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SCIENCE
PASSION
TECHNOLOGY

HV-COM² - WORKING PACKAGE 3
EXISTING MEASURING SYSTEMS AT TESTING LABORATORIES

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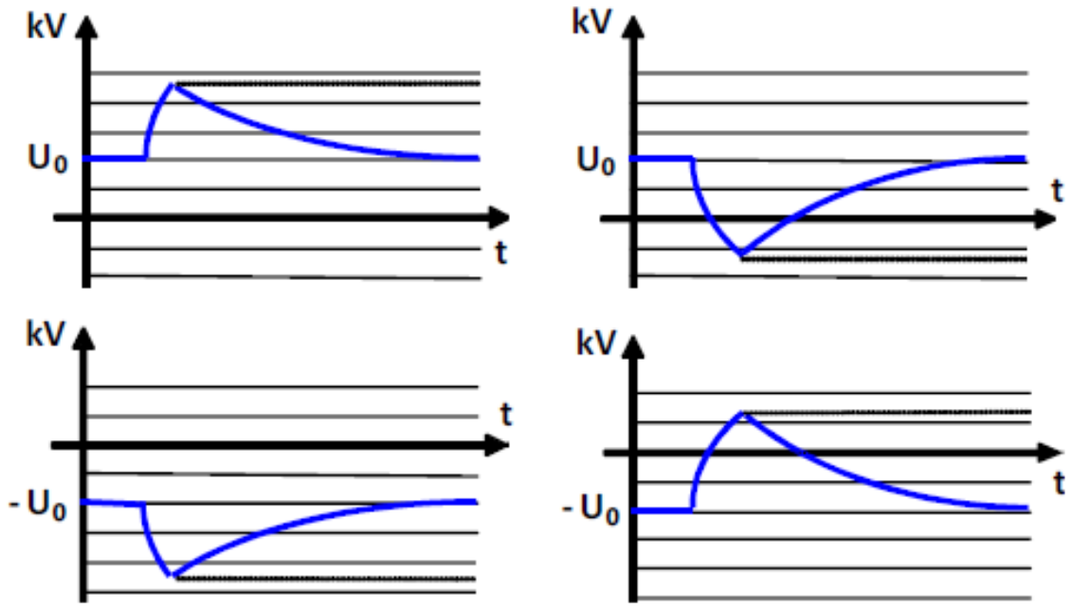
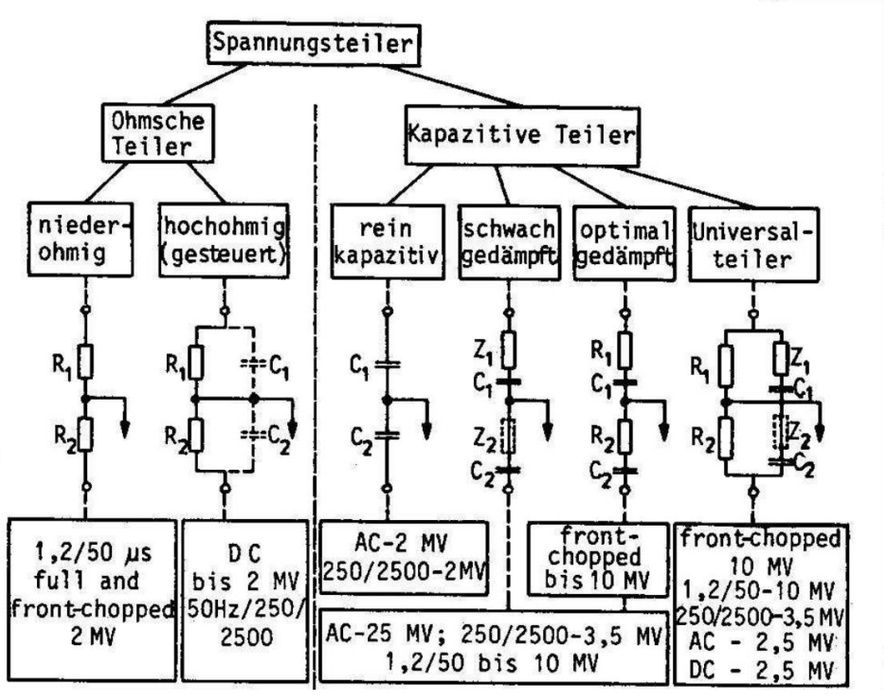
Motivation

- Power equipment in operation is stressed by operating voltage and superimposed impulse voltages
- Realistic replication in laboratory ⇨ superimposed voltage tests
- Most common: DC + lightning impulse (LI) or switching impulse (SI)
  - Dielectric testing of gas-insulated HVDC systems (CIGRE TB 842)
  - Testing of extruded HVDC cables (CIGRE TB 852, IEC 62895)



Motivation

- It is mandatory to measure the generated superimposed test voltage directly at the test object
- Measurement is ideally performed with a resisitve-capacitive divider (RC divider)
  - Widest frequency range: damped RC divider ⇨ universal voltage divider (RCR) ⇨ AC, DC, SI, LI



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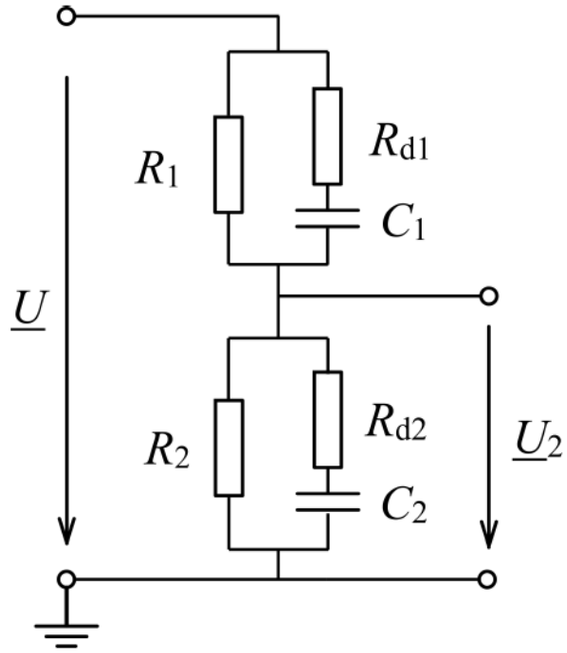

Motivation

- **Universal voltage dividers are not yet subject to any form of standardization**
- **Calibration and linearity verification are unclear**

- Example of normative gap: IEC 62895 for the testing of HVDC cables
  - Tests with superimposed voltages required ⇨ … *in accordance with IEC 60060-2* …
  - … *measurement of **individual** voltage components according to IEC 60060-2* …
  - Possibility of mutual influence due to the superposition is neglected
  - Change of divider's capacitance due to DC bias? ⇨ influence on impulse voltage measurement

Research questions at HV-com² – WP3

- For tests with superimposed voltages: Does the presence of one voltage waveform influence the performance of a measurement system based on universal voltage dividers with respect to the other voltage waveform?
- Point of view of calibration: Is it sufficient to calibrate measurement systems for composite voltages with the respective voltage forms individually, or is it necessary to perform it with composite voltages?
- Practical point of view: Does a DC voltage affect the measurement of superimposed LI/SI?

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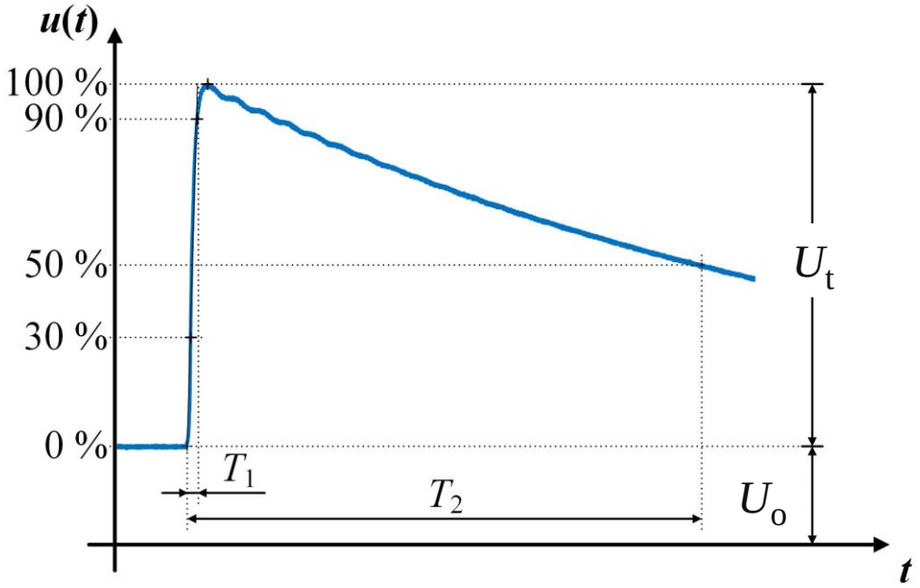
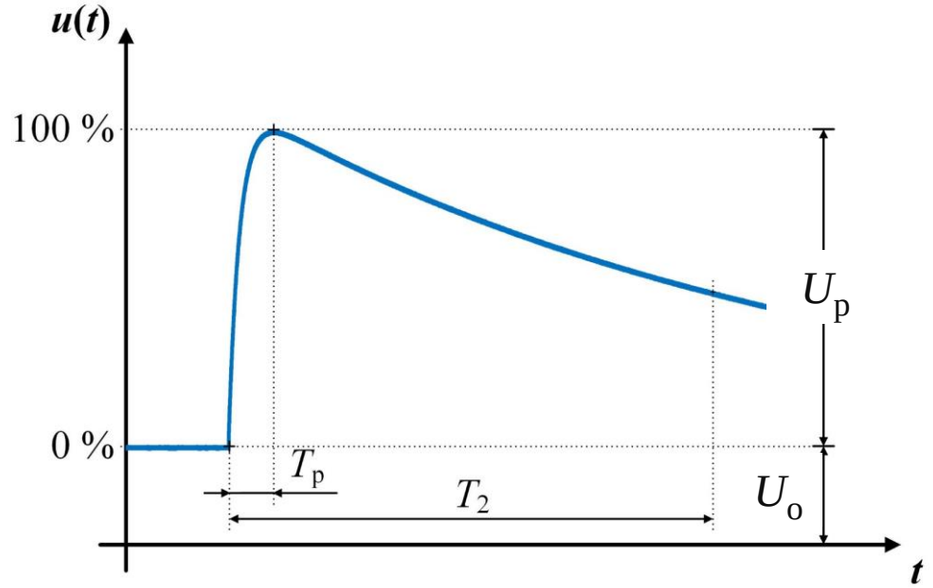
- Focus on composite DC + LI/SI (two terminal test objects)

