		350.0		1.257		51.64		< 1
6		349.3		1.257		51.63		< 1

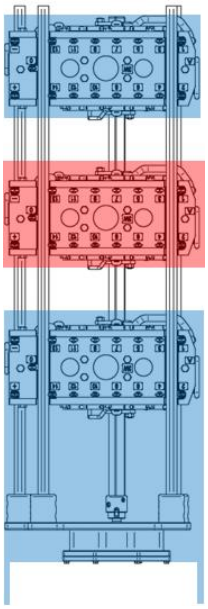
Table 3: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “b1”.





Figures 11a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “b1”.

7.1.4 Insulating distance “b2”

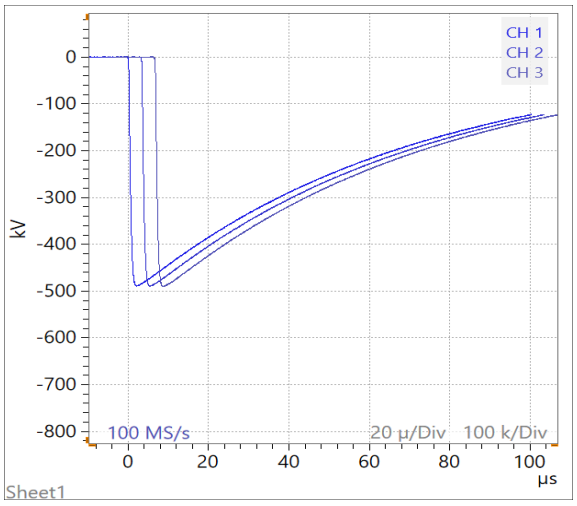


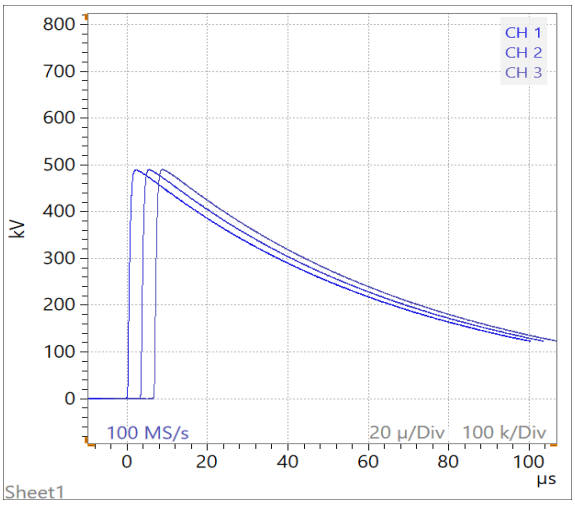
BLUE: Grounded
RED: 100% test voltage

Figure 12: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-490	-489.4	1.2	1.253	50	51.72	≤ 5	< 1
2		-489.6		1.251		51.72		< 1
3		-490.6		1.253		51.74		< 1
4	490	489.4		1.263		51.81		< 1
5		490.0		1.267		51.82		< 1
6		490.4		1.267		51.82		< 1

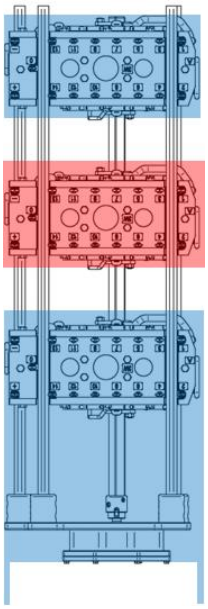
Table 4: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “b2”.





Figures 13a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “b2”.

7.1.5 Insulating distance “b3”

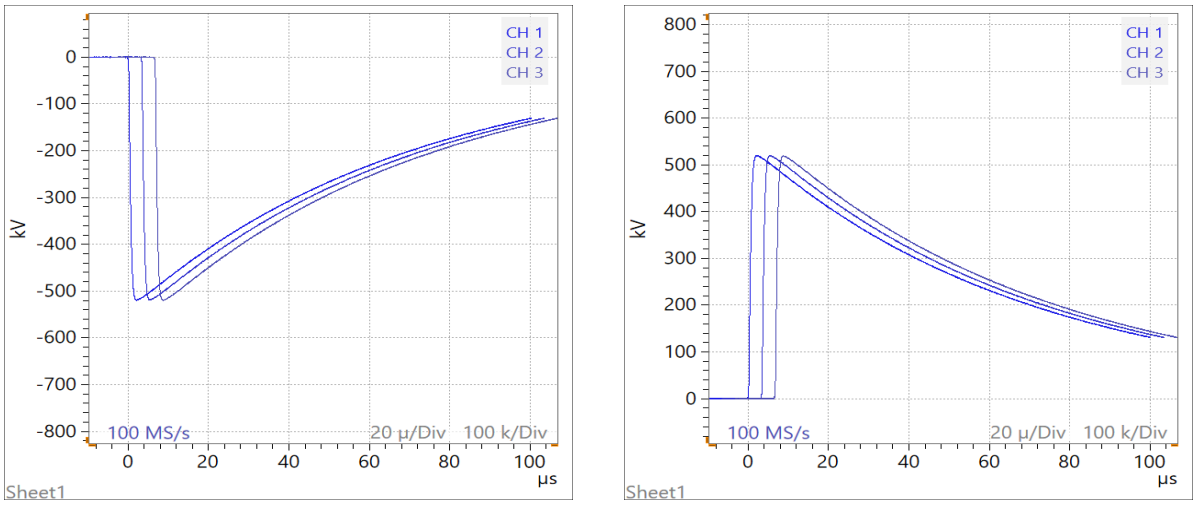


BLUE: Grounded
RED: 100% test voltage

Figure 14: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-520	-519.9	1.2	1.257	50	51.74	≤ 5	< 1
2		-519.3		1.255		51.76		< 1
3		-520.1		1.256		51.75		< 1
4	520	519.9		1.269		51.83		< 1
5		519.9		1.269		51.85		< 1
6		519.3		1.269		51.82		< 1

Table 5: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “b3”.



Figures 15a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “b3”.

7.1.6 Insulating distance “a” (circuit 1)

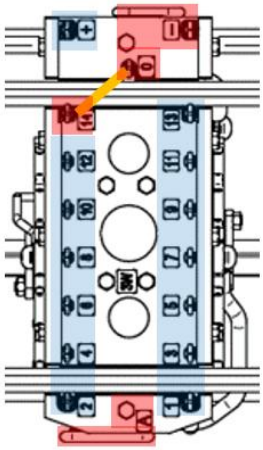
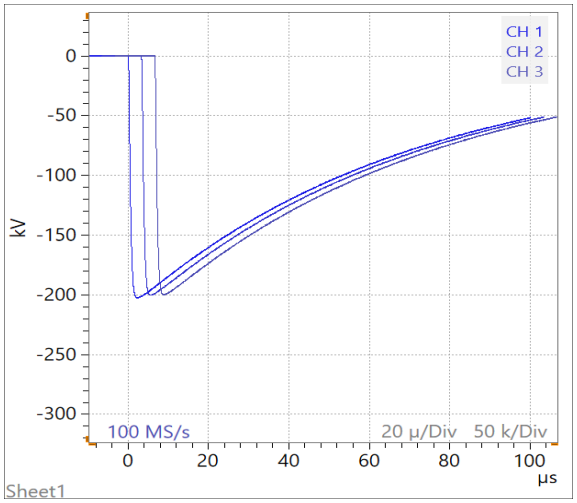
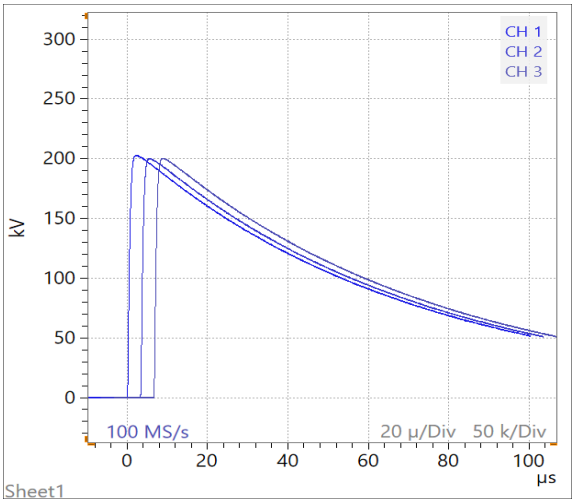


Figure 16: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß' in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-200	-202.6	1.2	1.286	50	52.32	≤ 5	< 1
2		-200.3		1.286		52.37		< 1
3		-199.9		1.284		52.33		< 1
4	200	202.8		1.290		52.29		< 1
5		200.2		1.287		52.31		< 1
6		200.3		1.290		52.32		< 1

Table 6: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “a”.





Figures 17a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “a”.

7.1.7 Insulating distance “a” (circuit 2)

BLUE: Grounded
RED: 100% test voltage

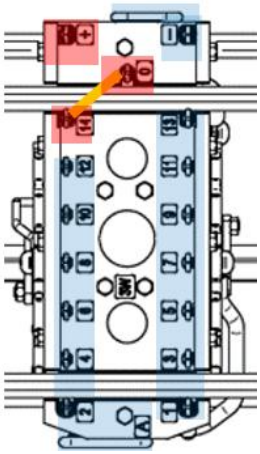
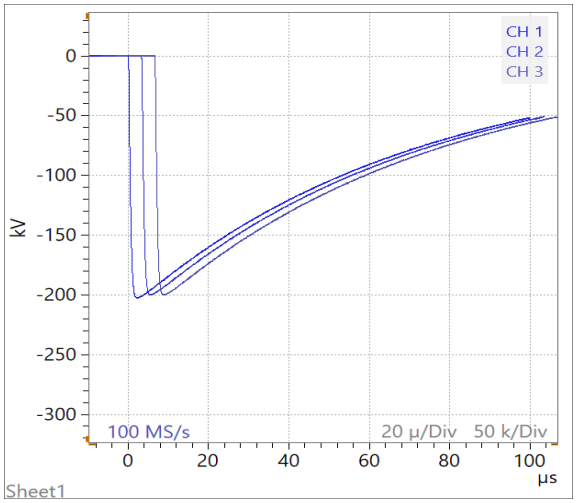
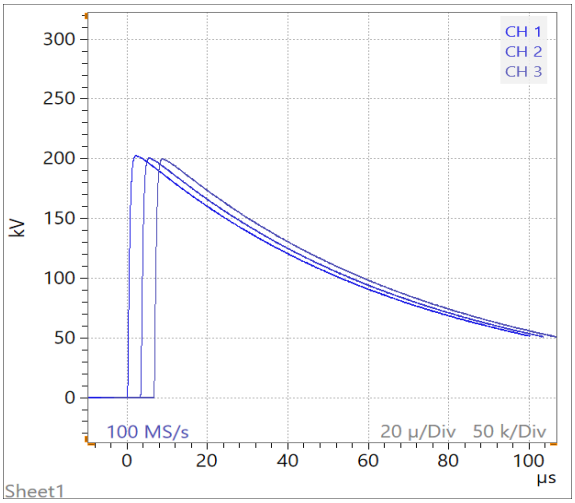


Figure 18: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-200	-202.6	1.2	1.271	50	52.29	≤ 5	< 1
2		-200.1		1.271		52.24		< 1
3		-200.2		1.270		52.30		< 1
4	200	202.5		1.273		52.25		< 1
5		200.5		1.272		52.23		< 1
6		199.9		1.273		52.25		< 1

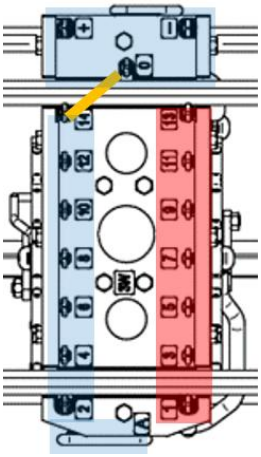
Table 7: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “a”.





Figures 19a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “a”.

7.1.8 Insulating distance “a1”

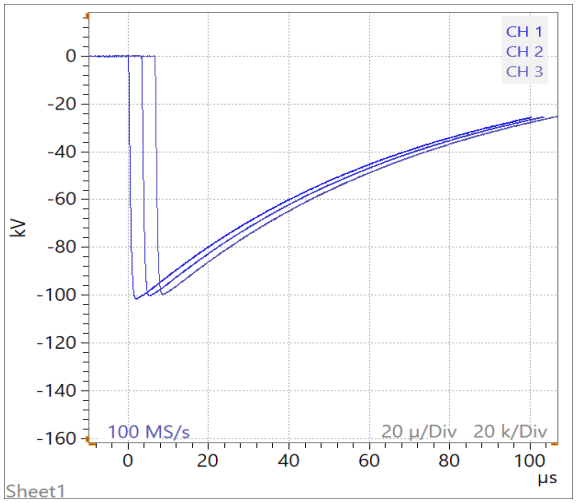


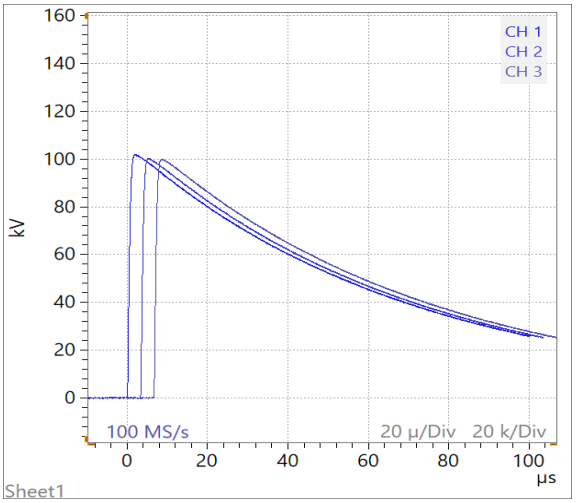
BLUE: Grounded
RED: 100% test voltage

Figure 20: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-100	-101.6	1.2	1.212	50	51.86	≤ 5	< 1
2		-100.3		1.214		51.82		< 1
3		-99.73		1.212		51.83		< 1
4	100	101.9		1.212		51.83		< 1
5		100.1		1.212		51.88		< 1
6		99.90		1.211		51.84		< 1

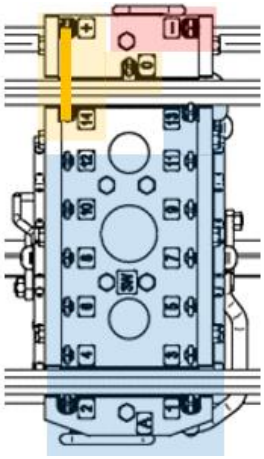
Table 8: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “a1”.





Figures 21a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “a1”.

7.1.9 Insulating distance “c1”

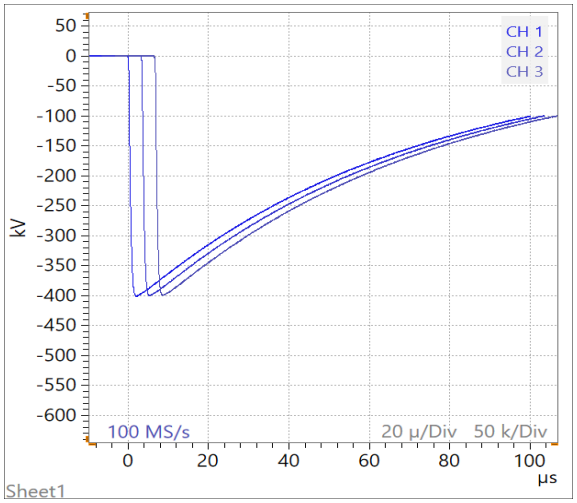


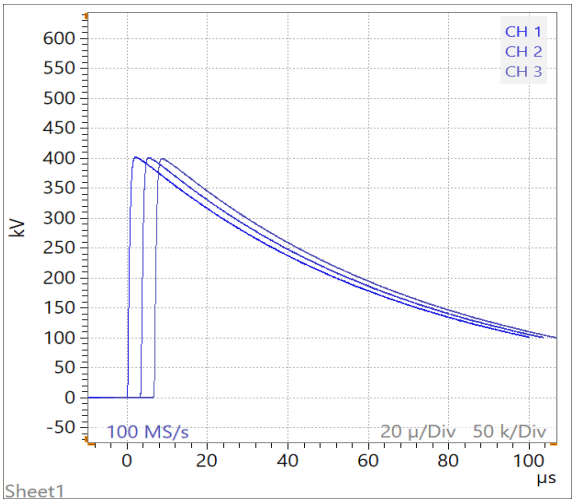
BLUE: Grounded
RED: 100% test voltage
YELLOW: 50% test voltage

Figure 22: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-400	-401.3	1.2	1.217	50	51.52	≤ 5	< 1
2		-400.3		1.218		51.49		< 1
3		-399.9		1.220		51.50		< 1
4	400	402.0		1.231		51.59		< 1
5		400.8		1.228		51.59		< 1
6		399.7		1.229		51.54		< 1

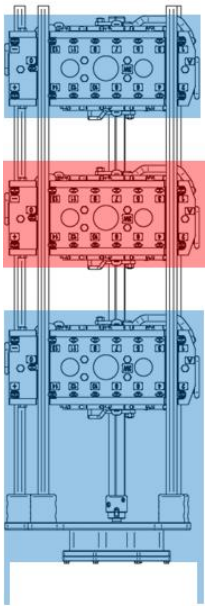
Table 9: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “c1”.





Figures 23a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “c1”.

7.1.10 Insulating distance “c21”

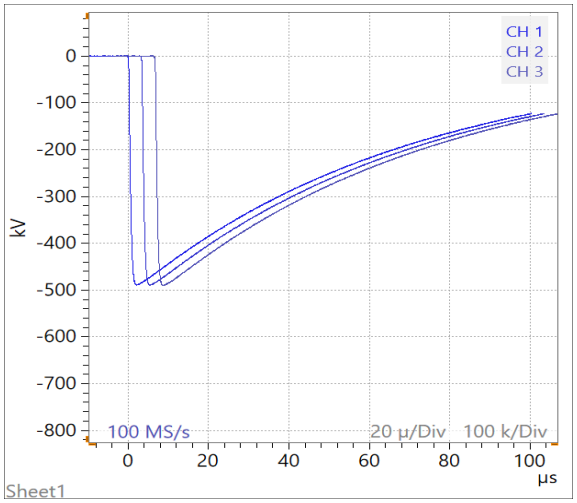


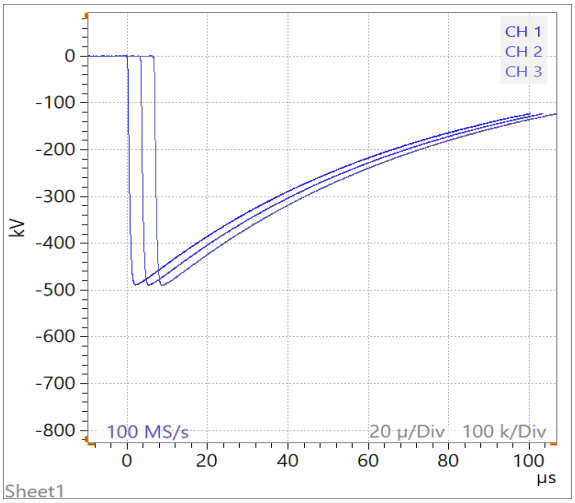
BLUE: Grounded
RED: 100% test voltage

Figure 24: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-490	-489.4	1.2	1.253	50	51.72	≤ 5	< 1
2		-489.6		1.251		51.72		< 1
3		-490.6		1.253		51.74		< 1
4	490	489.4		1.263		51.81		< 1
5		490.0		1.267		51.82		< 1
6		490.4		1.267		51.82		< 1

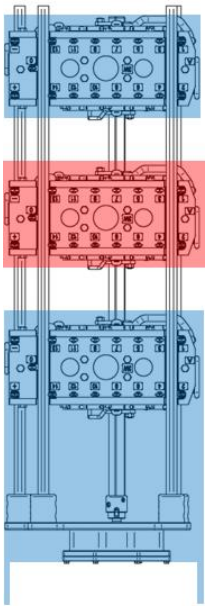
Table 10: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “c21”.





Figures 25a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “c21”.

7.1.11 Insulating distance “c22”

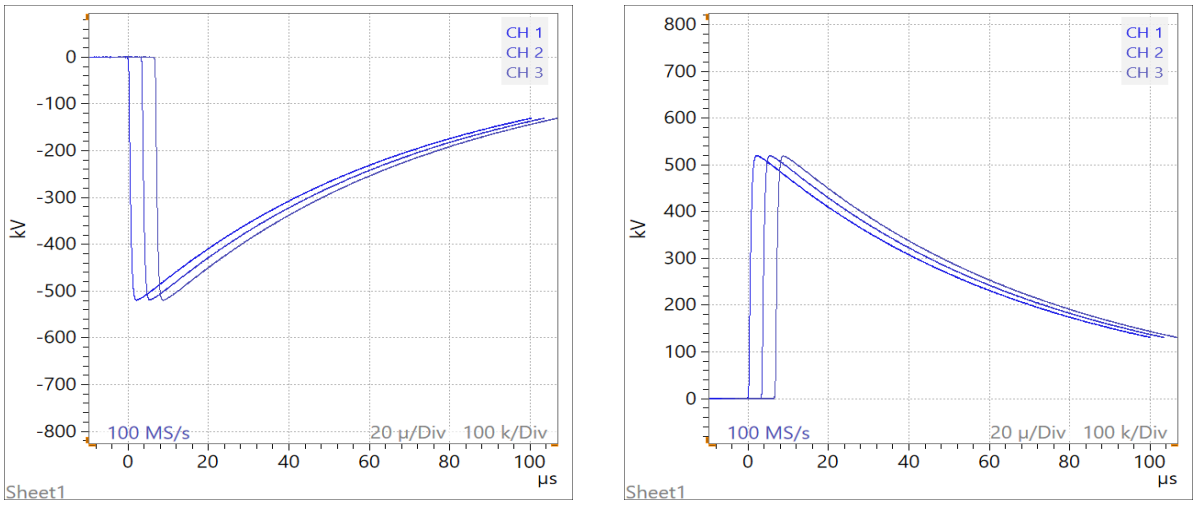


BLUE: Grounded
RED: 100% test voltage

Figure 26: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to half-value T_2 in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-520	-519.9	1.2	1.257	50	51.74	≤ 5	< 1
2		-519.3		1.255		51.76		< 1
3		-520.1		1.256		51.75		< 1
4	520	519.9		1.269		51.83		< 1
5		519.9		1.269		51.85		< 1
6		519.3		1.269		51.82		< 1

Table 11: Test results of full wave lightning impulse test (1.2/50 µs) on insulating distance “c22”.



Figures 27a-b: Oscillograms of full wave lightning impulse test (1.2/50 µs) on insulating distance “c22”.

7.2 Chopped wave lightning impulse test (LIC)

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8.6 IEEE C37-151-2024, sub-clause 5.2.8.6
Impulse voltage generator:	See chapter 6.3 (max. charging: 1800 kV)
Voltage waveform ($T_1/T_2/T_c$):	1.2 / 50 / 3 µs
Number of applications:	Three applications with positive and three with negative polarity

7.2.1 Insulating distance “f1”

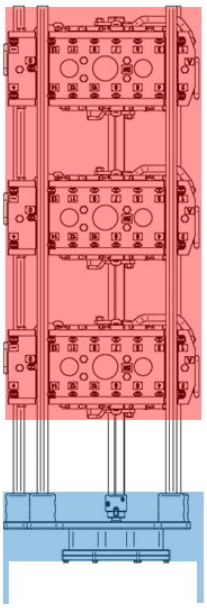
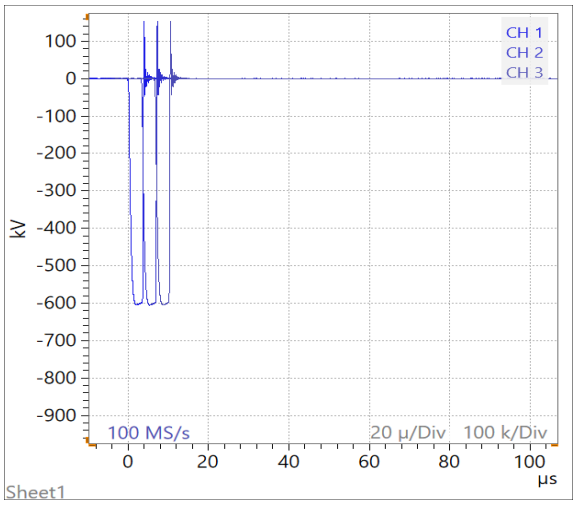
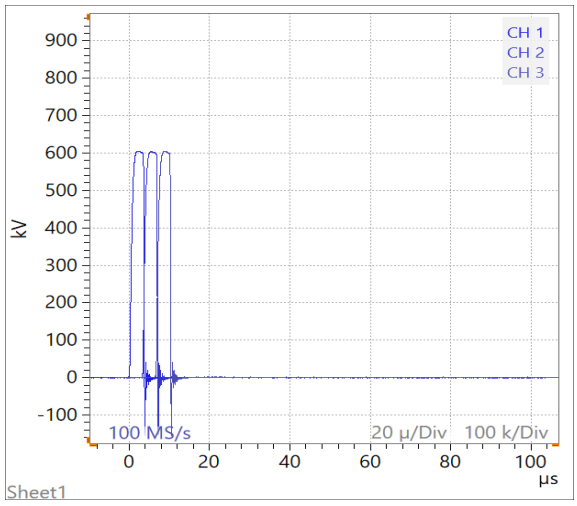


Figure 28: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-605	-605.1	1.2	1.262	3	3.700	≤ 5	< 1
2		-605.3		1.266		3.679		< 1
3		-605.2		1.263		3.692		< 1
4	605	604.7		1.282		3.665		< 1
5		603.8		1.279		3.638		< 1
6		604.9		1.283		3.656		< 1

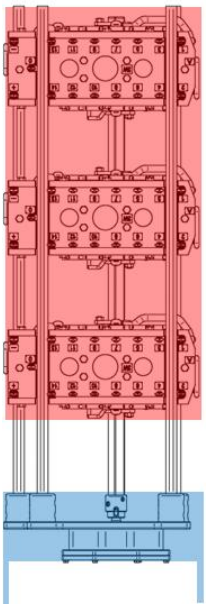
Table 12: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “f1”.





Figures 29a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “f1”.

7.2.2 Insulating distance “f2”

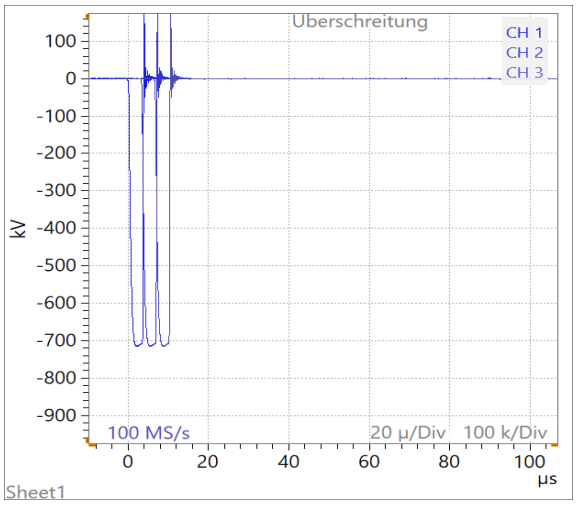


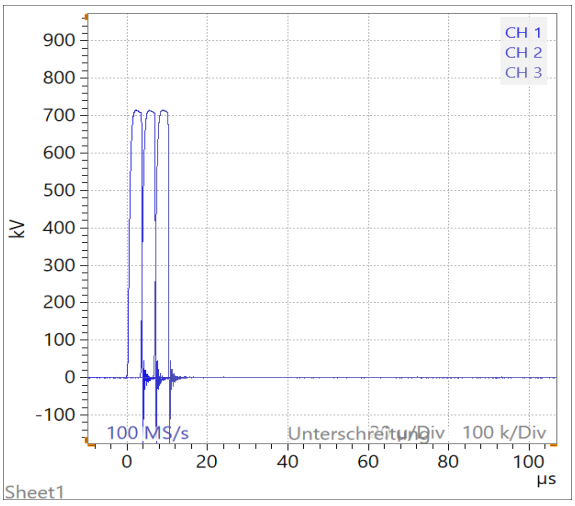
BLUE: Grounded
RED: 100% test voltage

Figure 30: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-715	-715.4	1.2	1.264	3	3.703	≤ 5	< 1
2		-714.9		1.268		3.715		< 1
3		-715.2		1.263		3.708		< 1
4	715	714.2		1.286		3.682		< 1
5		714.2		1.280		3.675		< 1
6		714.8		1.279		3.695		< 1

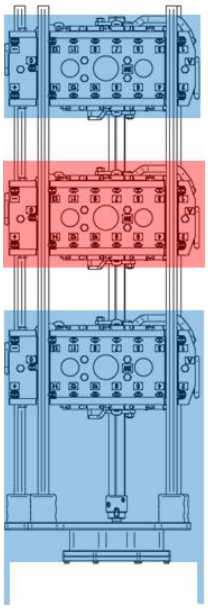
Table 13: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “f2”.





Figures 31a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “f2”.

7.2.3 Insulating distance “b1”

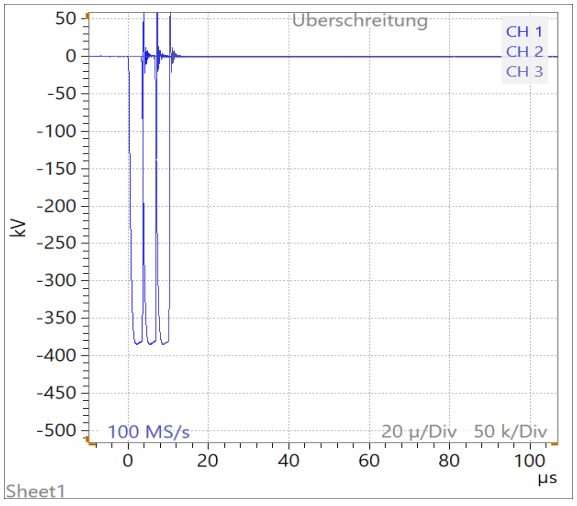


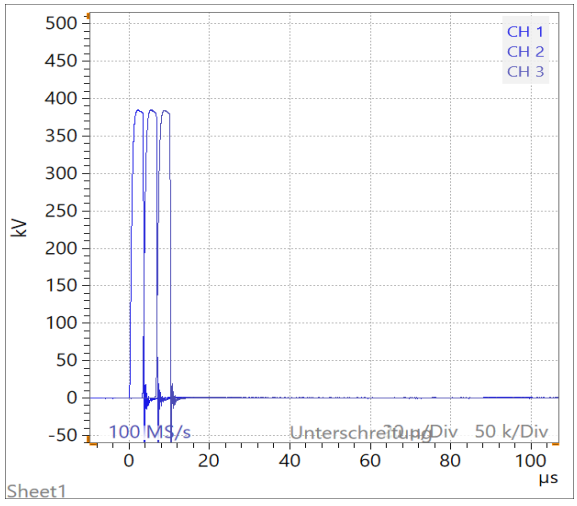
BLUE: Grounded
RED: 100% test voltage

Figure 32: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-385	-384.8	1.2	1.261	3	3.636	≤ 5	< 1
2		-384.9		1.252		3.639		< 1
3		-384.9		1.256		3.644		< 1
4	385	384.9		1.261		3.565		< 1
5		384.8		1.255		3.598		< 1
6		384.4		1.259		3.599		< 1

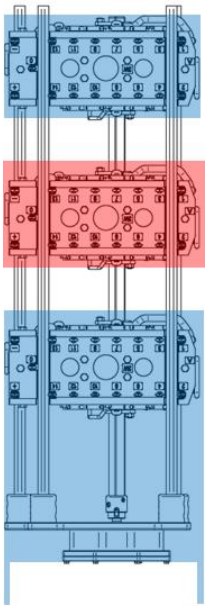
Table 14: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b1”.





Figures 33a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b1”.