Approach

- Comparison of commercially available RCR dividers with reference divider in **comparison campaign**
- Reference universal voltage divider was developed and tested in HV-com² project
- Evaluation of measurement error (deviation) regarding voltage and time parameters

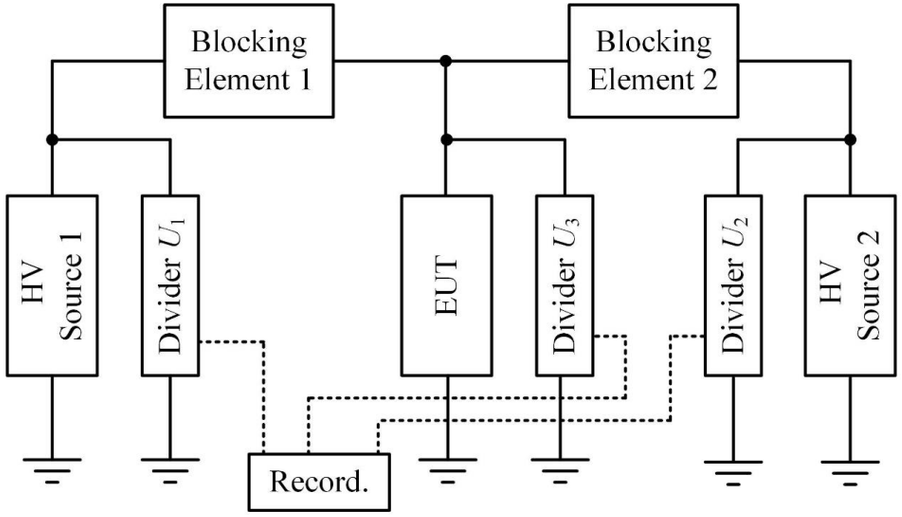


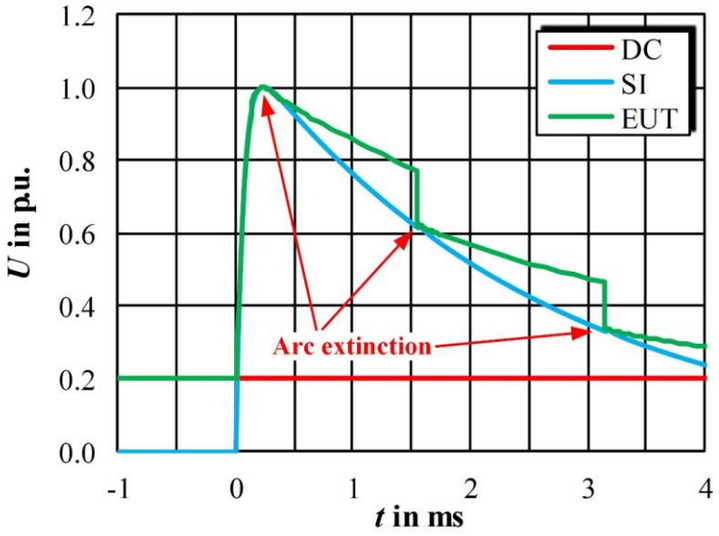


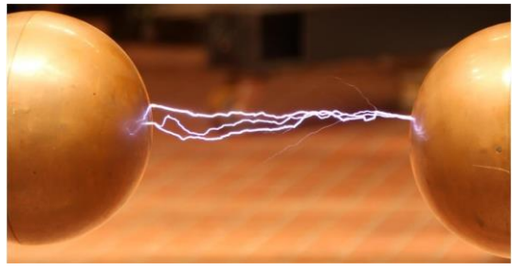
Definition of test circuit

- Superimposed test voltages are created by combining a DC source and an impulse generator (LI/SI)
- Blocking and coupling elements are needed to protect the sources from mutual influence
  - DC source protected with resistor
  - Impulse generator: blocking spark gap or blocking capacitor possible

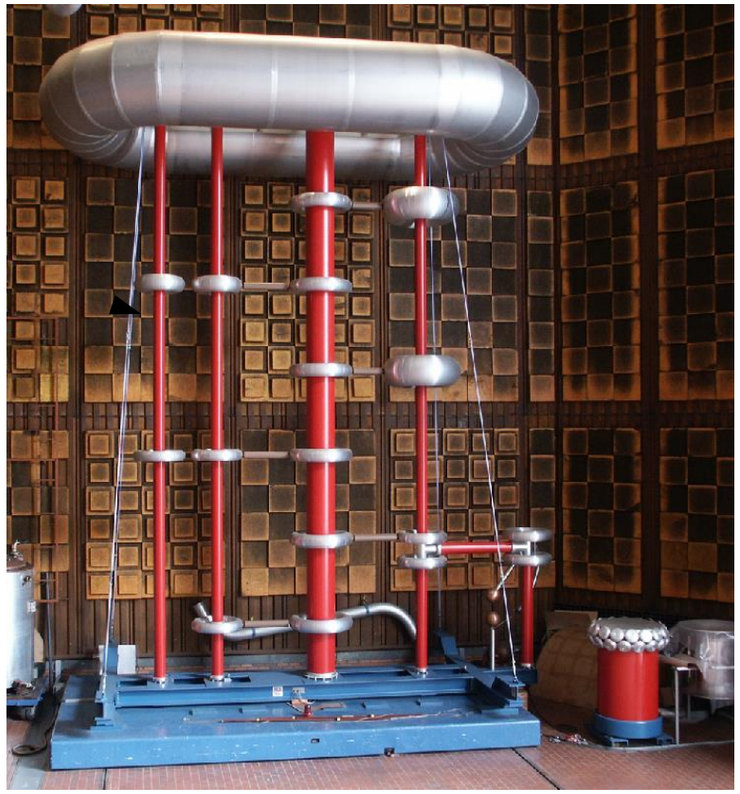
    ⇨ TUG supports the use of **blocking capacitor**