7.2.4 Insulating distance “b2”

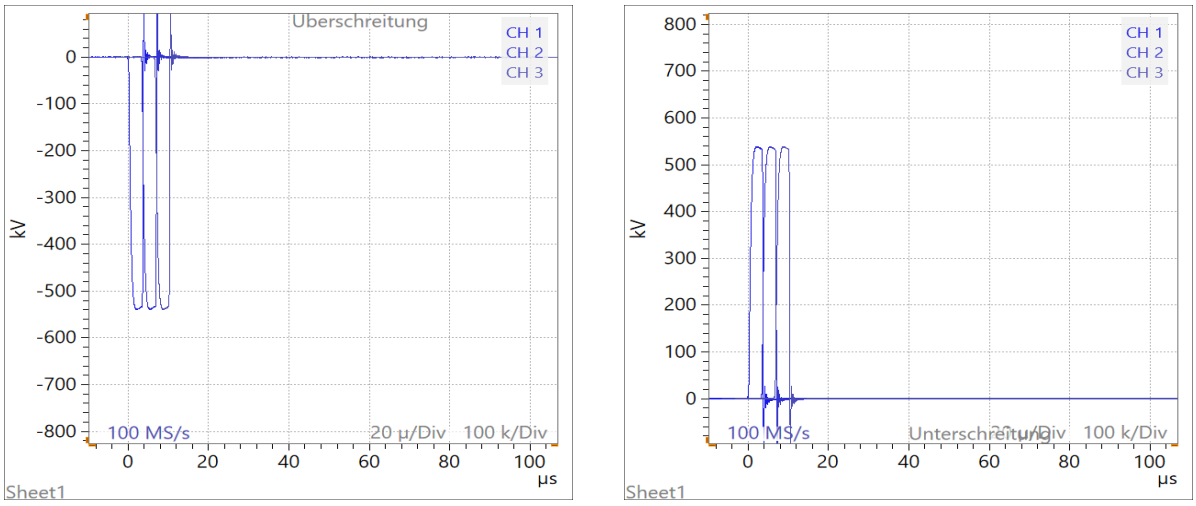


BLUE: Grounded
RED: 100% test voltage

Figure 34: Wirings and connections on the test sample.

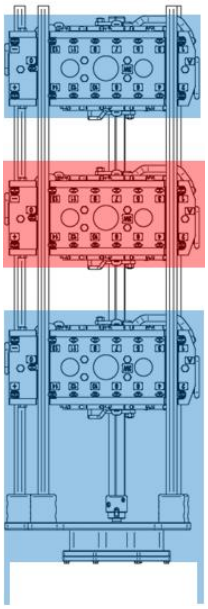
Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-539	-539.1	1.2	1.257	3	3.654	≤ 5	< 1
2		-539.1		1.258		3.683		< 1
3		-539.1		1.257		3.684		< 1
4	539	538.8		1.264		3.631		< 1
5		538.3		1.259		3.618		< 1
6		538.5		1.269		3.655		< 1

Table 15: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b2”.



Figures 35a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b2”.

7.2.5 Insulating distance “b3”

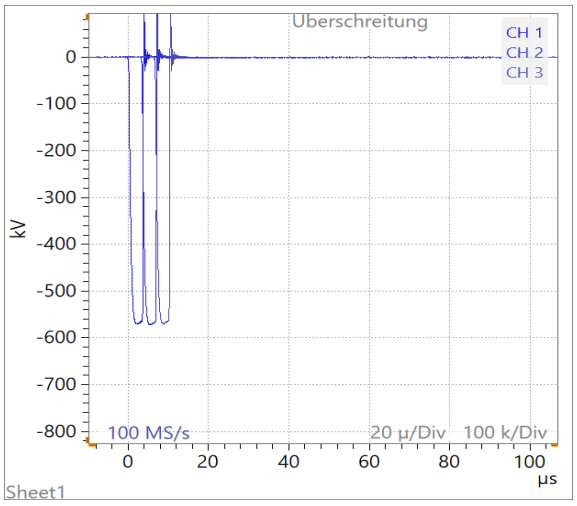


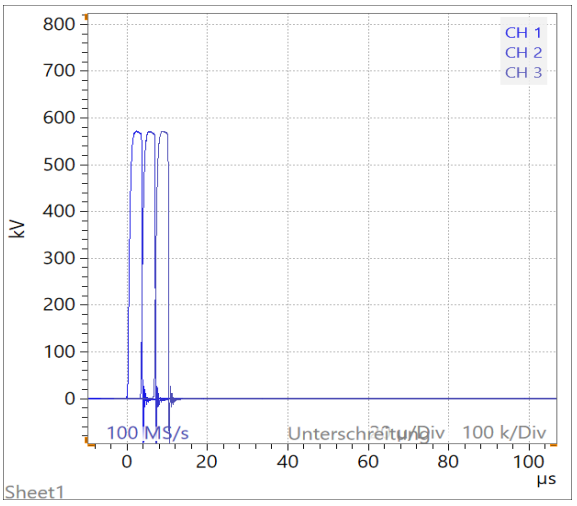
BLUE: Grounded
RED: 100% test voltage

Figure 36: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-572	-570.7	1.2	1.273	3	3.684	≤ 5	< 1
2		-572.3		1.271		3.687		< 1
3		-569.6		1.267		3.688		< 1
4	572	571.7		1.272		3.694		< 1
5		571.3		1.275		3.644		< 1
6		571.8		1.274		3.649		< 1

Table 16: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b3”.





Figures 37a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “b3”.

7.2.6 Insulating distance “a” (circuit 1)

BLUE: Grounded
RED: 100% test voltage

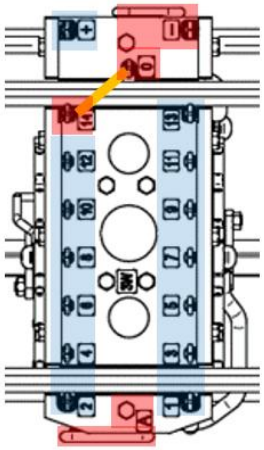
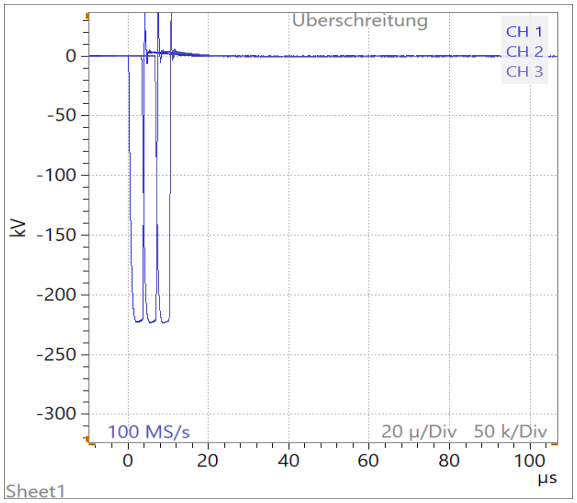
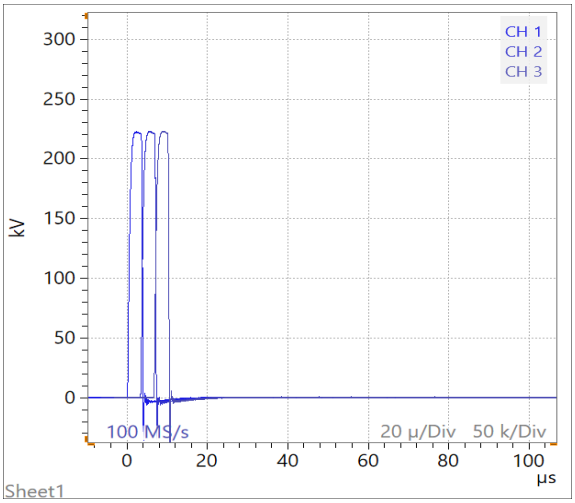


Figure 38: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-220	-222.9	1.2	1.294	3	3.769	≤ 5	< 1
2		-223.3		1.296		3.802		< 1
3		-223.4		1.289		3.782		< 1
4	220	222.5		1.293		3.751		< 1
5		222.8		1.286		3.752		< 1
6		223.0		1.289		3.717		< 1

Table 17: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a”.





Figures 39a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a”.

7.2.7 Insulating distance “a” (circuit 2)

BLUE: Grounded
RED: 100% test voltage

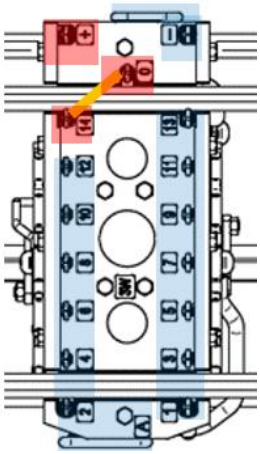
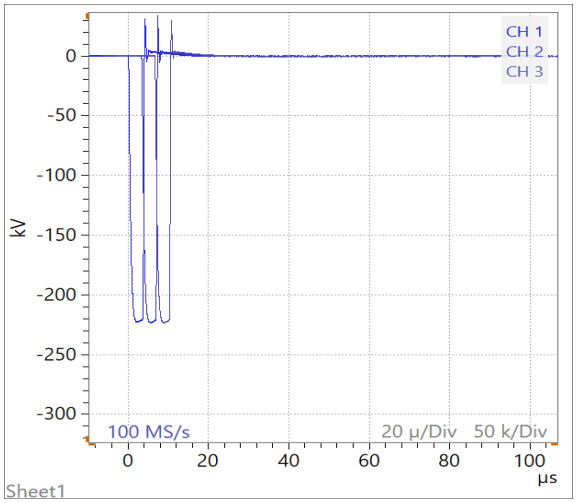
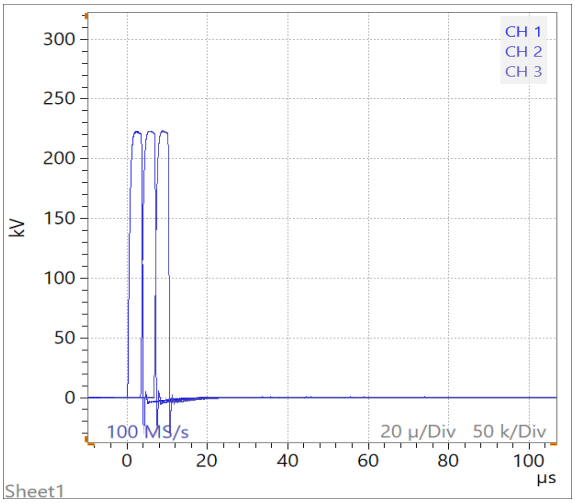


Figure 40: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-220	-222.8	1.2	1.278	3	3.799	≤ 5	< 1
2		-223.3		1.277		3.780		< 1
3		-223.4		1.276		3.787		< 1
4	220	222.6		1.276		3.720		< 1
5		223.1		1.273		3.718		< 1
6		223.1		1.277		3.748		< 1

Table 18: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a”.





Figures 41a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a”.

7.2.8 Insulating distance “a1”

BLUE: Grounded
RED: 100% test voltage

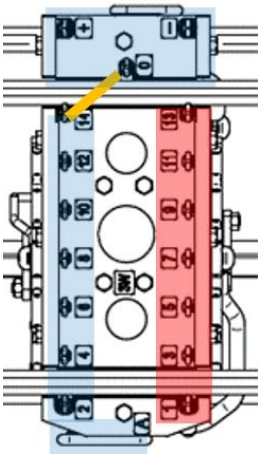
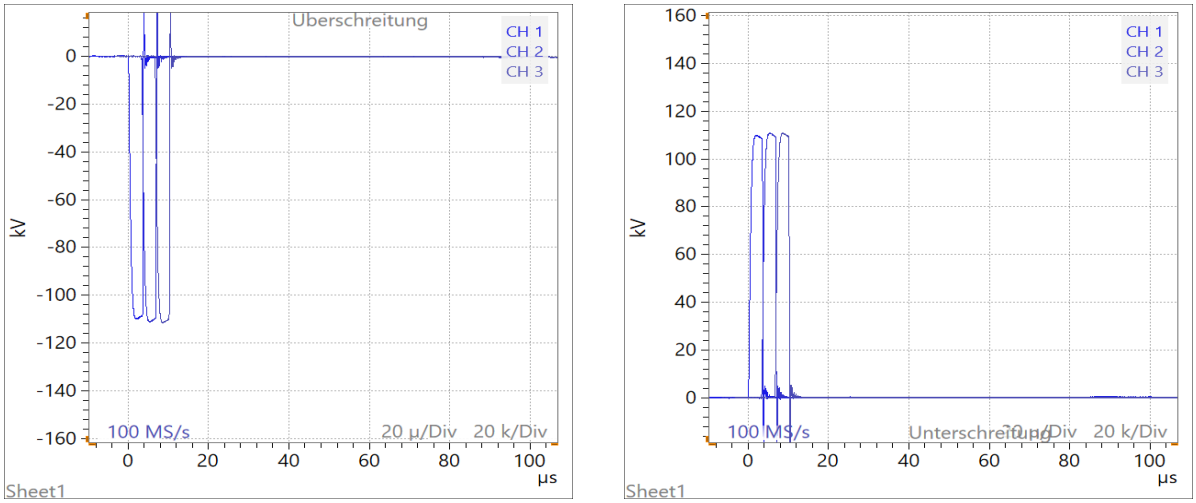


Figure 42: Wirings and connections on the test sample.

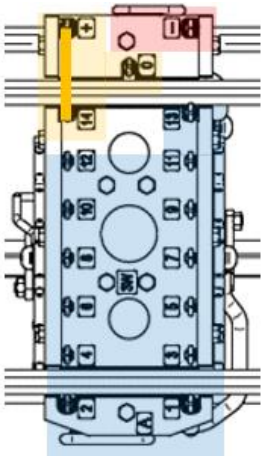
Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-110	-110.0	1.2	1.219	3	3.664	≤ 5	< 1
2		-111.1		1.219		3.653		< 1
3		-111.5		1.222		3.654		< 1
4	110	109.9		1.213		3.594		< 1
5		110.8		1.220		3.594		< 1
6		110.7		1.219		3.578		< 1

Table 19: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a1”.



Figures 43a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “a1”.

7.2.9 Insulating distance “c1”

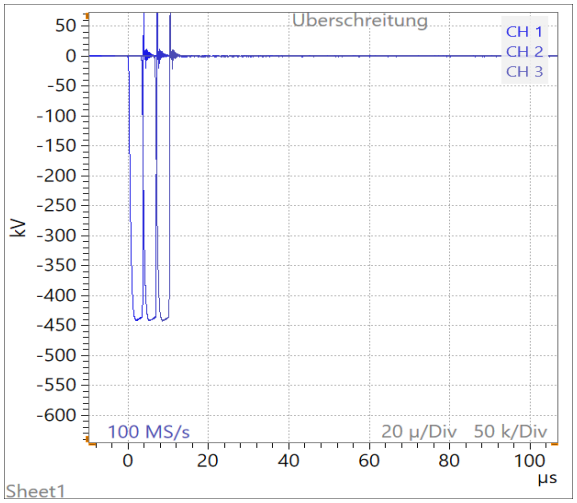


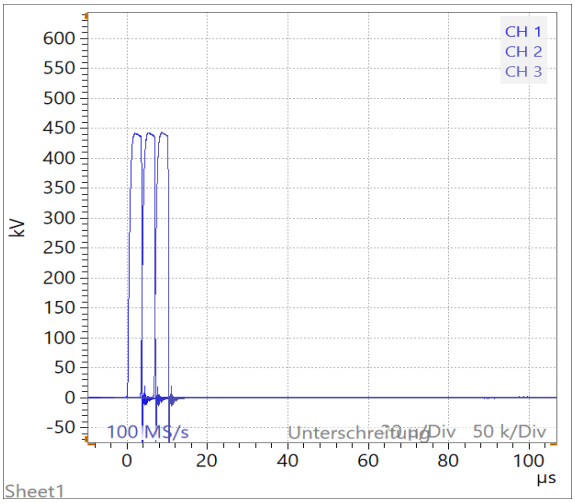
BLUE: Grounded
RED: 100% test voltage
YELLOW: 50% test voltage

Figure 44: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-440	-441.5	1.2	1.229	3	3.665	≤ 5	< 1
2		-442.0		1.229		3.653		< 1
3		-442.2		1.226		3.666		< 1
4	440	441.4		1.232		3.626		< 1
5		442.4		1.235		3.620		< 1
6		442.5		1.231		3.639		< 1

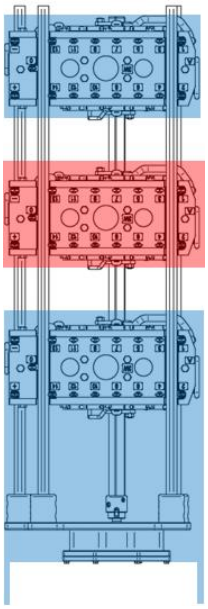
Table 20: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c1”.





Figures 45a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c1”.

7.2.10 Insulating distance “c21”

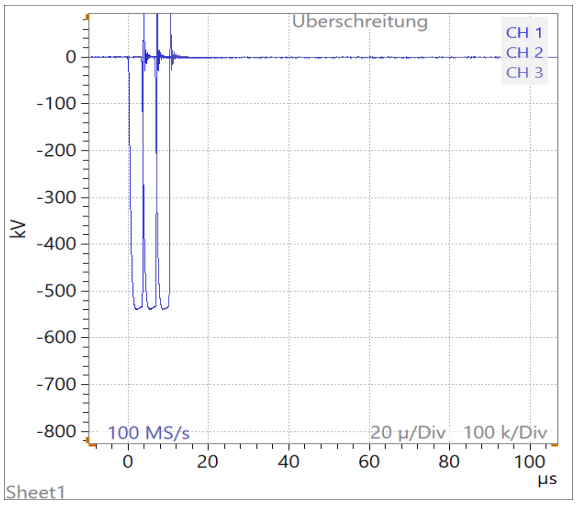


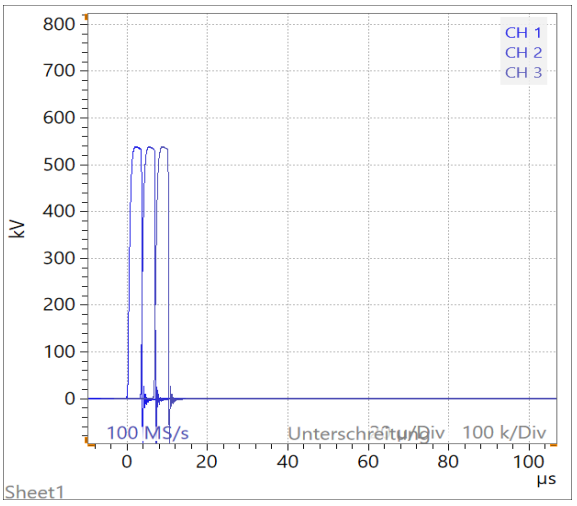
BLUE: Grounded
RED: 100% test voltage

Figure 46: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-539	-539.1	1.2	1.257	3	3.654	≤ 5	< 1
2		-539.1		1.258		3.683		< 1
3		-539.1		1.257		3.684		< 1
4	539	538.8		1.264		3.631		< 1
5		538.3		1.259		3.618		< 1
6		538.5		1.269		3.655		< 1

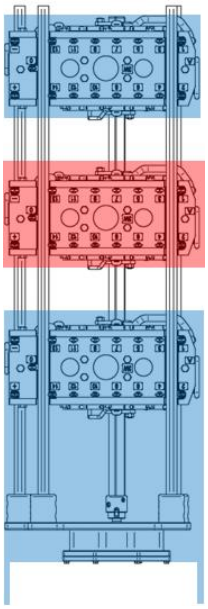
Table 21: Test results of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c21”.





Figures 47a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c21”.

7.2.11 Insulating distance “c22”

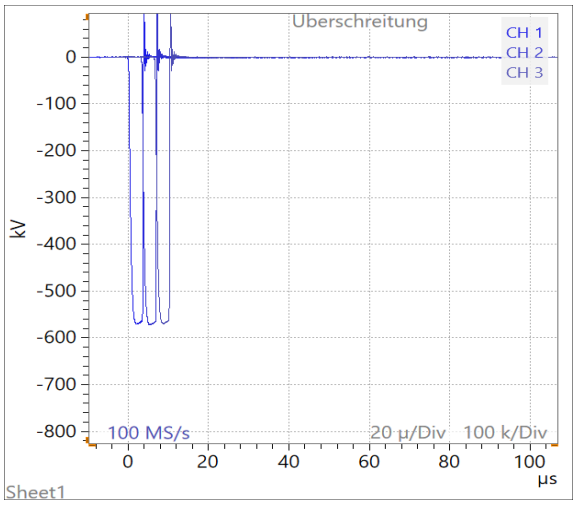


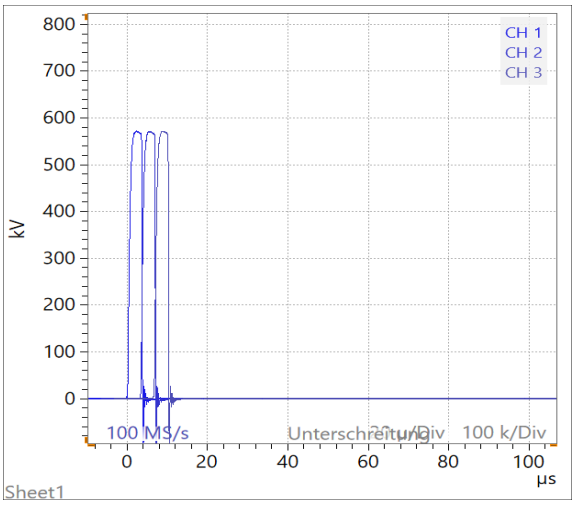
BLUE: Grounded
RED: 100% test voltage

Figure 48: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Front time T_1 in µs		Time to chopping T_C in µs		Overshoot ß’ in %	
	Nominal	Tested	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-572	-570.7	1.2	1.273	3	3.684	≤ 5	< 1
2		-572.3		1.271		3.687		< 1
3		-569.6		1.267		3.688		< 1
4	572	571.7		1.272		3.694		< 1
5		571.3		1.275		3.644		< 1
6		571.8		1.274		3.649		< 1

Table 22: Test results chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c22”.



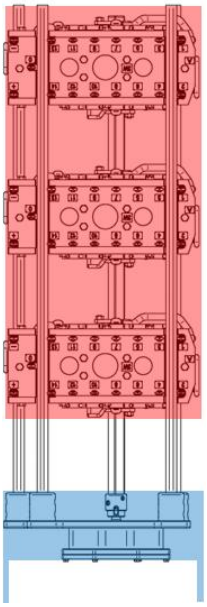


Figures 49a-b: Oscillograms of chopped wave lightning impulse test (1.2/50/3 µs) on insulating distance “c22”.

7.3 Switching impulse test (SI)

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8.7 IEEE C37-151-2024, sub-clause 5.2.8.7
Impulse voltage generator:	See chapter 6.3 (max. charging: 1800 kV)
Voltage waveform (T_P/T_2):	250 / 2500 µs
Number of applications:	Three applications with positive and three with negative polarity

7.3.1 Insulating distance “f1”

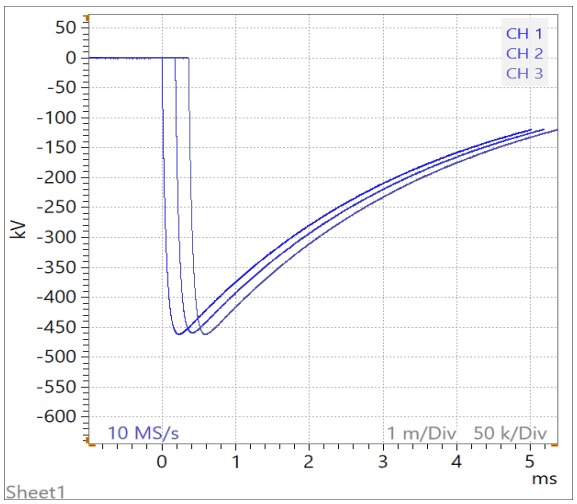


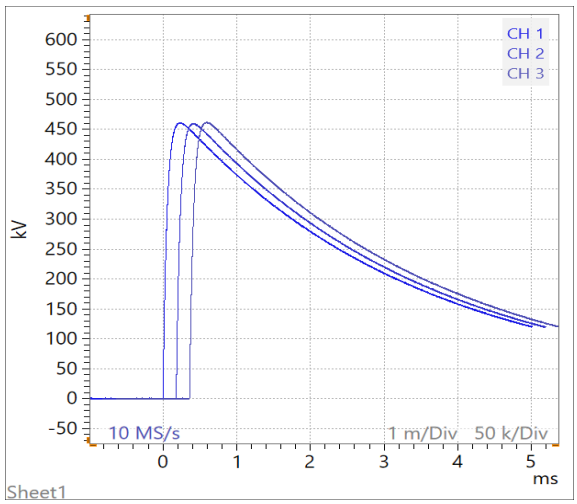
BLUE: Grounded
RED: 100% test voltage

Figure 50: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-460	-461.4	250	226.6	2500	2669
2		-458.9		226.6		2669
3		-461.6		226.7		2669
4	460	460.4		228.6		2670
5		459.0		228.4		2669
6		461.3		228.6		2670

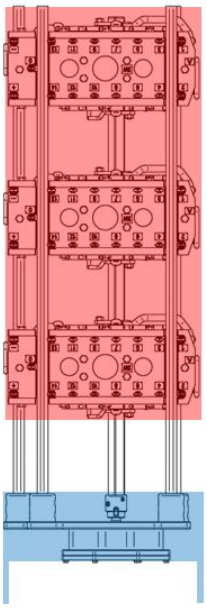
Table 23: Test results of switching impulse test (250/2500 µs) on insulating distance “f1”.





Figures 51a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “f2”.

7.3.2 Insulating distance “f2”

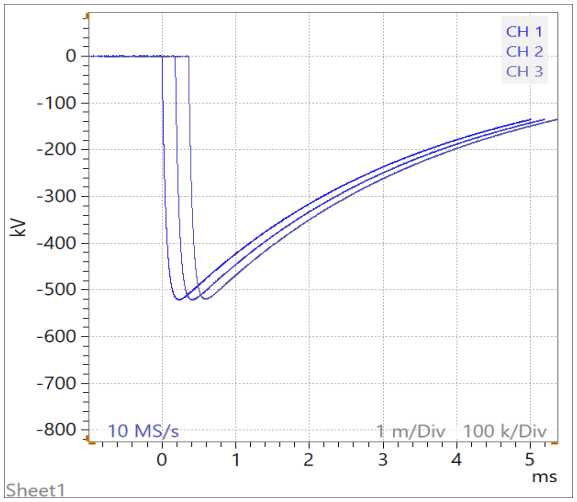


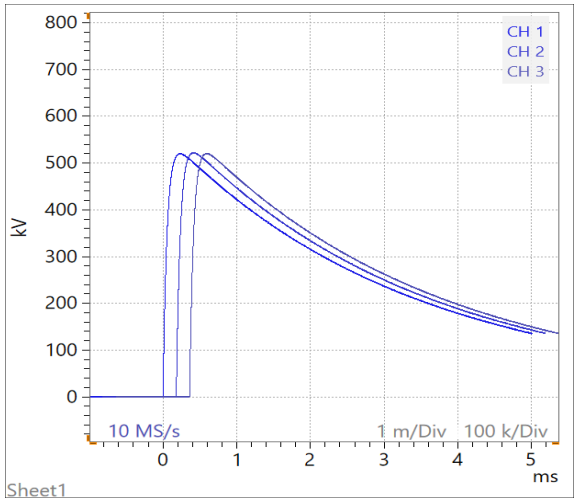
BLUE: Grounded
RED: 100% test voltage

Figure 52: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-520	-520.6	250	226.6	2500	2670
2		-520.6		226.6		2672
3		-519.3		226.5		2672
4	520	519.4		228.9		2674
5		521.5		229.0		2674
6		519.8		228.9		2675

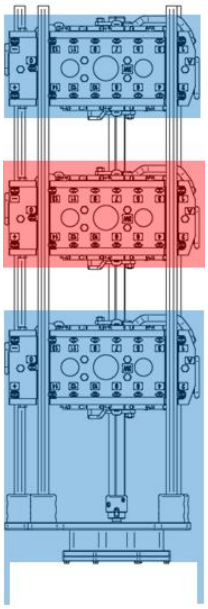
Table 24: Test results of switching impulse test (250/2500 µs) on insulating distance “f2”.





Figures 53a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “f2”.

7.3.3 Insulating distance “b1”

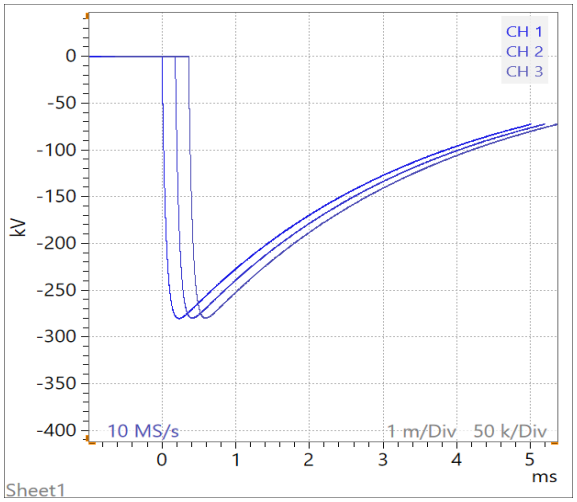


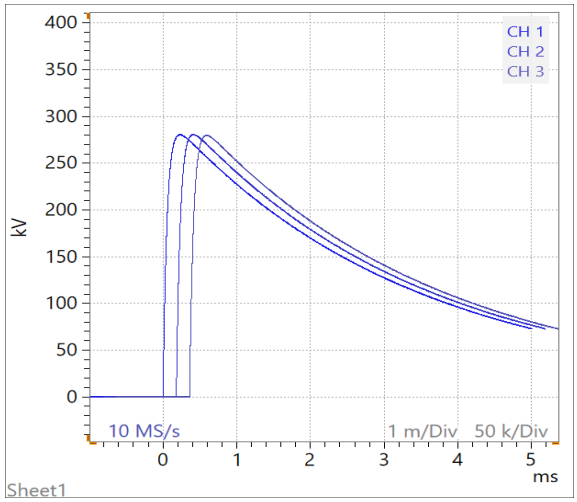
BLUE: Grounded
RED: 100% test voltage

Figure 54: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-280	-280.2	250	226.8	2500	2665
2		-279.9		226.9		2667
3		-279.8		226.7		2666
4	280	280.2		227.2		2667
5		280.3		227.5		2667
6		279.4		227.2		2668

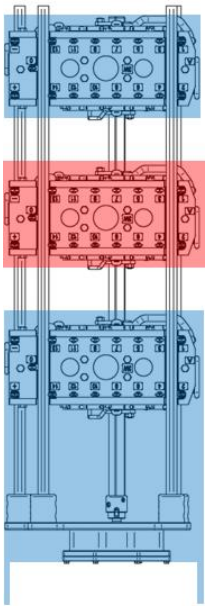
Table 25: Test results of switching impulse test (250/2500 µs) on insulating distance “b1”.





Figures 55a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “b1”.

7.3.4 Insulating distance “b2”

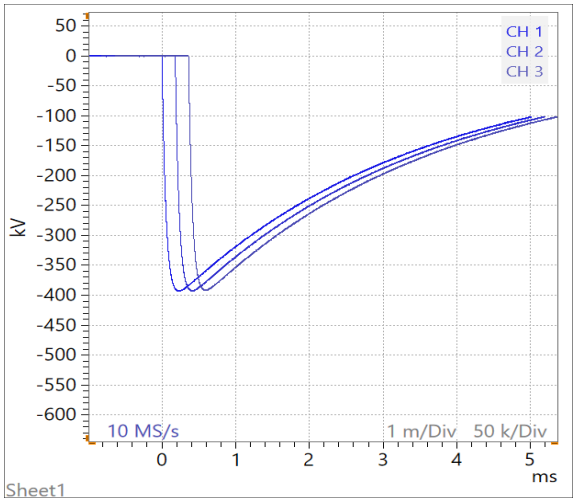


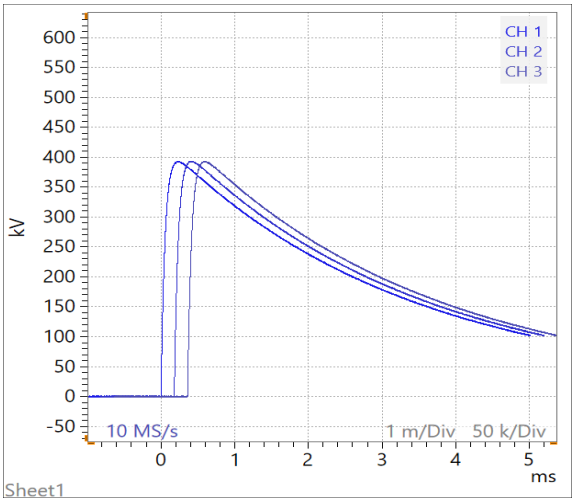
BLUE: Grounded
RED: 100% test voltage

Figure 56: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-392	-392.6	250	226.8	2500	2671
2		-392.2		226.9		2671
3		-391.4		226.9		2670
4	392	392.0		228.1		2671
5		392.5		228.3		2672
6		392.2		228.5		2670

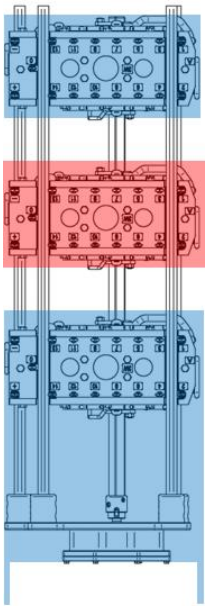
Table 26: Test results of switching impulse test (250/2500 µs) on insulating distance “b2”.