Test circuit



R Divider

U_{DC}

DC: 1500 kV, 20 mA

Protection Resistor

DUT

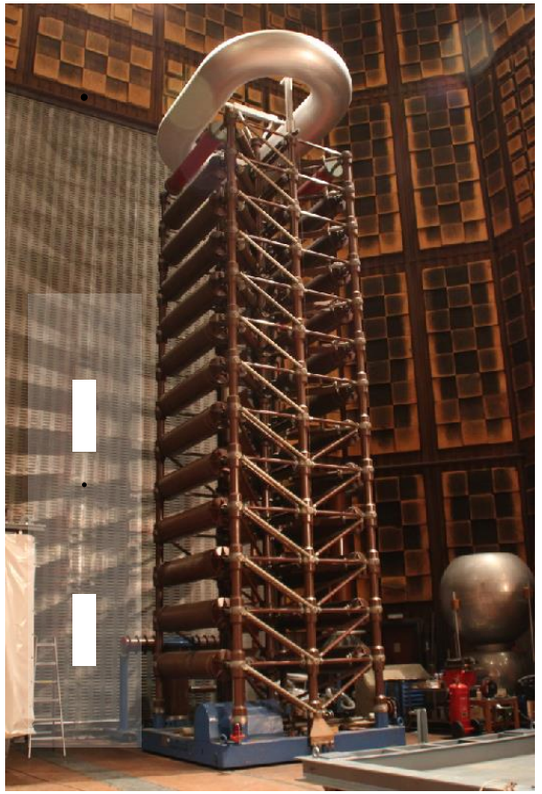
Recorder

Blocking Capacitor

Reference Divider

Recorder

Damped Capacitive Divider



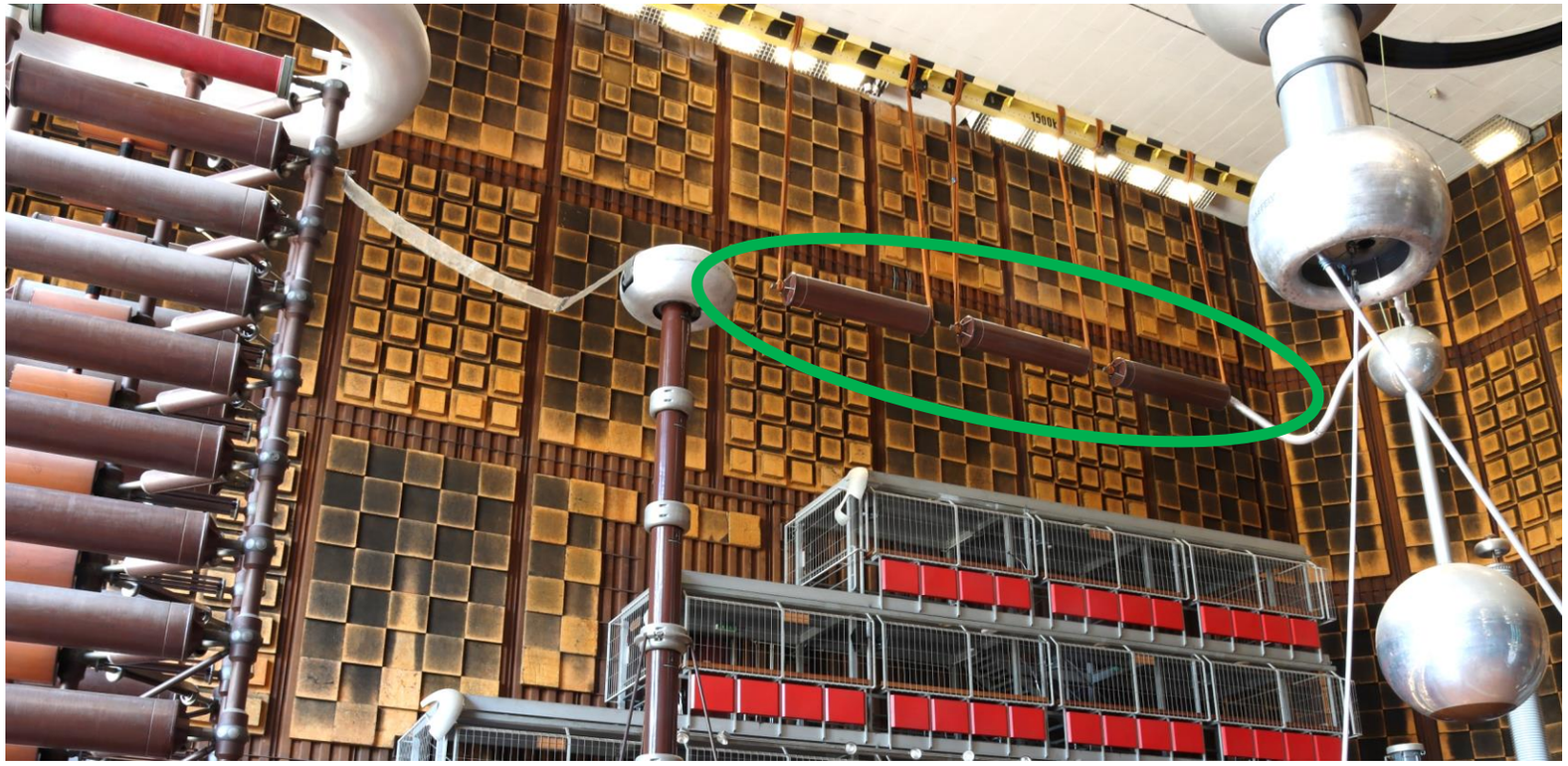
$U_{LI/SI}$

Impulse: 3250 kV, 165 kJ

HV Laboratory: 35 m × 25 m × 21 m

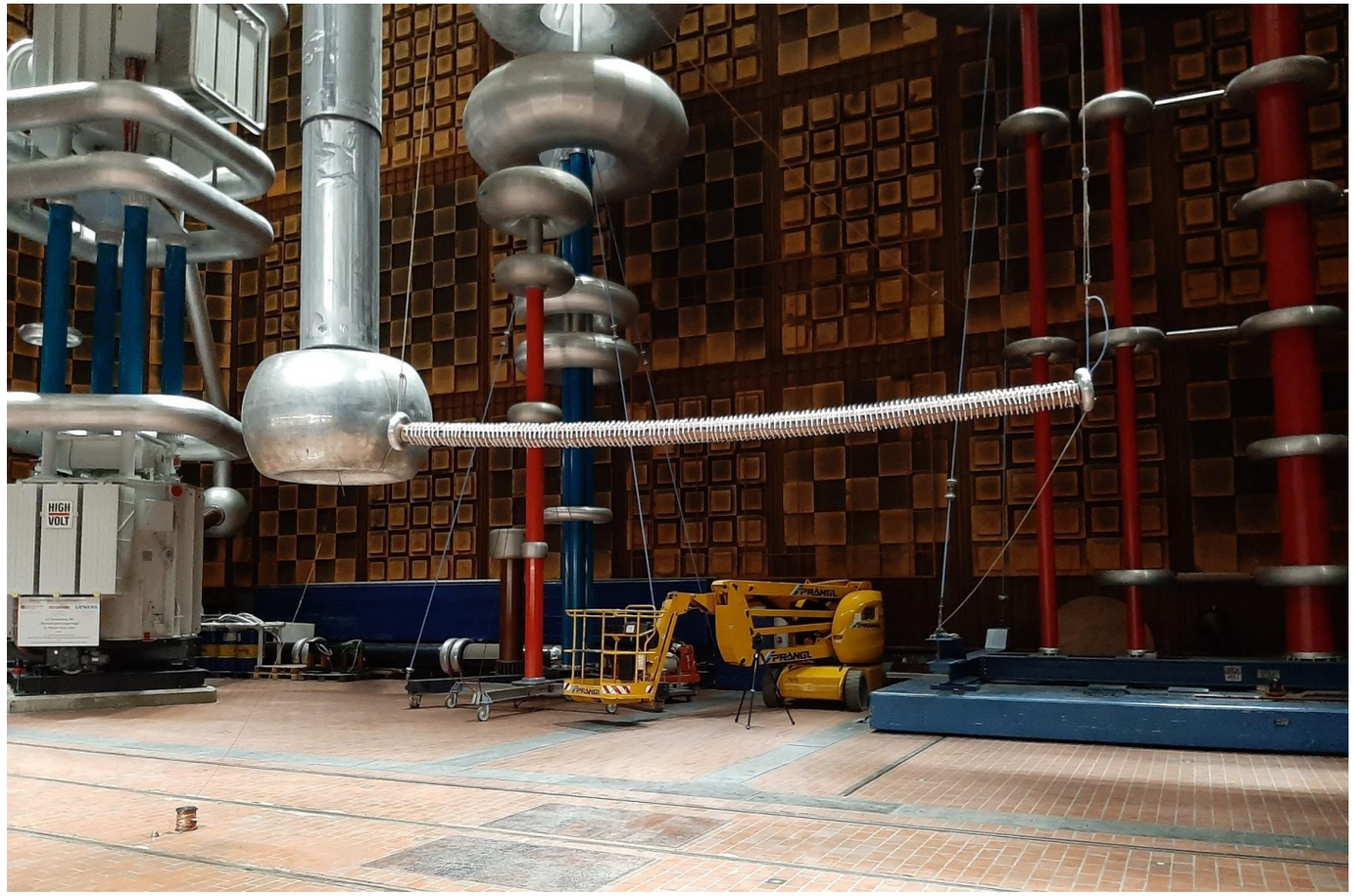
Blocking and coupling elements

- Coupling capacitor
  - 3 capacitors in series (each 200 nF, 2.6 m, 250 kV)



Blocking and coupling elements

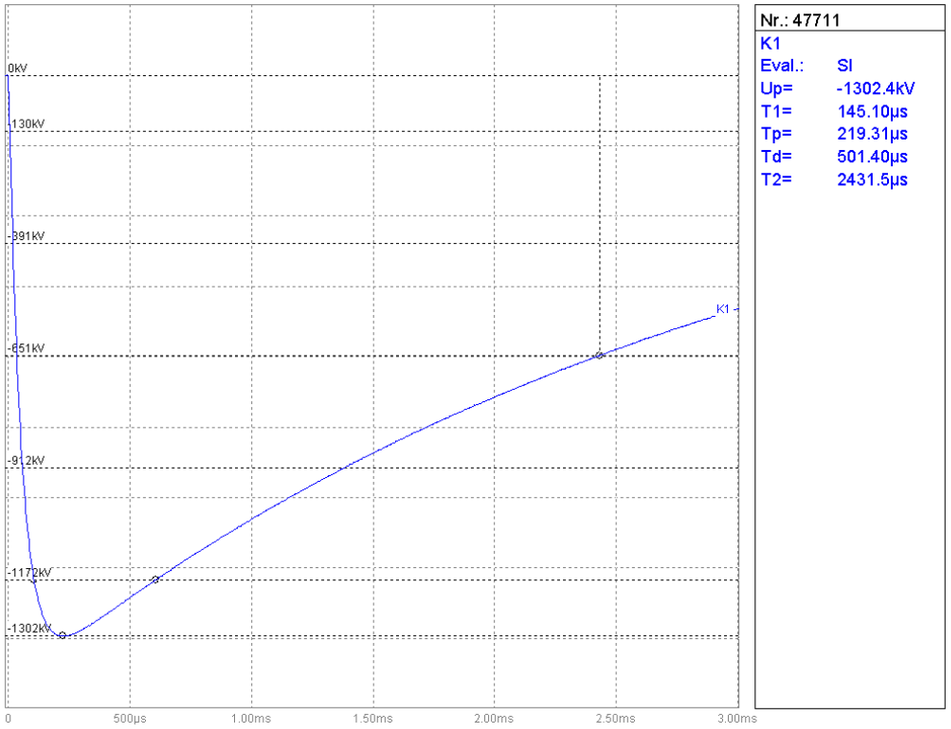
- Protection resistor
  - Taylor made by TUG
  - R = 23 MΩ
    (approx. 750 individual resistors)