Figures 57a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “b2”.

7.3.5 Insulating distance “b3”

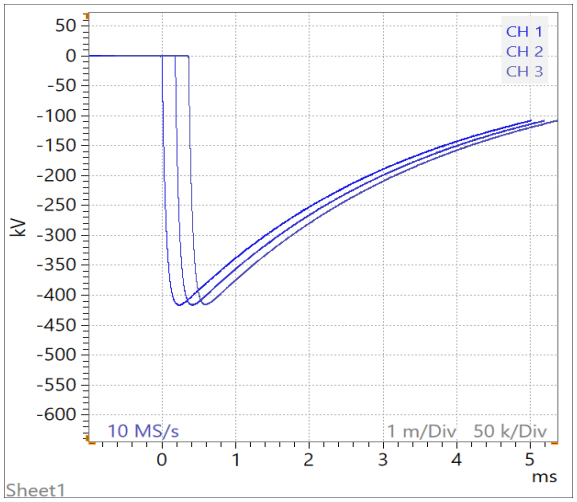


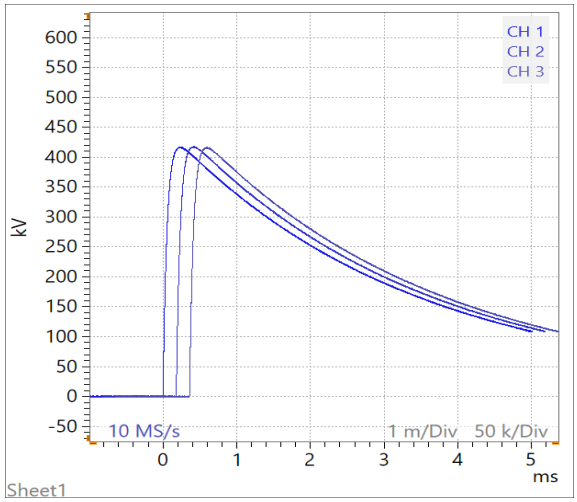
BLUE: Grounded
RED: 100% test voltage

Figure 58: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-416	-416.1	250	227.0	2500	2670
2		-416.1		227.1		2670
3		-415.2		227.0		2670
4	416	416.0		228.6		2672
5		416.9		228.5		2672
6		415.4		228.5		2671

Table 27: Test results of switching impulse test (250/2500 µs) on insulating distance “b3”.





Figures 59a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance distance “b3”.

7.3.6 Insulating distance “a” (circuit 1)

BLUE: Connected contacts
RED: 100% test voltage

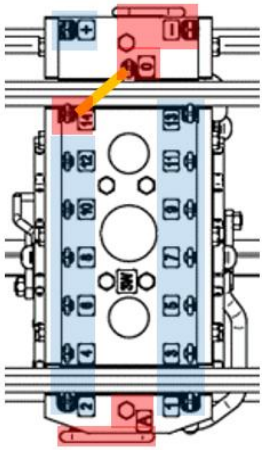
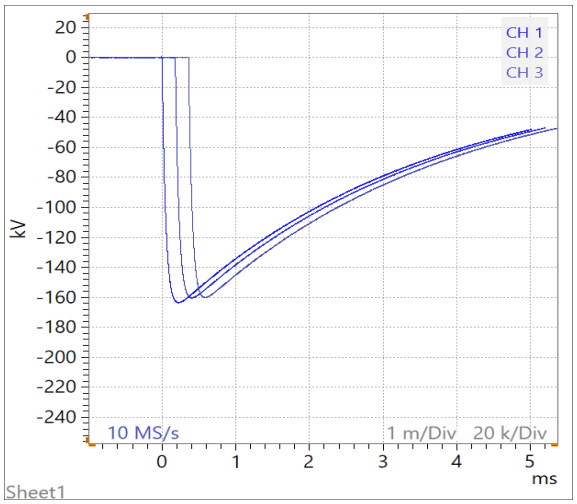
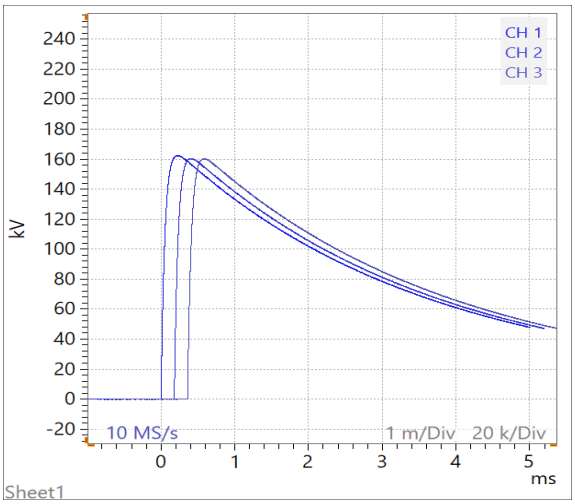


Figure 60: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-160	-163.4	250	220.8	2500	2873
2		-160.3		221.0		2874
3		-160.1		221.1		2873
4	160	162.1		221.2		2873
5		160.2		221.0		2872
6		160.1		221.2		2871

Table 28: Test results of switching impulse test (250/2500 µs) on insulating distance “a”.





Figures 61a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “a”.

7.3.7 Insulating distance “a” (circuit 2)

BLUE: Grounded
RED: 100% test voltage

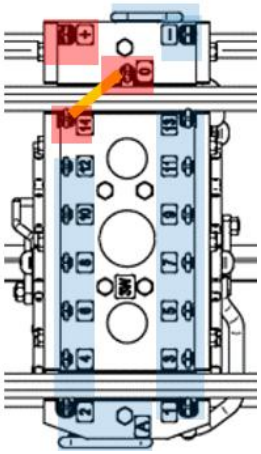
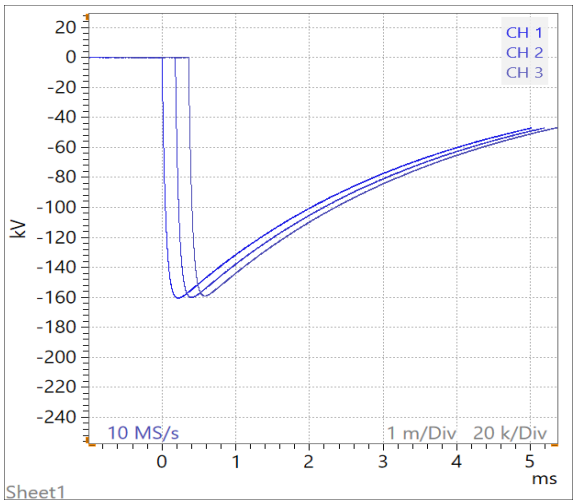
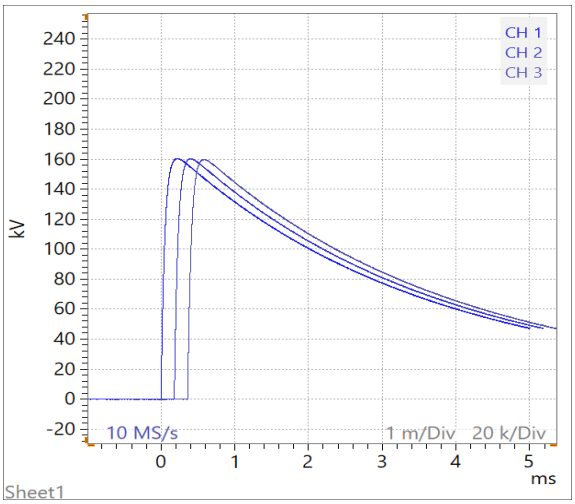


Figure 62: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-160	-160.4	250	217.0	2500	2867
2		-160.0		217.3		2866
3		-159.1		217.0		2867
4	160	160.2		217.1		2866
5		160.1		217.3		2865
6		159.6		217.2		2866

Table 29: Test results of switching impulse test (250/2500 µs) on insulating distance “a”.





Figures 63a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “a”.

7.3.8 Insulating distance “a1”

BLUE: Connected contacts
RED: 100% test voltage

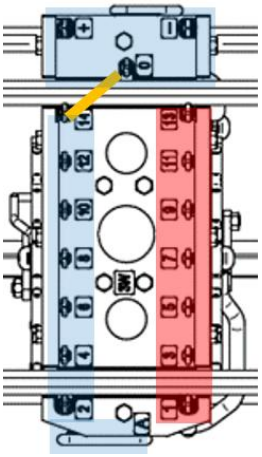
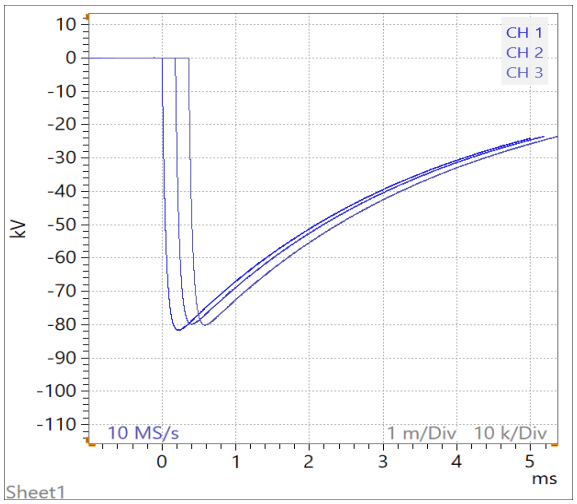
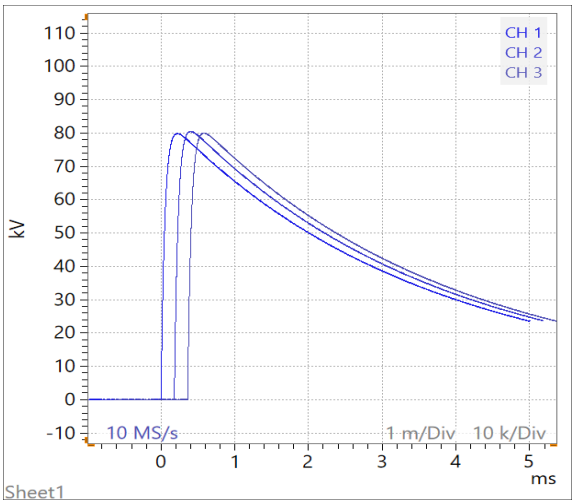


Figure 64: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-80	-81.62	250	218.8	2500	2870
2		-79.77		218.8		2871
3		-80.07		218.6		2872
4	80	79.77		218.6		2873
5		80.41		219.4		2871
6		79.96		219.6		2870

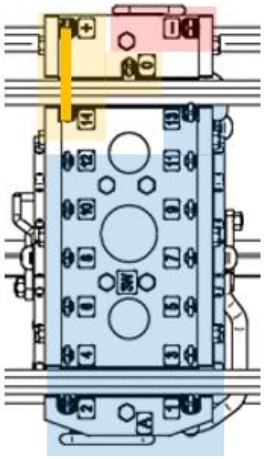
Table 30: Test results of switching impulse test (250/2500 µs) on insulating distance “a1”.





Figures 65a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “a1”.

7.3.9 Insulating distance “c1”

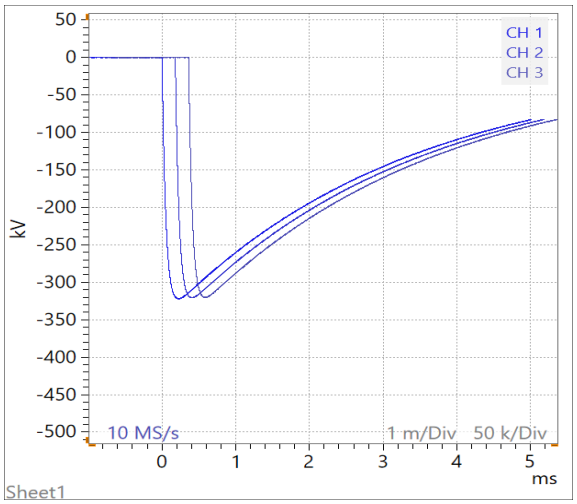


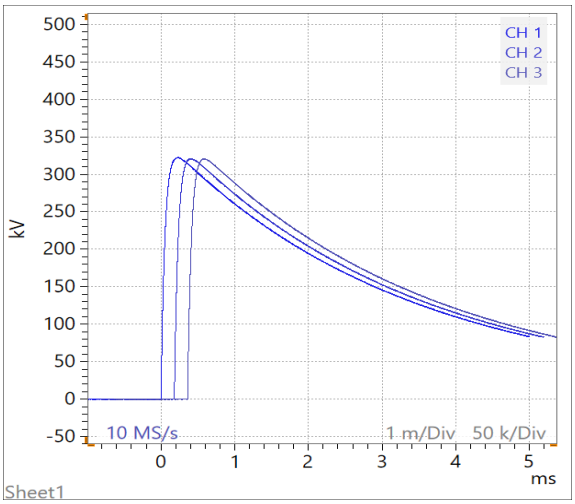
BLUE: Grounded
RED: 100% test voltage
YELLOW: 50% test voltage

Figure 66: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-320	-321.8	250	220.0	2500	2652
2		-320.4		220.0		2652
3		-320.1		219.8		2652
4	320	321.9		221.1		2652
5		320.4		220.8		2653
6		320.2		221.3		2652

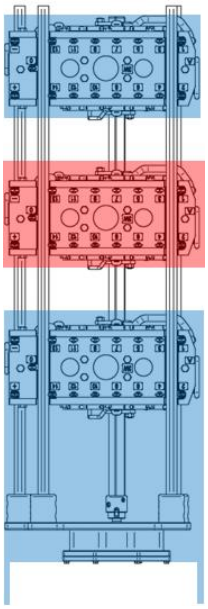
Table 31: Test results of switching impulse test (250/2500 µs) on insulating distance “c1”.





Figures 67a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “c1”.

7.3.10 Insulating distance “c21”

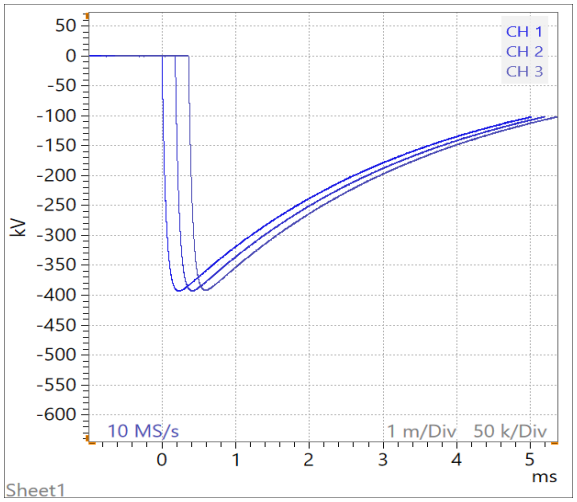


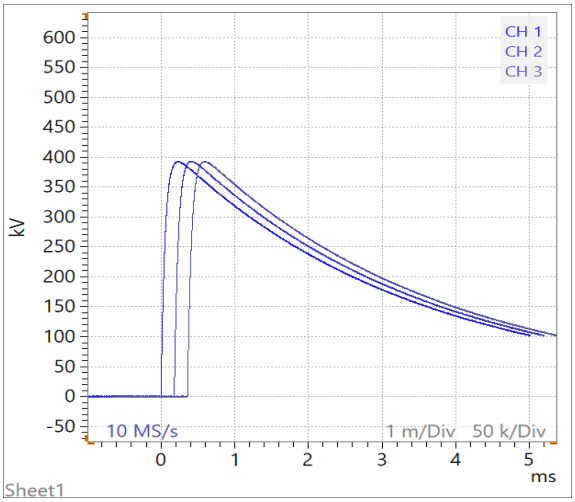
BLUE: Grounded
RED: 100% test voltage

Figure 68: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-392	-392.6	250	226.8	2500	2671
2		-392.2		226.9		2671
3		-391.4		226.9		2670
4	392	392.0		228.1		2671
5		392.5		228.3		2672
6		392.2		228.5		2670

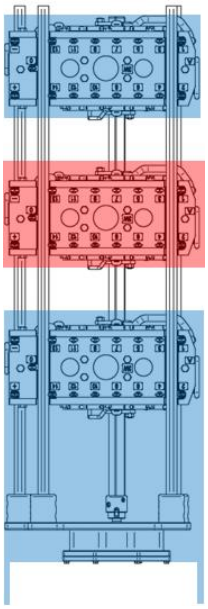
Table 32: Test results of switching impulse test (250/2500 µs) on insulating distance “c21”.