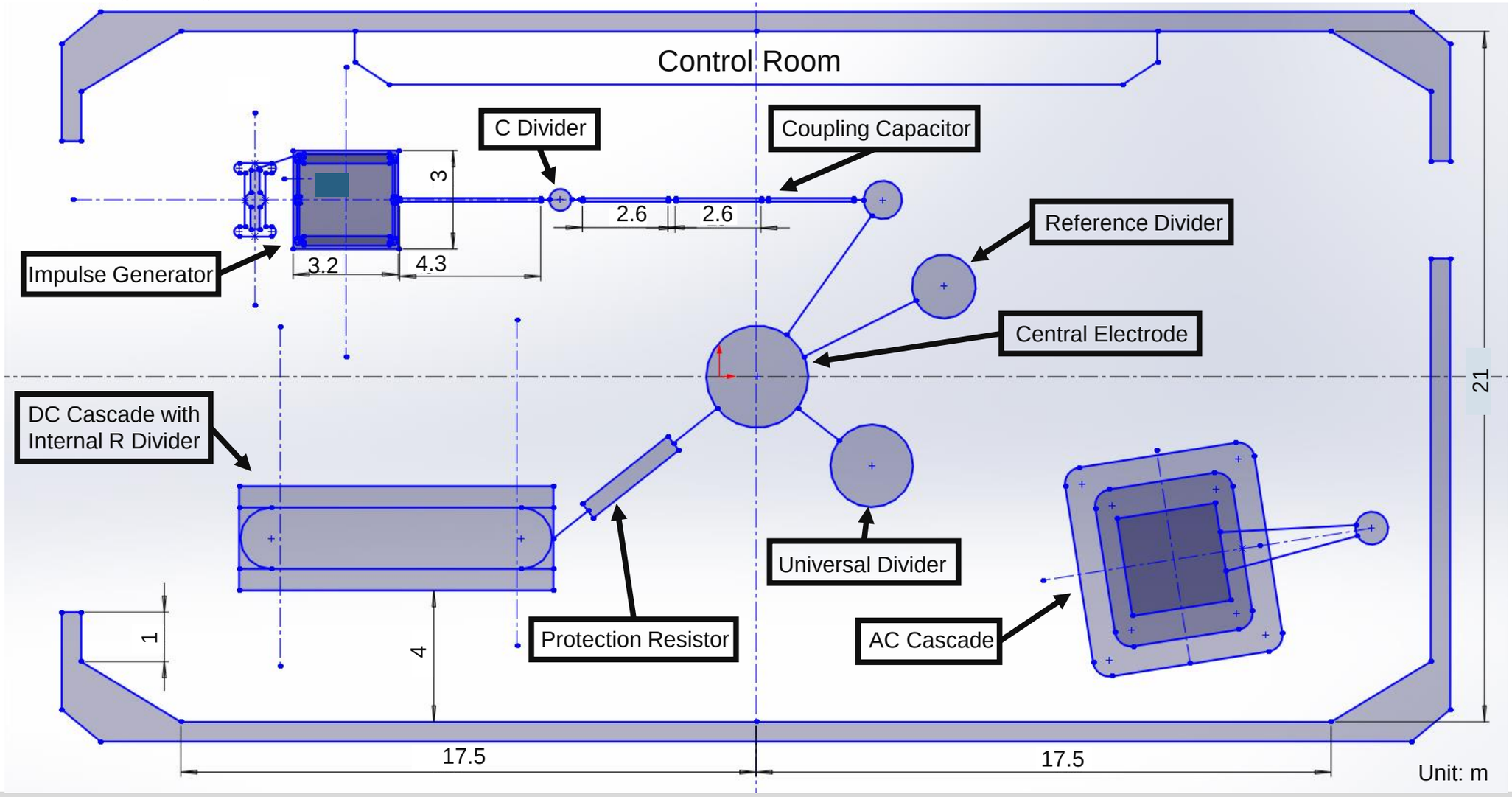
Testing of protection resistor

- LI at protection resistor
  - Negative polarity
  - Test voltage *U* = -250 kV to *U* = -1300 kV (**Δ***U* = -50 kV)
  - Five impulses at each test voltage level
  - ✓ **LI passed**

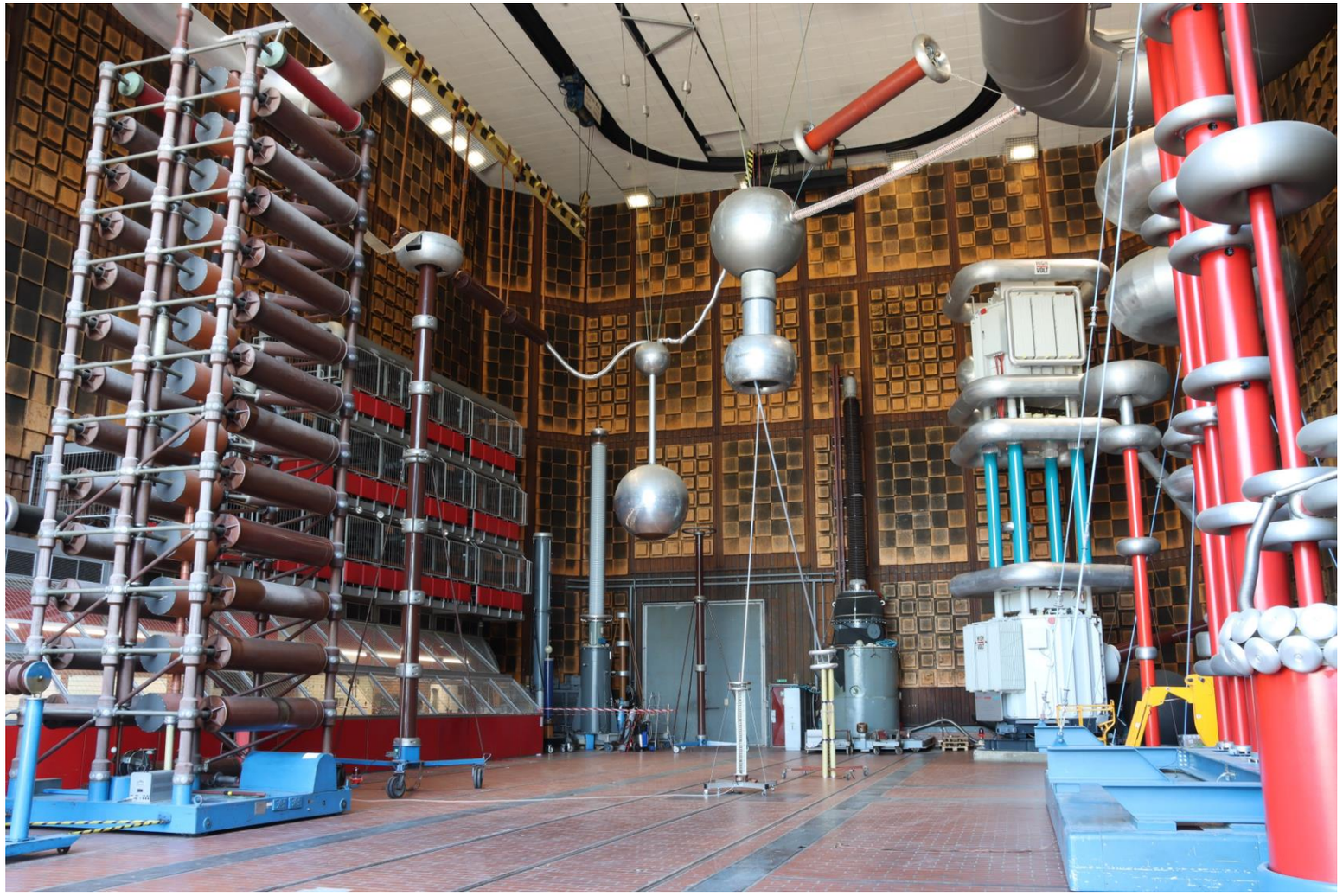
- SI at protection resistor
  - Negative polarity
  - Test voltage *U* = -400 kV to *U* = -1300 kV (**Δ***U* = -50 kV)
  - Five impulses at each test voltage level
  - ✓ **SI passed**