Figures 69a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “c21”.

7.3.11 Insulating distance “c22”

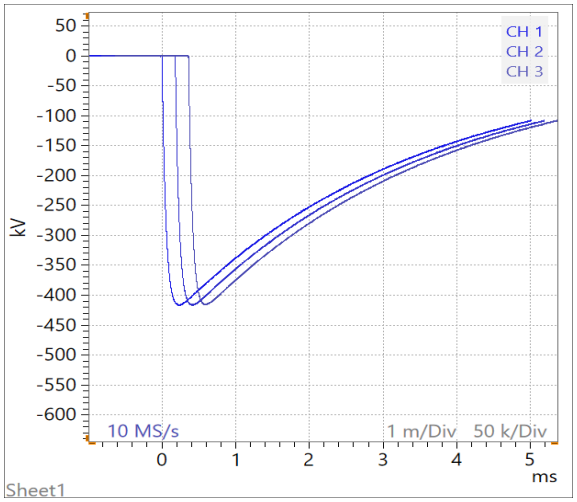


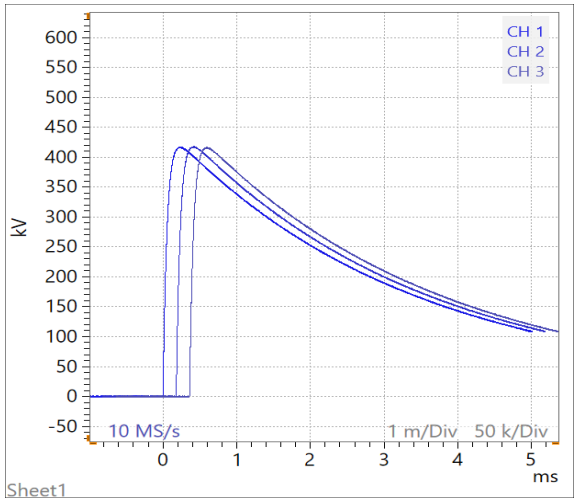
BLUE: Grounded
RED: 100% test voltage

Figure 70: Wirings and connections on the test sample.

Test no.	Peak amplitude U_p in kV		Time to peak T_P in µs		Time to half-value T_2 in µs	
	Nominal	Tested	Nominal	Tested	Nominal	Tested
1	-416	-416.1	250	227.0	2500	2670
2		-416.1		227.1		2670
3		-415.2		227.0		2670
4	416	416.0		228.6		2672
5		416.9		228.5		2672
6		415.4		228.5		2671

Table 33: Test results switching impulse test (250/2500 µs) on insulating distance “c22”.



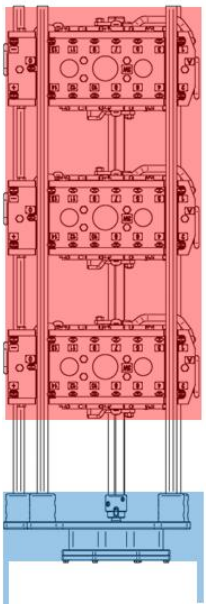


Figures 71a-b: Oscillograms of switching impulse test (250/2500 µs) on insulating distance “c22”.

7.4 Applied voltage test (AV)

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8.8 IEEE C57.131-2024, sub-clause 5.2.8.8
Voltage generator:	See chapter 6.2 (max. voltage: 700 kV)
Voltage waveform:	Sine-shaped (frequency: 50 Hz)
Test duration (t_D):	60 s

7.4.1 Insulating distance “f1”



BLUE: Connected contacts
RED: 100% test voltage

Figure 72: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
230	230.0	> 60	71.0

Table 34: Test results of applied voltage test (50 Hz) on insulating distance “f1”.

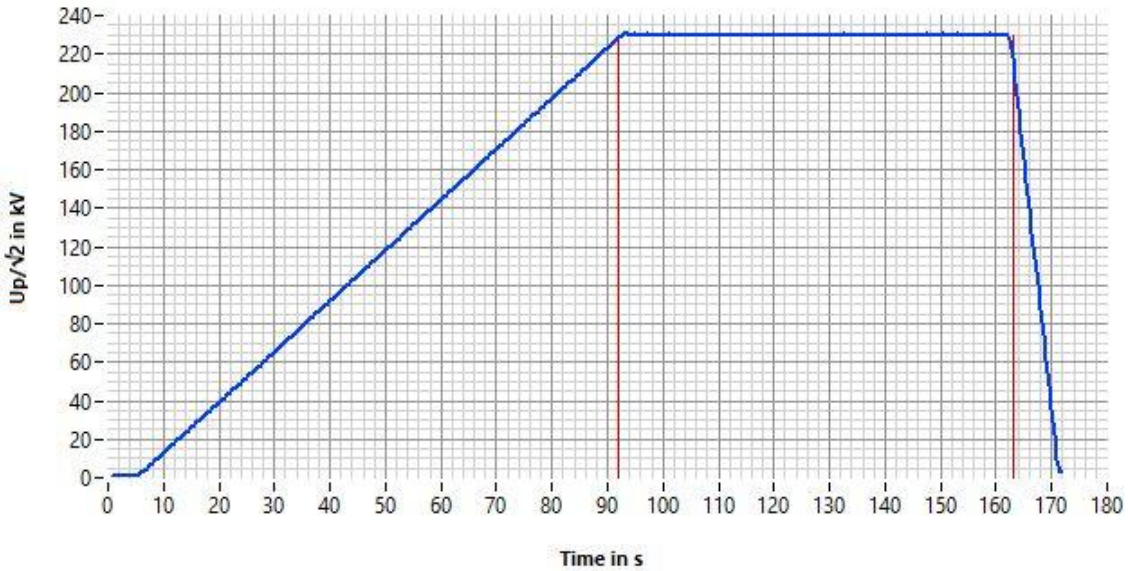
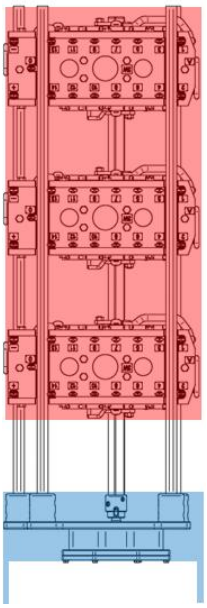


Figure 73: Oscillogram of applied voltage test (50 Hz) on insulating distance “f1”.

7.4.2 Insulating distance “f2”



BLUE: Grounded
RED: 100% test voltage

Figure 74: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
275	274.9	> 60	70.5

Table 35: Test results of applied voltage test (50 Hz) on insulating distance “f2”.

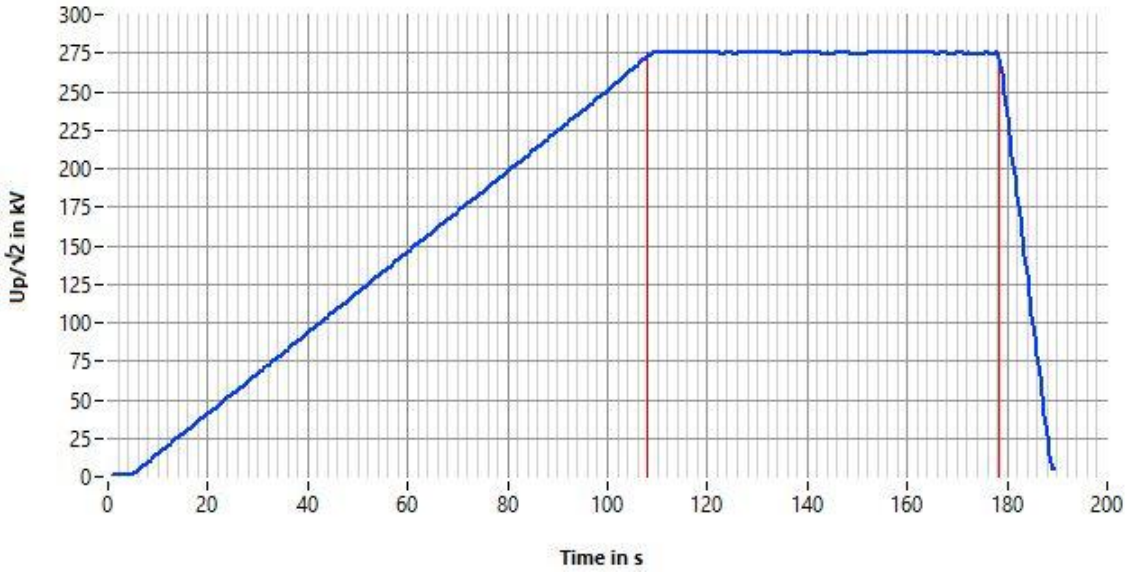
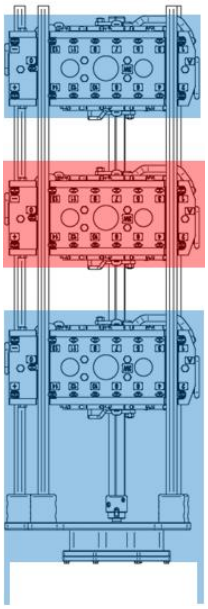


Figure 75: Oscillogram of applied voltage test (50 Hz) on insulating distance “f2”.

7.4.3 Insulating distance “b1”



BLUE: Grounded
RED: 100% test voltage

Figure 76: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
140	140.4	> 60	69.5

Table 36: Test results of applied voltage test (50 Hz) on insulating distance “b1”.

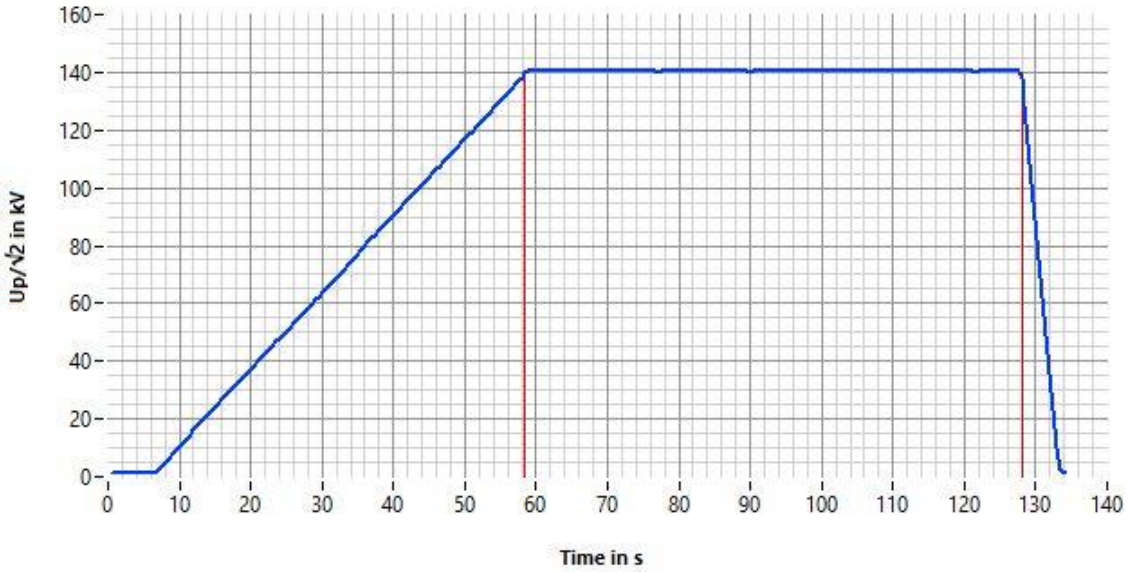
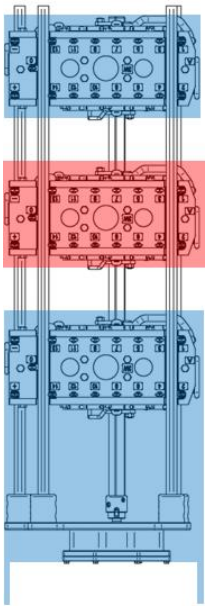


Figure 77: Oscillogram of applied voltage test (50 Hz) on insulating distance “b1”.

7.4.4 Insulating distance “b2”



BLUE: Grounded
RED: 100% test voltage

Figure 78: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
165	165.2	> 60	71.0

Table 37: Test results of applied voltage test (50 Hz) on insulating distance “b2.

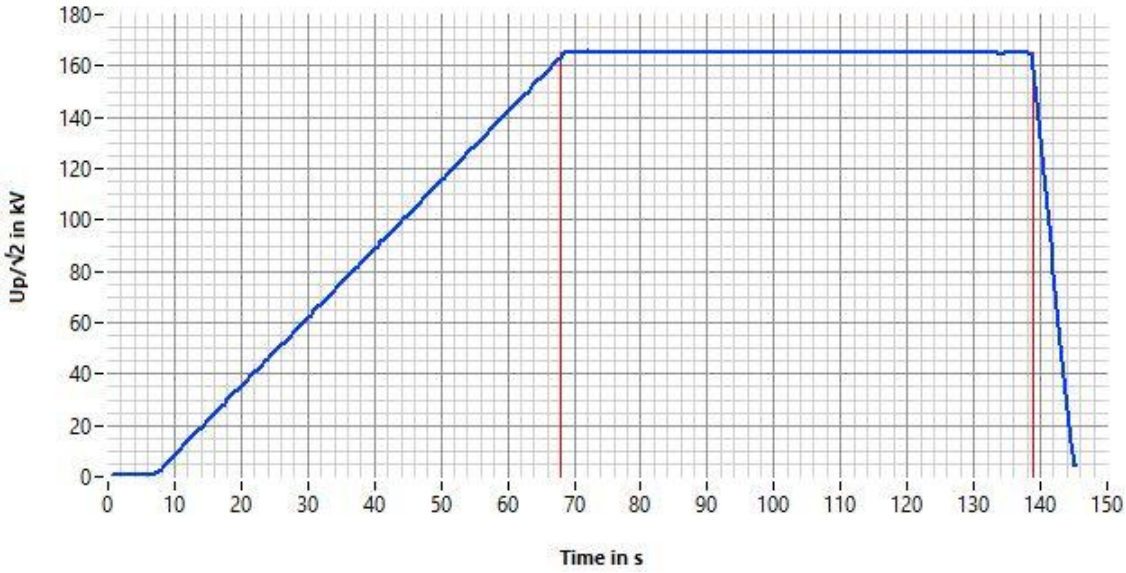
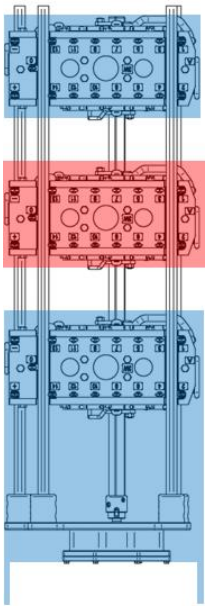


Figure 79: Oscillogram of applied voltage test (50 Hz) on insulating distance “b2”.

7.4.5 Insulating distance “b3”



BLUE: Grounded
RED: 100% test voltage

Figure 80: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
180	180.5	> 60	71.0

Table 38: Test results of applied voltage test (50 Hz) on insulating distance “b3”.

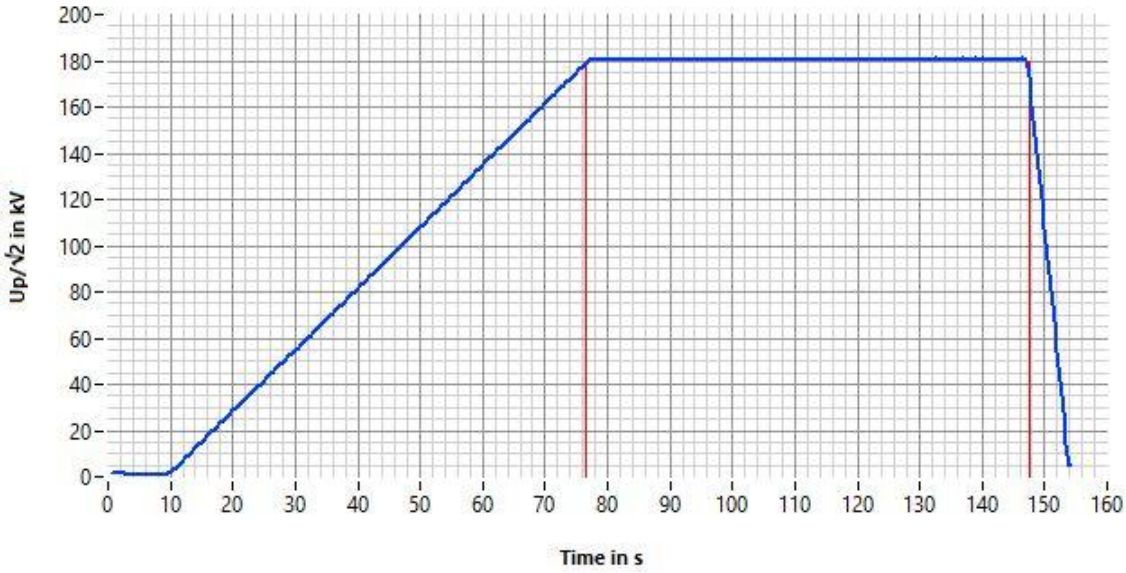


Figure 81: Oscillogram of applied voltage test (50 Hz) on insulating distance “b3”.