Laboratory layout, birds view



Preliminary testing of test circuit

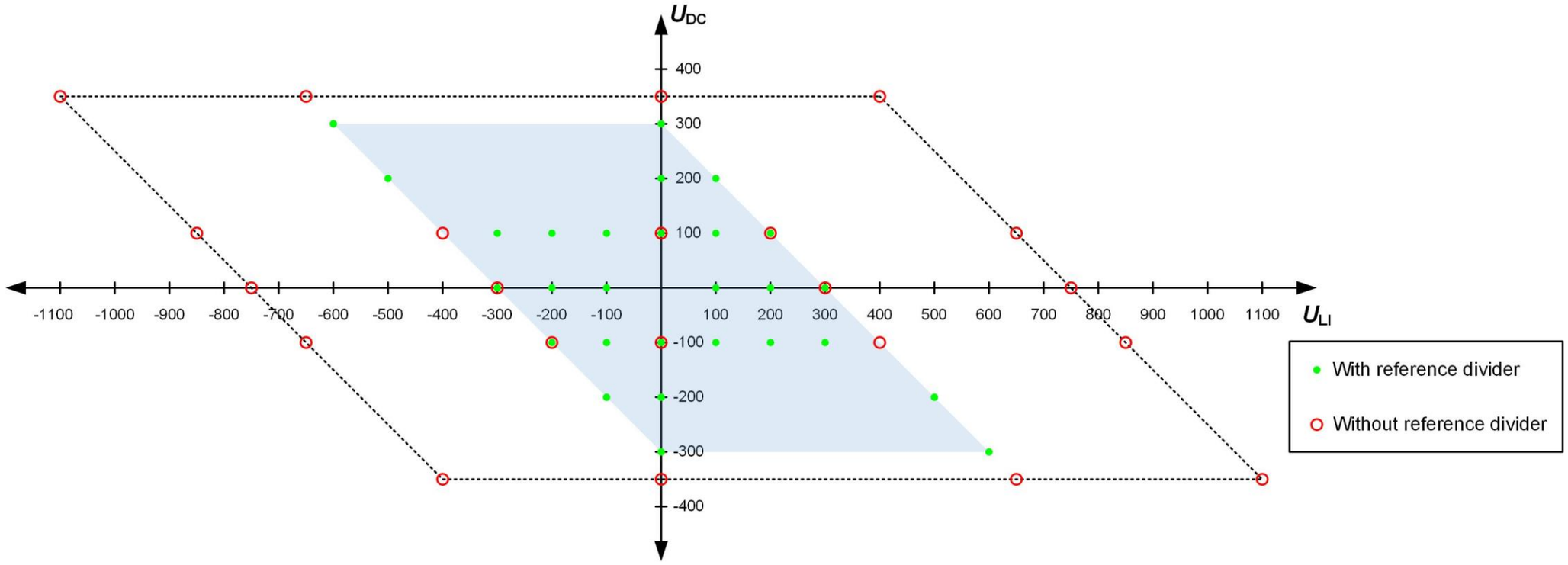


Comparison campaign

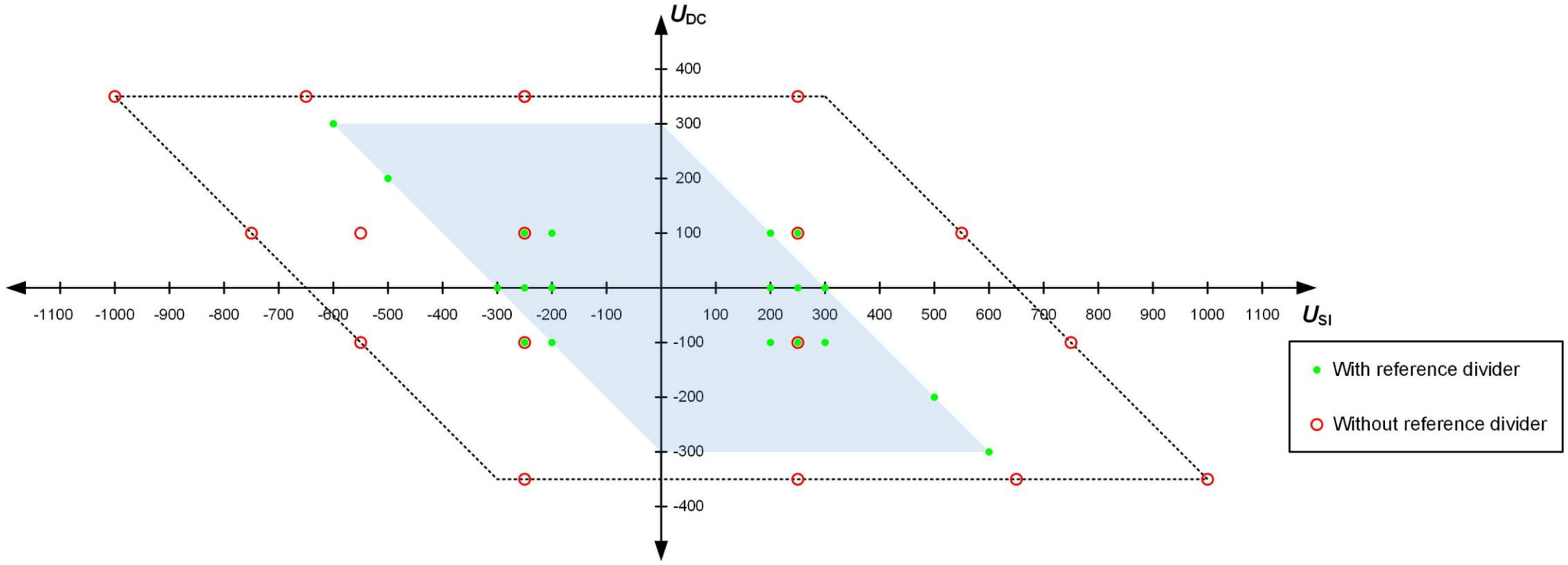
- Three measurement systems based on universal voltage dividers (including recorder, software etc.)
  - Reference system (developed in HV-com²) ⇨ Ref
  - Two commercial systems from different manufacturers ⇨ Com1 and Com2
- Composite voltages only (blocking capacitor): DC+LI, DC+SI, n = 10
- Reference divider limited to $U \leq 300$ kV for HV to ground
- Commercial dividers limited to $U \leq 750$ kV (DC+LI) and ≤ 650 kV (DC+SI) for HV to ground

- Two test sequences:
  - Sequence 1 ⇨ tests with reference divider: $U_{DC} \leq 300$ kV, $\hat{U}_{LI} \leq 300$ kV, $\hat{U}_{SI} \leq 300$ kV
  - Sequence 2 ⇨ reference divider disconneted: $U_{DC} \leq 350$ kV, $\hat{U}_{LI} \leq 1100$ kV, $\hat{U}_{SI} \leq 1000$ kV

Test voltage range (DC/LI)



Test voltage range (DC/SI)

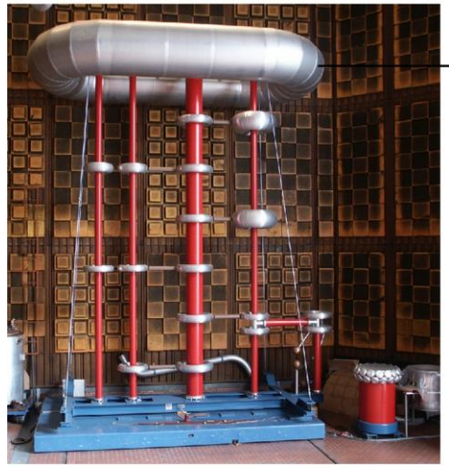


Comparison campaign

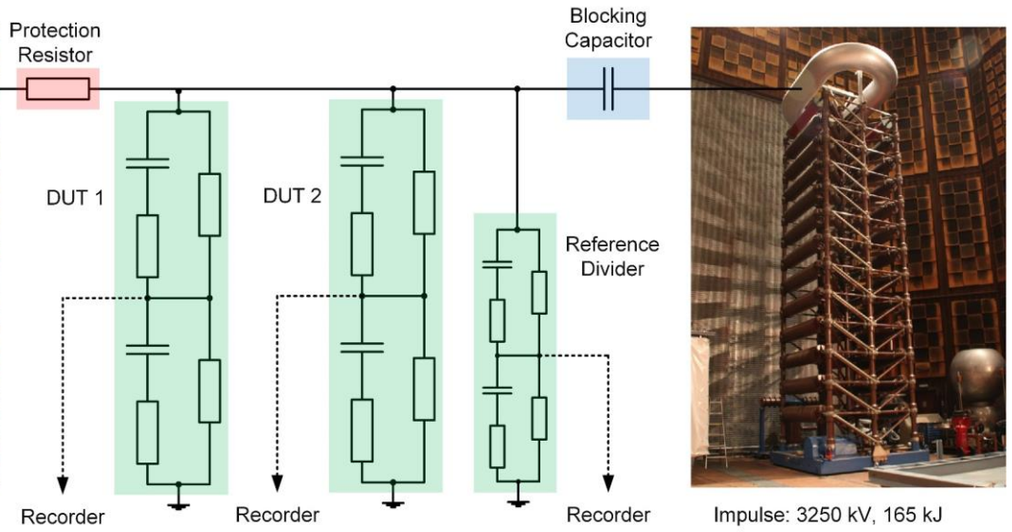
Sequence 1:

$U \leq 300$ kV

$U_{DC} \leq 300$ kV, $\hat{U}_{LI} \leq 300$ kV, $\hat{U}_{SI} \leq 300$ kV



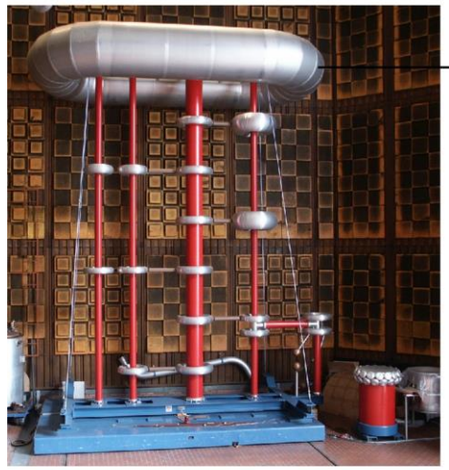
DC: 1500 kV, 20 mA



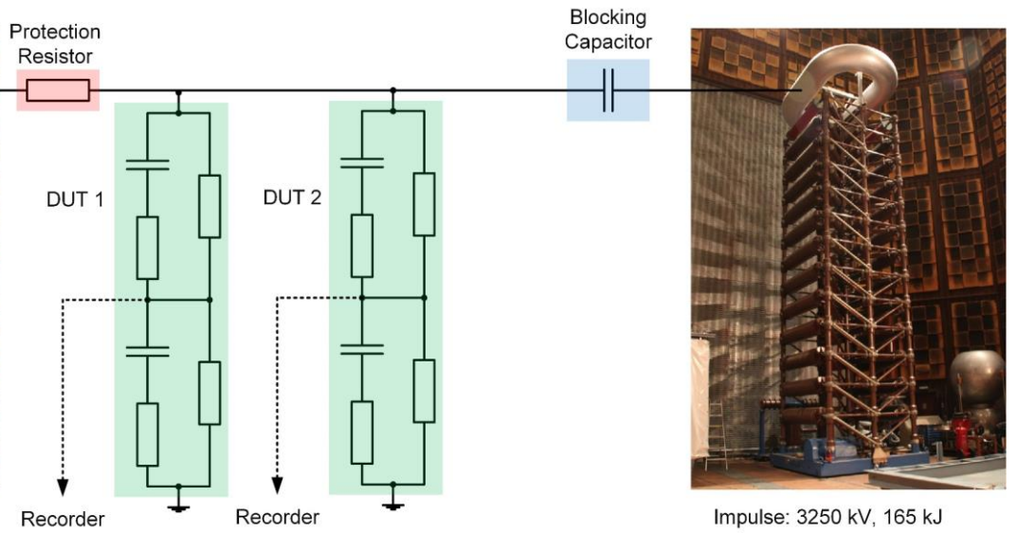
Sequence 2:

$U \leq \pm 750$ kV (DC+LI), $U \leq \pm 650$ kV (DC+SI)