7.4.6 Insulating distance “a” (circuit 1)

BLUE: Grounded
RED: 100% test voltage

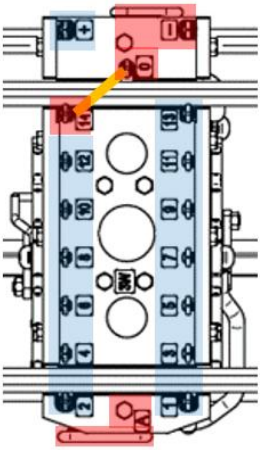


Figure 82: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
50	50.2	> 60	70.5

Table 39: Test results of applied voltage test (50 Hz) on insulating distance “a”.

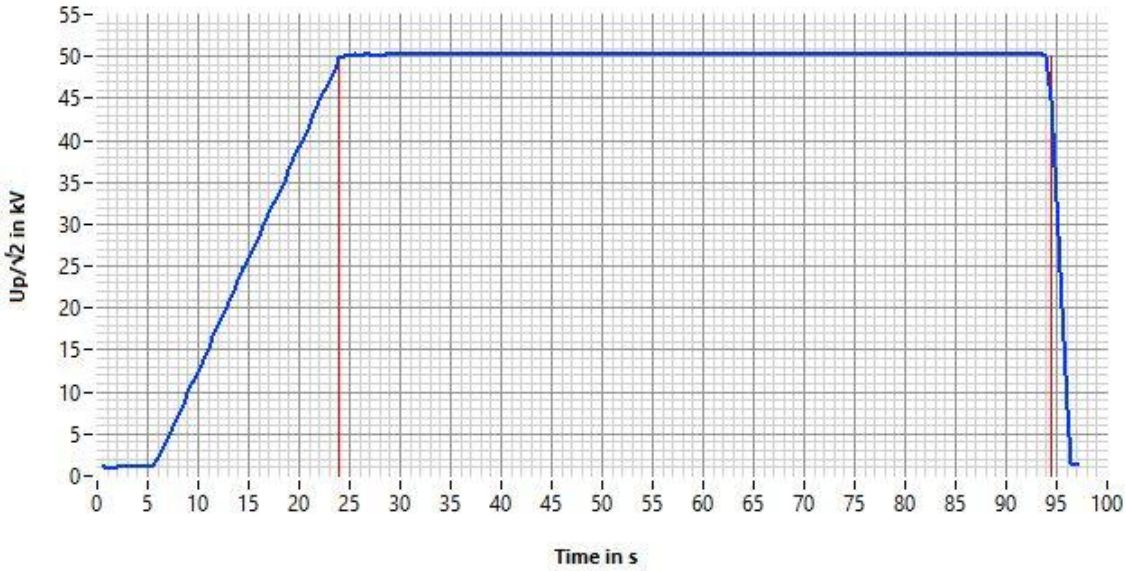


Figure 83: Oscillogram of applied voltage test (50 Hz) on insulating distance “a”.

7.4.7 Insulating distance “a” (circuit 2)

BLUE: Grounded
RED: 100% test voltage

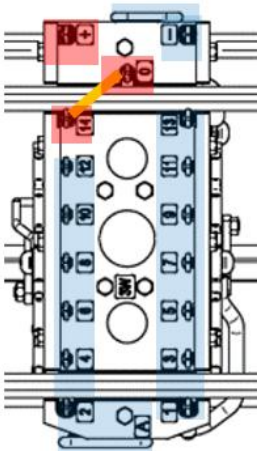


Figure 84: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
50	50.0	> 60	69.0

Table 40 Test results of applied voltage test (50 Hz) on insulating distance “a”.

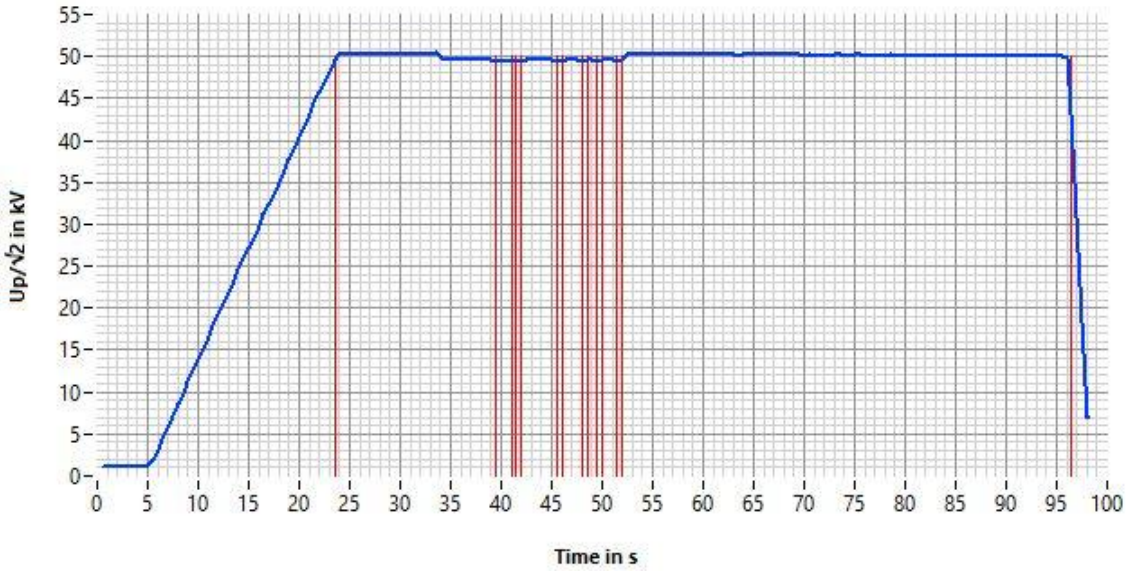


Figure 85: Oscillogram of applied voltage test (50 Hz) on insulating distance “a”.

7.4.8 Insulating distance “a1”

BLUE: Connected contacts
RED: 100% test voltage

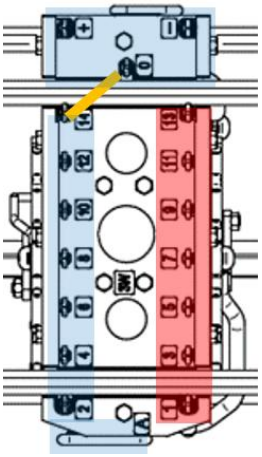


Figure 86: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
20	19.9	> 60	61.2

Table 41: Test results of applied voltage test (50 Hz) on insulating distance “a1”.

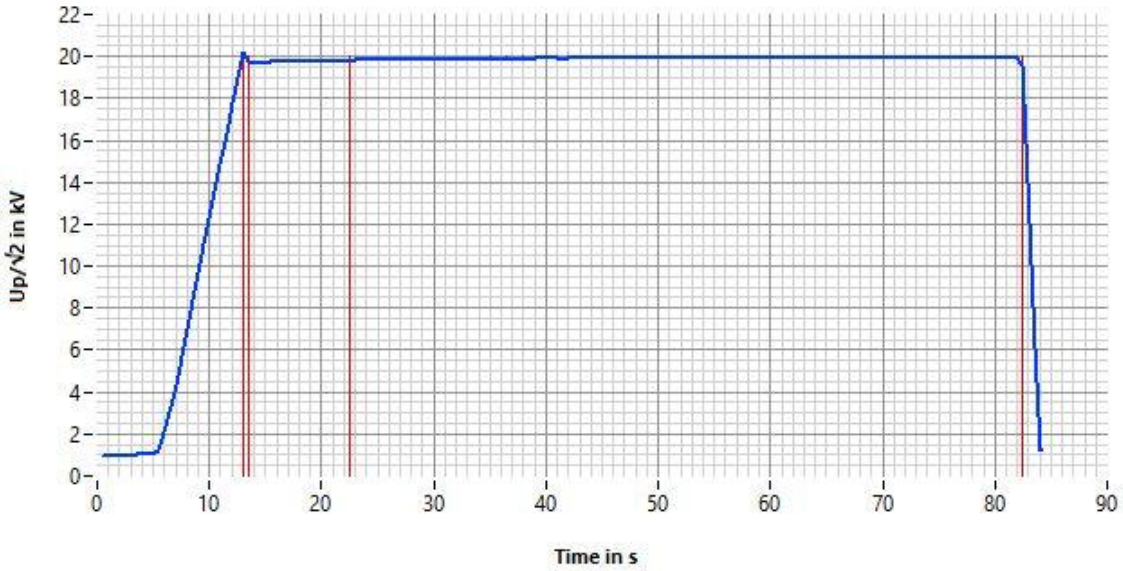
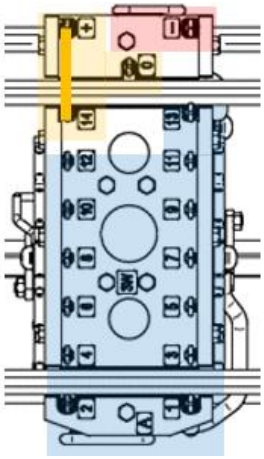


Figure 87: Oscillogram of applied voltage test (50 Hz) on insulating distance “a1”.

7.4.9 Insulating distance “c1”



BLUE: Connected contacts
RED: 100% test voltage
YELLOW: 50% test voltage

Figure 88: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
100	100.2	> 60	70.5

Table 42: Test results of applied voltage test (50 Hz) on insulating distance “c1”.

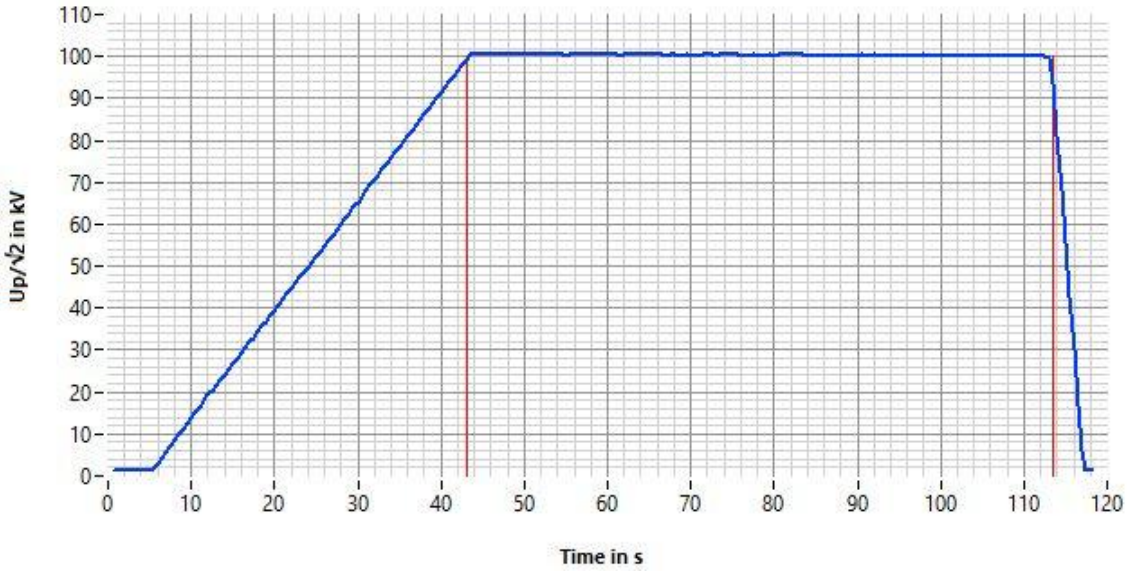
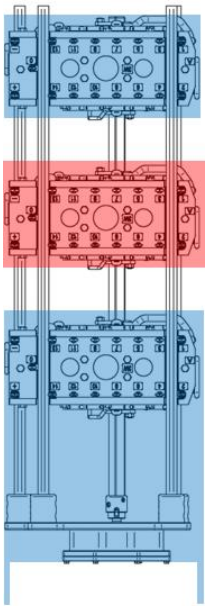


Figure 89: Oscillogram of applied voltage test (50 Hz) on insulating distance “c1”.

7.4.10 Insulating distance “c21”



BLUE: Grounded
RED: 100% test voltage

Figure 90: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
165	165.2	> 60	71.0

Table 43: Test results of applied voltage test (50 Hz) on insulating distance “b2.

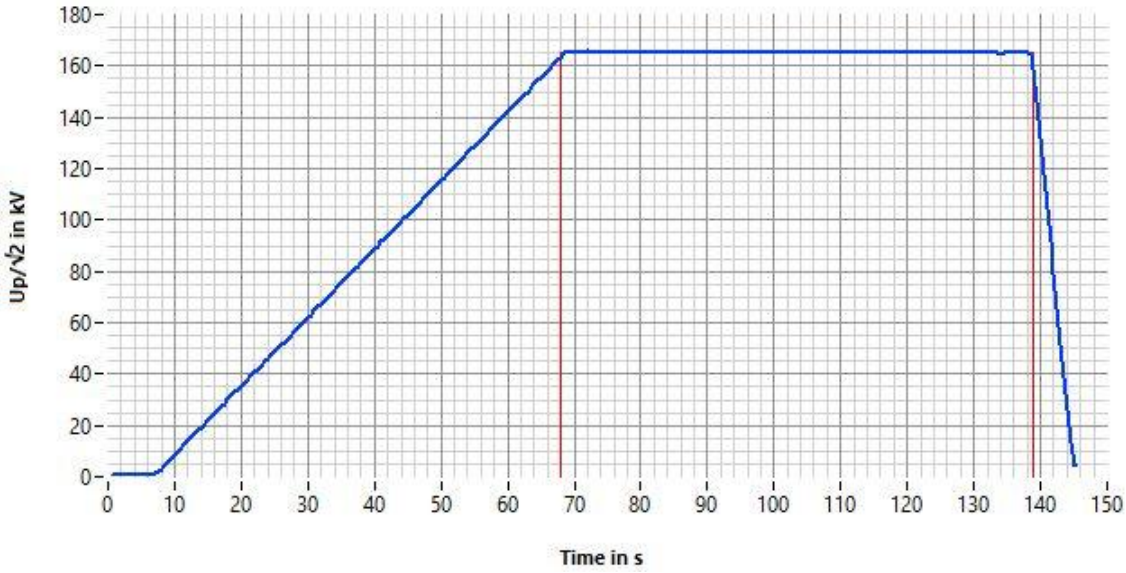
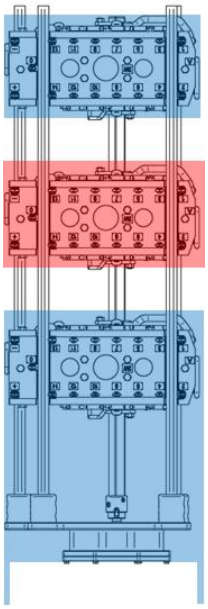


Figure 91: Oscillogram of applied voltage test (50 Hz) on insulating distance “c21”.

7.4.11 Insulating distance “c22”



BLUE: Grounded
RED: 100% test voltage

Figure 92: Wirings and connections on the test sample.

Applied voltage (50 Hz) (U_P / √2) in kV		Test duration in s	
Nominal	Tested	Nominal	Tested
180	180.5	> 60	71.0

Table 44: Test results of applied voltage test (50 Hz) on insulating distance “b3”.