$U_{DC} \leq 350$ kV, $\hat{U}_{LI} \leq 1100$ kV, $\hat{U}_{SI} \leq 1000$ kV



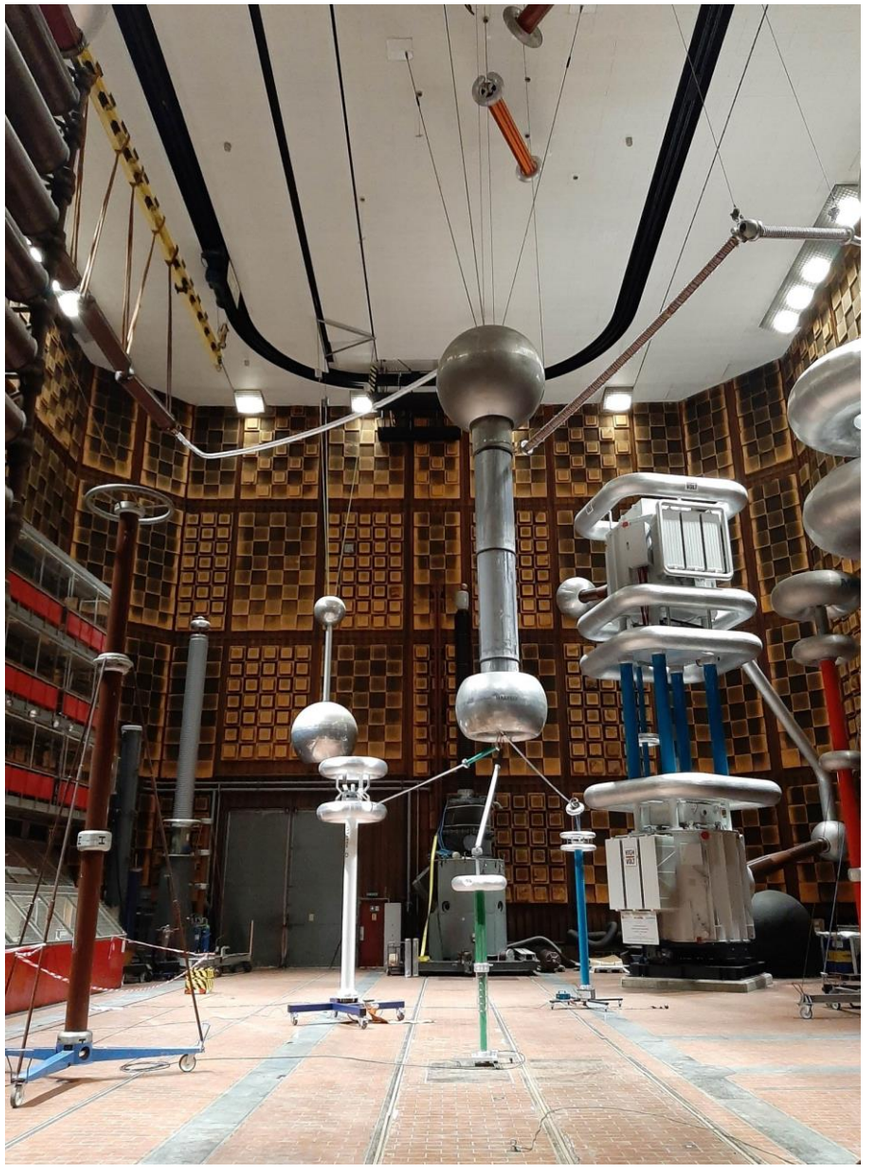
DC: 1500 kV, 20 mA



Comparison campaign

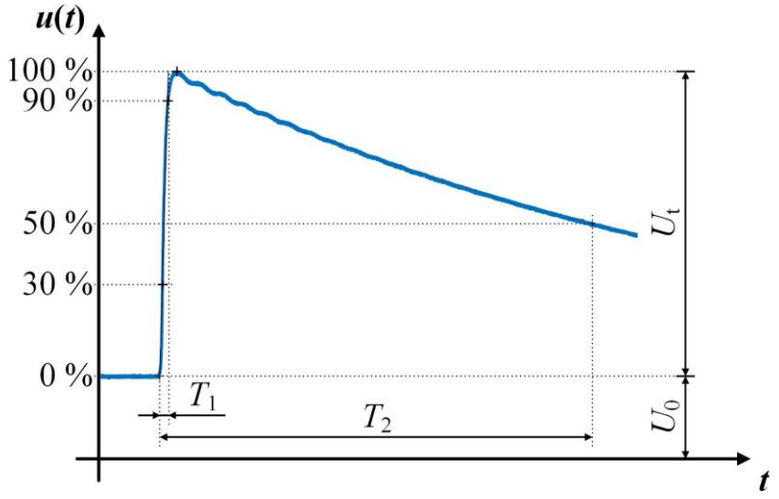
Complete test setup with
1 x reference divider
2 x commercial dividers

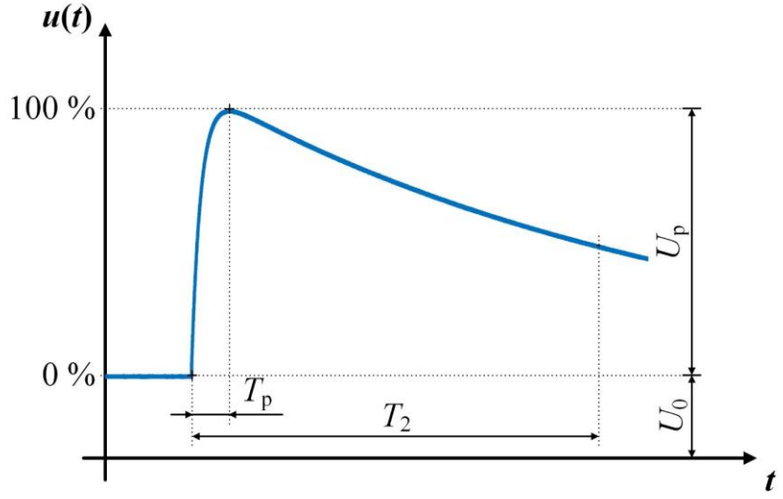
	Ref	Com1	Com2
R in GΩ	2,4	1	0,8
C in pF	205	700	375
R_D in Ω	480	180	800
$R_{D\text{-ext}}$ in Ω	529	355	207.5
max. U_{DC} in kV	± 300	± 600	± 400
max. U_{AC} in kV	300	400	400
max. U_{LI} in kV	±300	±1200	±750
max. U_{SI} in kV	±300	±1000	±650
Scale Factor F	820729	850	967
ADU	200 MHz 12 bit	250 MHz 16 bit	250 MHz 14 bit



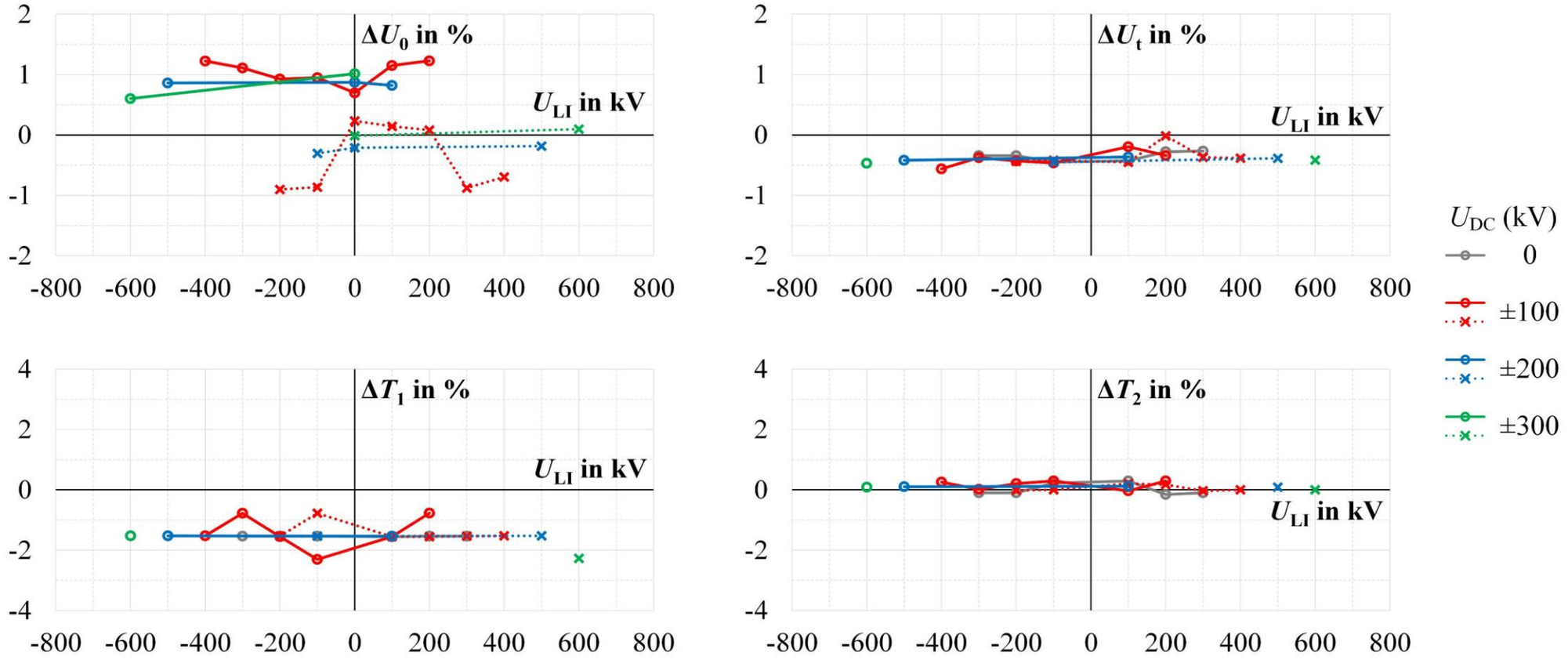
Evaluation

- Mean error (ΔU_0, ΔU_t, ΔT_1 etc):
  - Sequence 1 ⇨ com systems to ref system: e.g. $\Delta U_0 = \left(\frac{\frac{1}{10} \cdot \sum_{i=1}^{10} U_{0,\mathrm{Com1/Com2},i}}{\frac{1}{10} \cdot \sum_{i=1}^{10} U_{0,\mathrm{ref},i}} - 1 \right) \cdot 100\%$
  - Sequence 2 ⇨ com1 to com2: e.g. $\Delta U_0 = \left(\frac{\frac{1}{10} \cdot \sum_{i=1}^{10} U_{0,\mathrm{Com1},i}}{\frac{1}{10} \cdot \sum_{i=1}^{10} U_{0,\mathrm{Com2},i}} - 1 \right) \cdot 100\%$

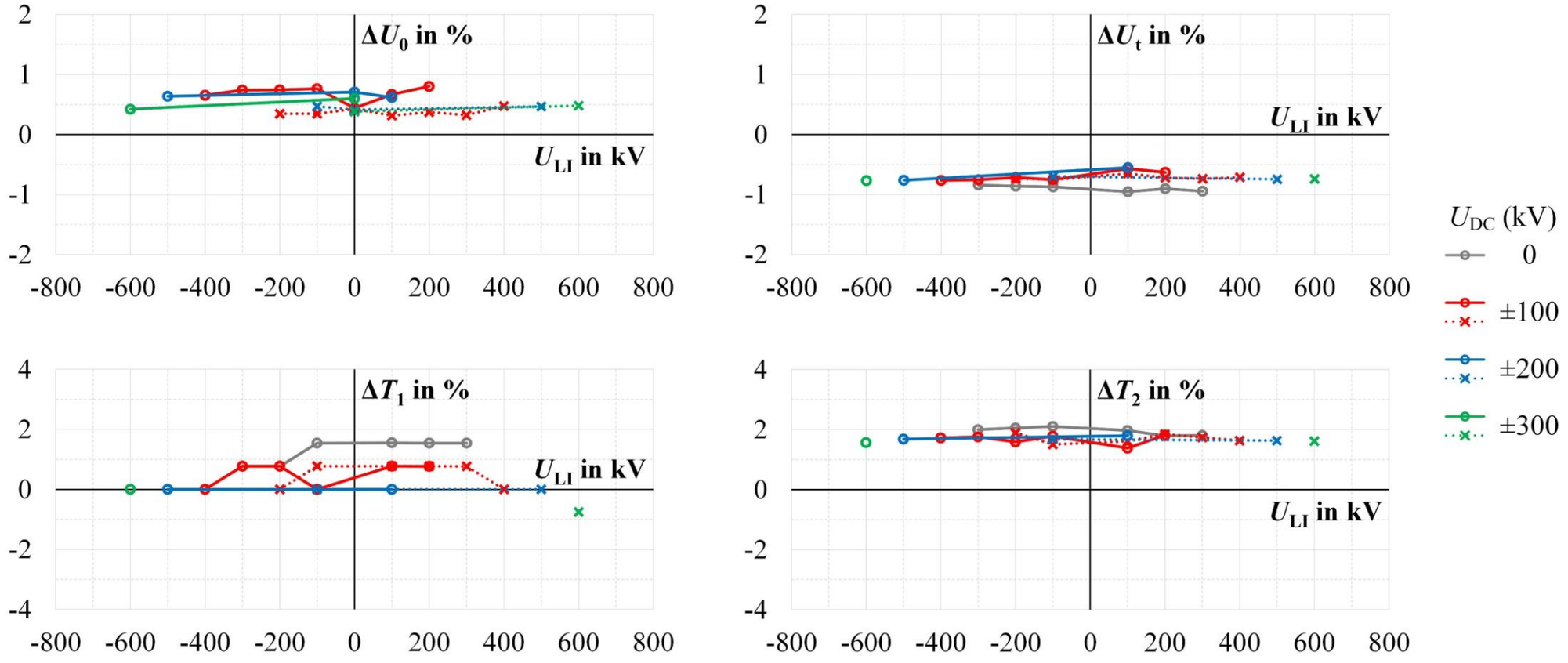




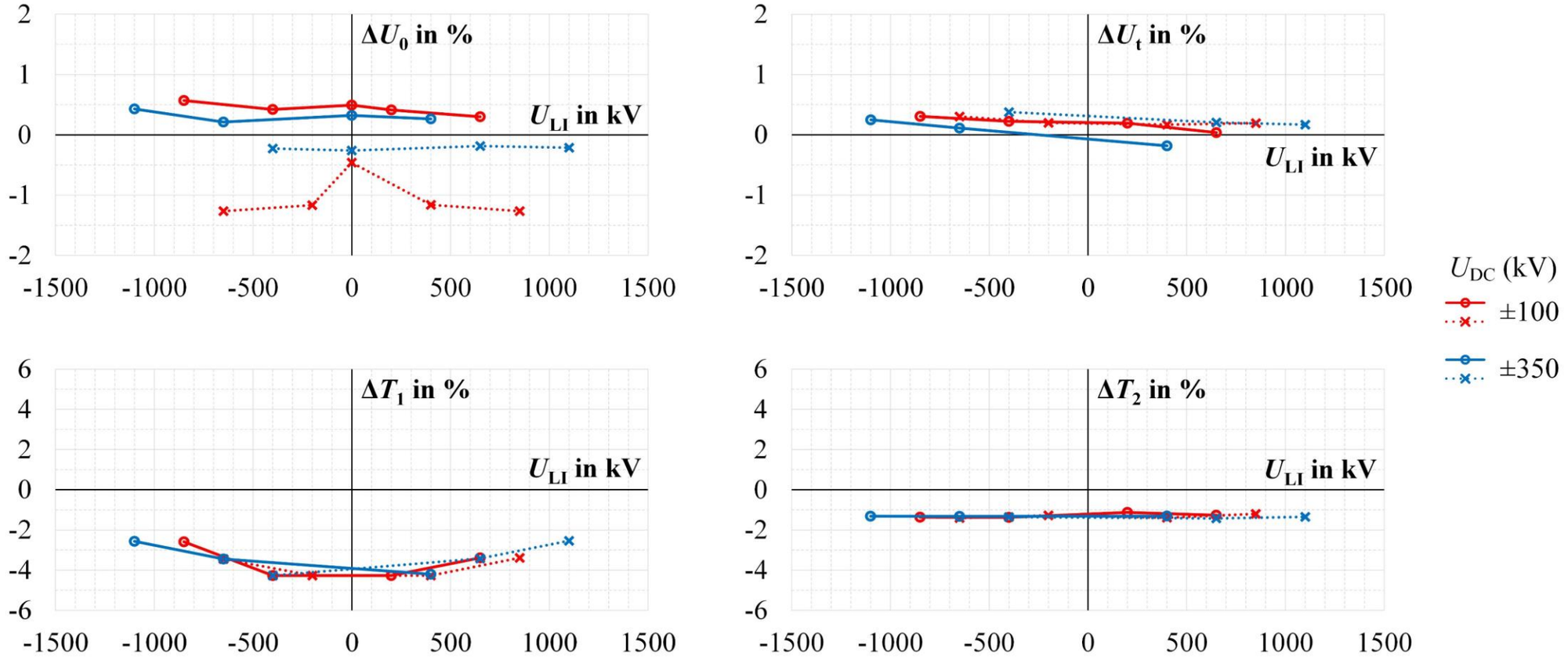
Results DC+LI – Com1 to Ref



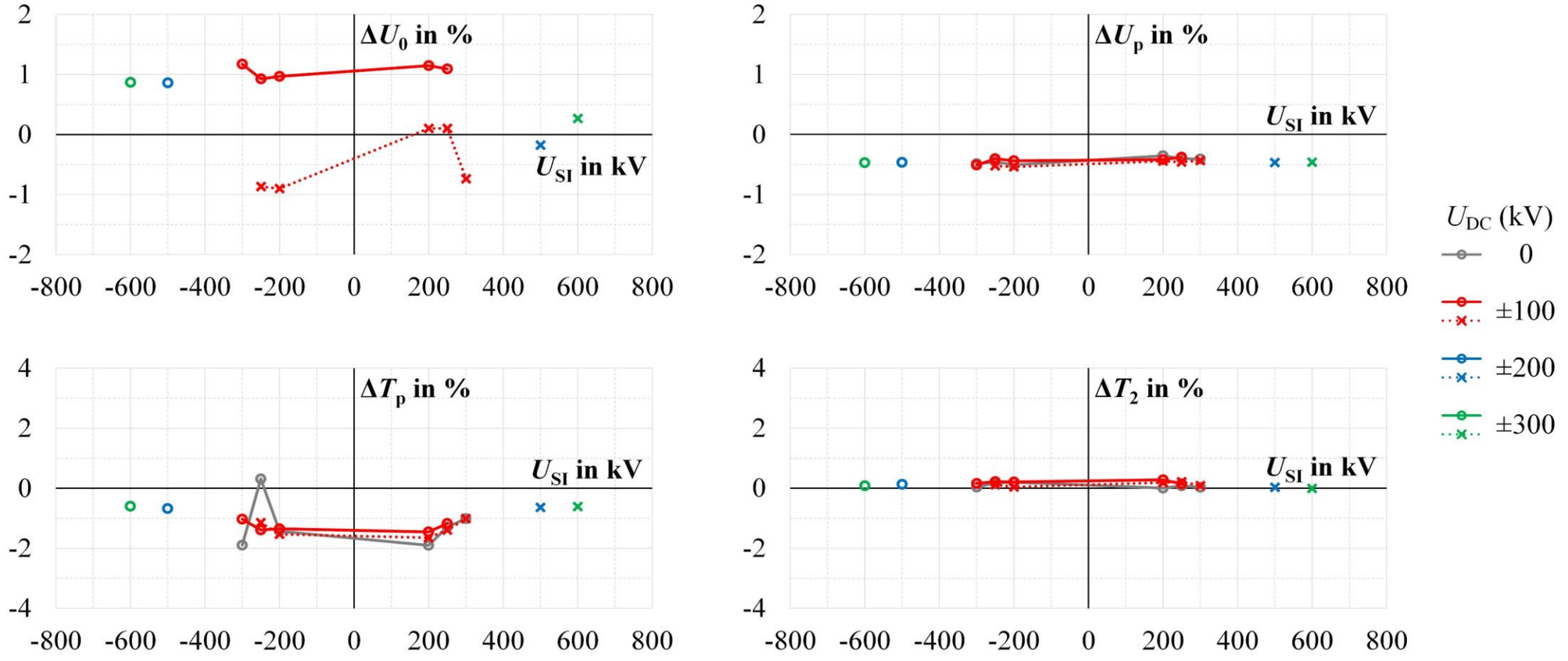
Results DC+LI – Com2 to Ref



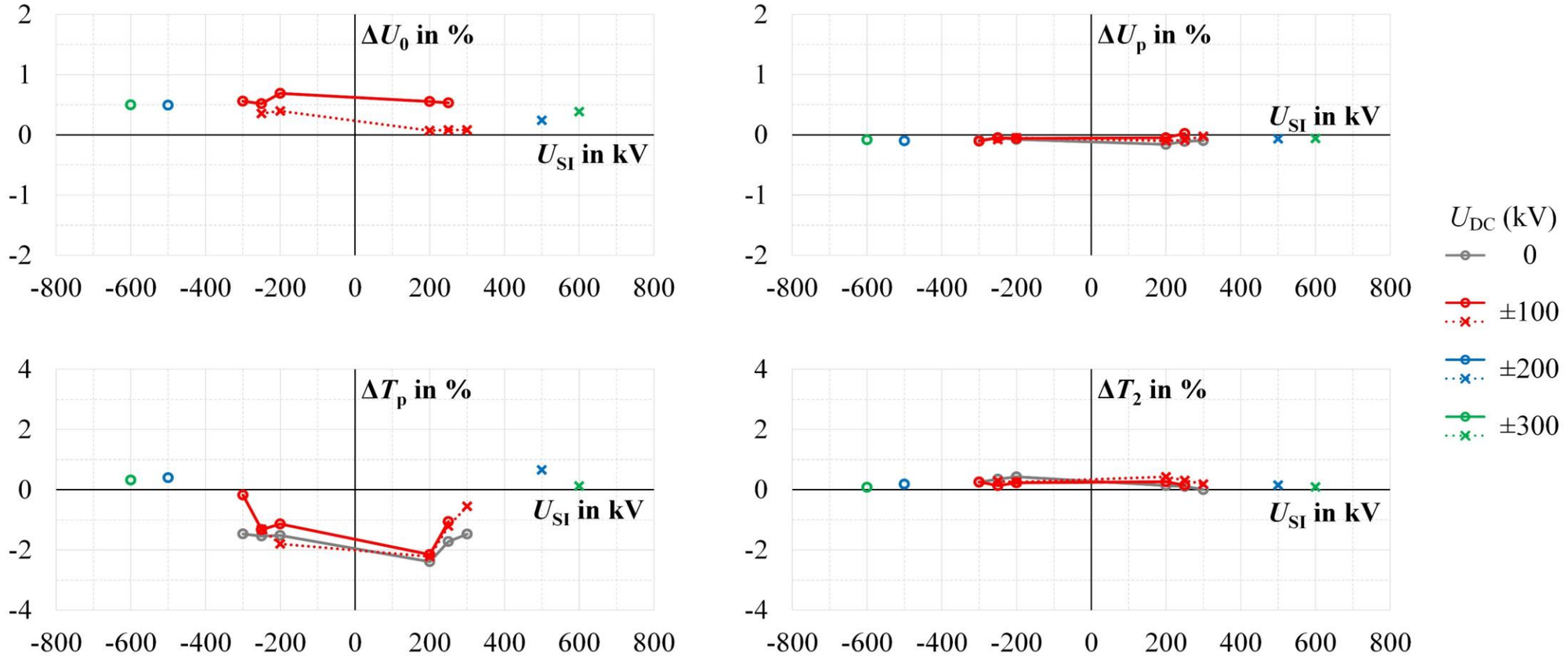
Results DC+LI – Com1 to Com2



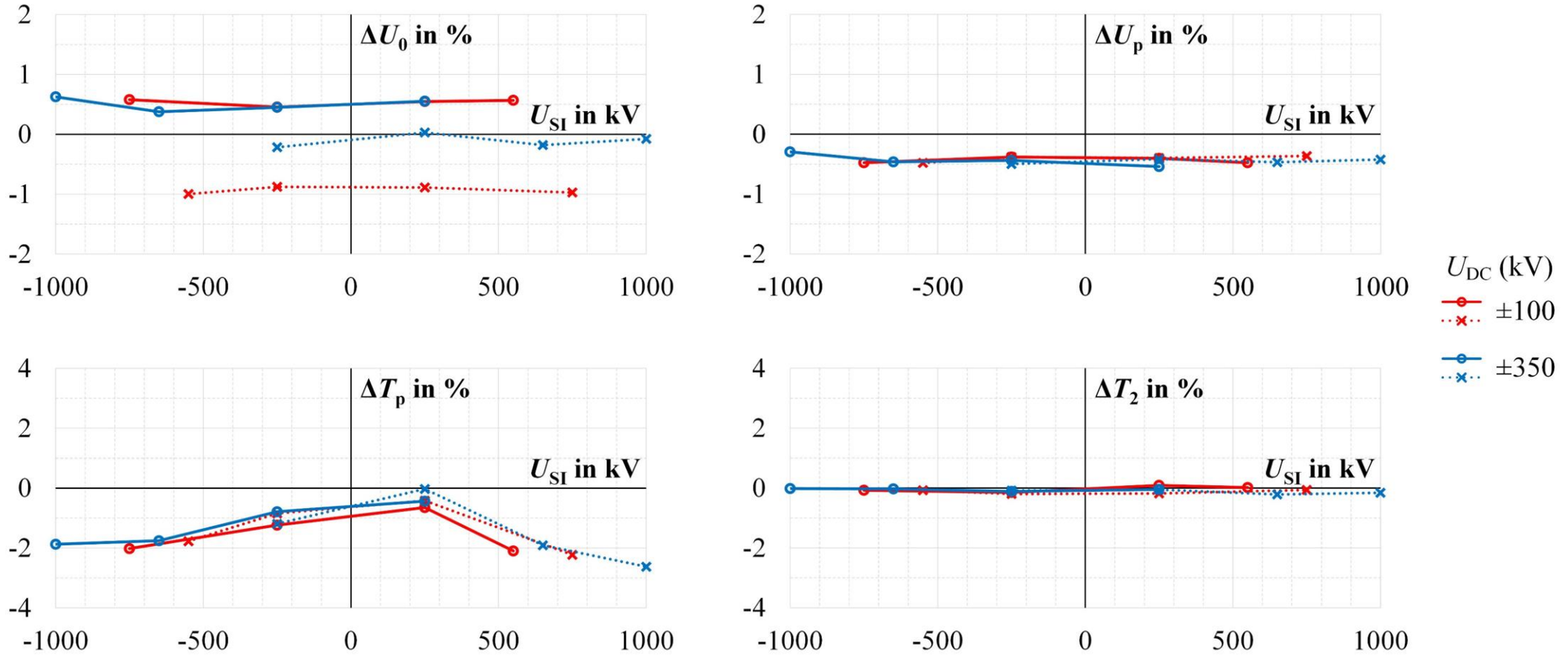
Results DC+SI – Com1 to Ref



Results DC+SI – Com2 to Ref



Results DC+SI – Com1 to Com2



Results – Summary

Min/max mean errors in % (DC+LI)

	ΔU_0	ΔU_t	ΔT_1	ΔT_2
Com1/Ref	-0.90 1.23	-0.56 -0.01	-2.31 -0,77	-0.15 0.29
Com2/Ref	0.32 0.80	-0.95 -0.55	0.76 1.55	1.38 2.10
Com1/Com2	-1.27 0.57	-0.18 0.38	-4.27 -2.54	-1.42 -1.12

Min/max mean errors in % (DC+SI)

	ΔU_0	ΔU_p	ΔT_p	ΔT_2
Com1/Ref	-0.90 1.17	-0.54 -0.36	-1.90 0.31	-0.01 0.28
Com2/Ref	0.07 0.69	-0.16 0.02	-2.39 0.65	0.00 0.43
Com1/Com2	-1.00 0.63	-0.54 -0.30	-2.63 -0.03	-0.21 0.09

Conclusion

- Commercially available measurement systems based on universal voltage dividers are capable of analyzing DC+LI/SI superimposed voltages with the accuracy required for high voltage testing.