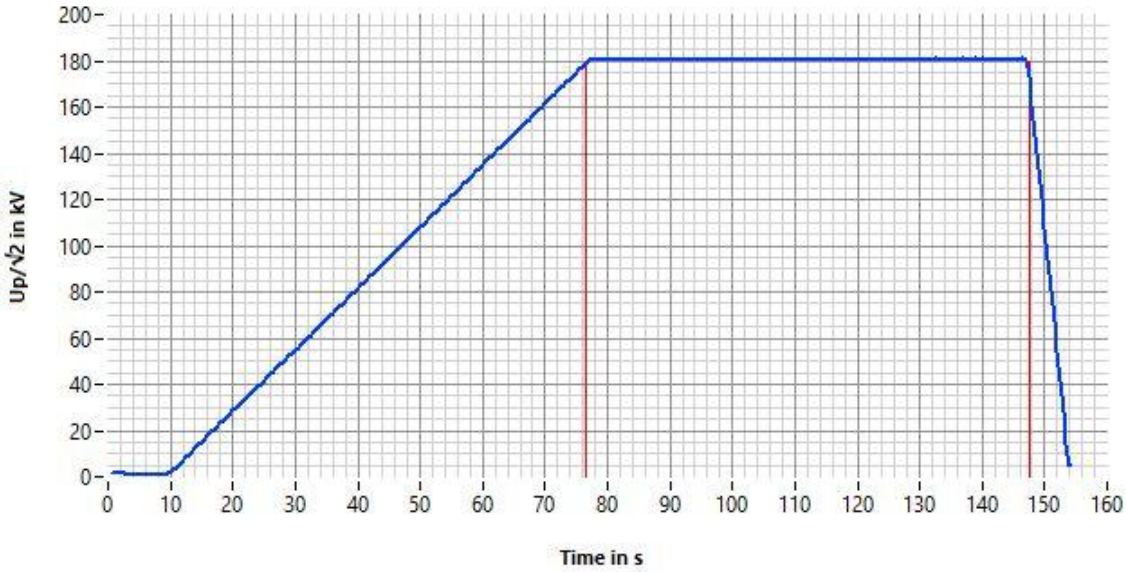


Figure 93: Oscillogram of applied voltage test (50 Hz) on insulating distance “c22”.

7.5 Measurement of partial discharges (PD)

Test standards:	IEC 60214-1:2014, sub-clause 5.2.8.9 IEEE C57.131-2024, sub-clause 5.2.8.9
Voltage generator:	See chapter 6.4 (max. voltage: 700 kV)
Voltage waveform:	Sine-shaped (frequency: 50 Hz)

7.5.1 Insulating distance “f”

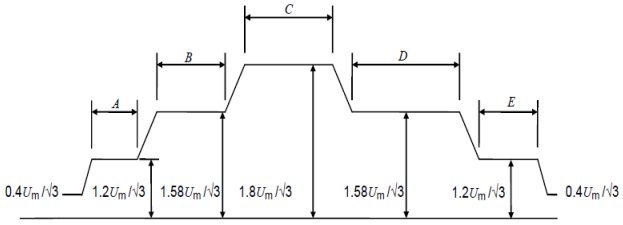
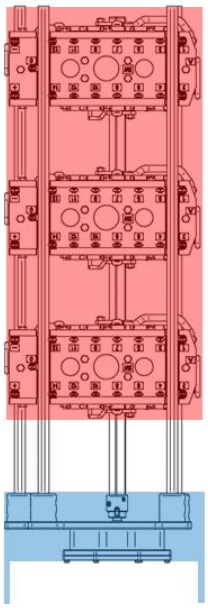


Figure 94: Test procedure for insulation distance “f” to earth.



BLUE: Grounded
RED: 100% test voltage

Figure 95: Wirings and connections of test sample.

Test step (see fig. 103)	Duration t_D in s		Test voltage (U_P / √2) in kV	
	Nominal	Tested	Nominal	Tested
(U_{start})	-	38	28.4	28.5
A	60	74	85.2	85.5
B	300	315	112.2	112.4
C	60	71	127.8	128.3
D	3600	3643	112.2	112.0
E	60	72	85.2	84.8
(U_{stop})	-	36	28.4	28.6

Table 45: Nominal and tested voltages and durations for insulation distance “f” to earth.

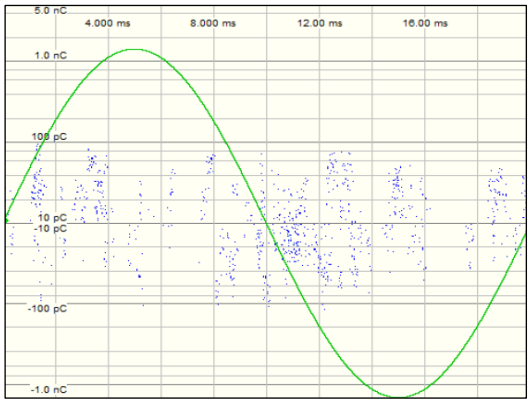


Figure 96: Measurement of partial discharges at insulation distance “f” to earth.

Tested insulation distance	PD background level in pC			PD at 1.58 U_m / √3 during 60 min in pC		PD at 1.2 U_m / √3 during 1 min in pC	
	Nominal	Maximum at begin of PD measurement	Maximum at end of PD measurement	Nominal	Tested	Nominal	Tested
f	< 10	< 10	< 10	< 50	< 10	< 30	< 10

Table 46: Partial discharge test at insulation distance „f” to earth.

7.5.2 Insulating distance “b”

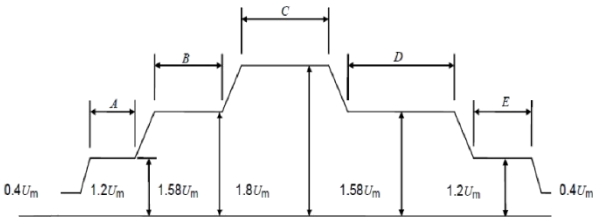
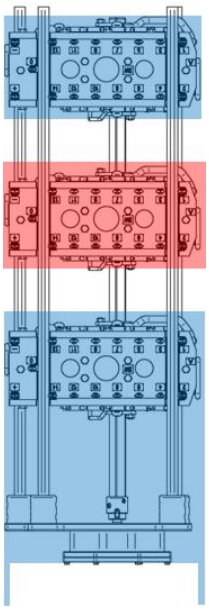


Figure 97: Test procedure for insulation distance “b” between phases.



BLUE: Grounded
RED: 100% test voltage

Figure 98: Wirings and connections on test sample.

Test step (see fig. 106)	Duration t_D in s		Test voltage (U_P / √2) in kV	
	Nominal	Tested	Nominal	Tested
(U_{start})	-	38	30.4	30.3
A	60	74	91.2	91.6
B	300	314	120.1	120.4
C	60	71	136.8	137.2
D	3600	3623	120.1	120.1
E	60	72	91.2	91.4
(U_{stop})	-	36	30.4	30.5

Table 47: Nominal and tested voltages and durations for insulation distance “b” between phases.

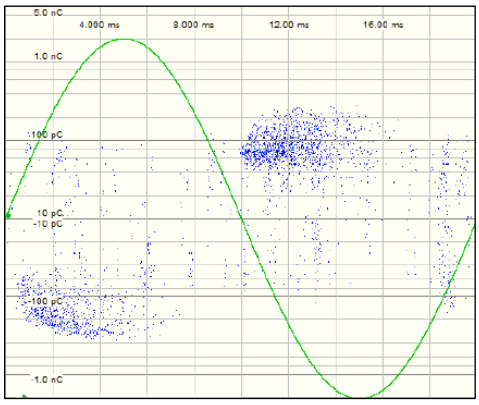


Figure 99: Measurement of partial discharges at insulation distance “b” between phases.

Tested insulation distance	PD background level in pC			PD at 1.58 U_m / √3 during 60 min in pC		PD at 1.2 U_m / √3 during 1 min in pC	
	Nominal	Maximum at begin of PD measurement	Maximum at end of PD measurement	Nominal	Tested	Nominal	Tested
b	< 10	< 10	< 10	< 50	< 10	< 30	< 10

Table 48: Partial discharge test at insulation distance „b” between phases.

8. Test results

The requirements of IEC 60214-1:2014 “Tap-changers - Part 1: Performance requirements and test methods”, sub-clause 5.2.8 “Dielectric tests” and IEEE C57.131-2024, sub-clause 5.2.8 “Dielectric tests for LTCs” were met.

The full wave lightning impulse voltage tests (LI), the chopped wave lightning impulse tests (LIC), the switching impulse tests (SI) as well as the applied voltage tests (AV) were withstood without any disruptive discharge. The confirmed values are shown in table 49.

Tested insulating distance (Symbol see figs. 1 - 3)	Full wave lightning impulse test (LI) 1.2/50 µs in kV peak	Chopped wave lightning impulse test (LIC) 1.2/50/3 µs in kV peak	Switching impulse test (SI)[1] 250/2500 µs in kV peak	Power-frequency voltage tests 50 Hz / 60 s in kV r.m.s.
f1	550	605	460	230
f2	650	715	520	275
b1	350	385	280	140
b2	490	539	392	165
b3	520	572	416	180
a1	100	110	80	20
a	200	220	160	50
c1	400	440	320	100
c21	490	539	392	165
c22	520	572	416	180

Table 49: Confirmed withstand voltages of defined insulation distances.

During the partial discharge (PD) measurements, no collapse of the test voltage and no continuously rising tendency occurred. The levels of partial discharges did not exceed the corresponding permissible limits.

9. Appendix

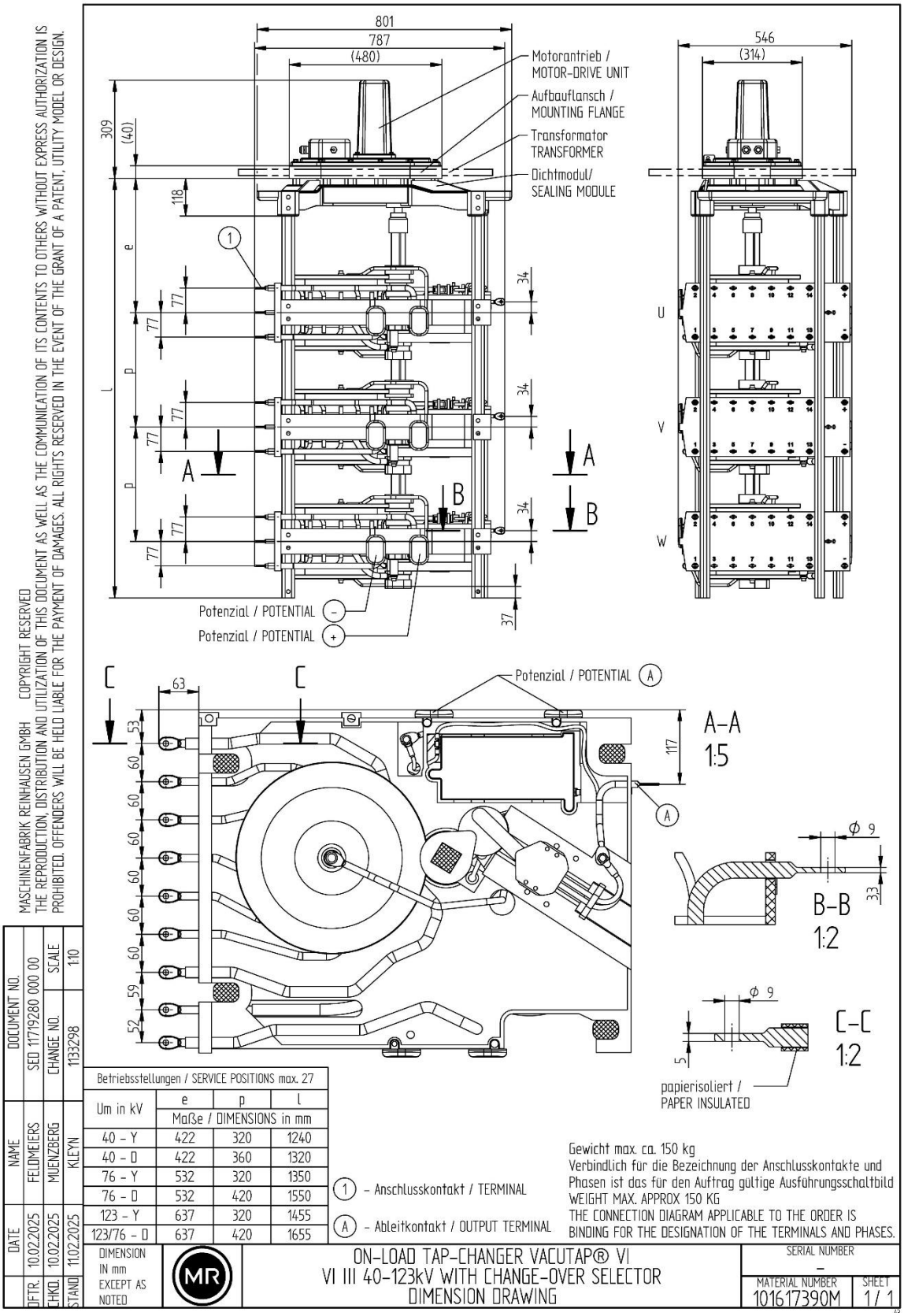
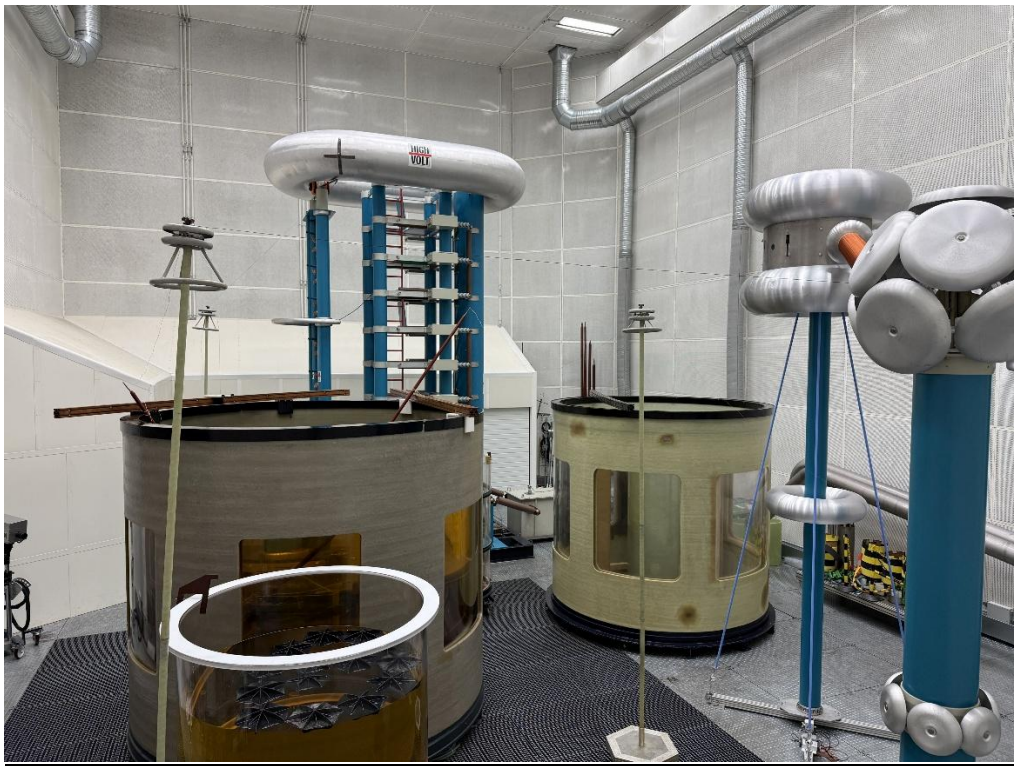
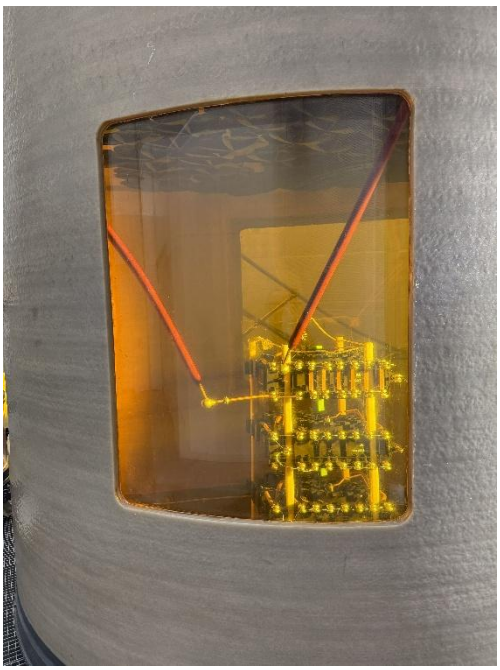


Figure 100: Dimension drawing of the test sample.



Pictures 1: Test setup.



Pictures 2: Test sample prepared for the dielectric tests (example).

10. List of amendments

Version	Date	Author	Amendment
01	17.07.2025	R. Wagner	---

End of document.