- All systems retained their high overall accuracy during all superimposed voltage tests, especially regarding their dynamic behaviour.
- A DC component did not have any negative effect on the performance of the measurement systems.

- It is sufficient to calibrate a measurement system based on universal voltage dividers for use with composite voltages with the respective individual voltages.
  - Scale factors for the different voltage waveforms should agree within ±1%.
  - Deviation regarding time parameters should not exceed ±2%.

Publications

ISH 2021

PREQUALIFICATION OF CAPACITORS FOR HIGH-PRECISION VOLTAGE DIVIDERS

Hai Jiang[1], Oliver Pischler[1], Uwe Schichler[1], Jussi Havunen[2], Jari Hällström[2], Ahmet Merev[3], Serkan Dedeoglu[3], Sami Özer[3], Johann Meisner[4], Stephan Passon[4], Frank Gerdinand[4]*

CIGRE Symp. Cairns 2023

Paper title	Aspects of Standardization of RCR Dividers for Measurement of Composite Voltage on DC Cables and DC GIS/GIL
Study Committee	SC D1 – Materials and emerging test techniques

ISH 2023

PERFORMANCE OF UNIVERSAL VOLTAGE DIVIDERS FOR MEASUREMENT OF SUPERIMPOSED VOLTAGES

Oliver Pischler[1], Uwe Schichler[1], Johann Meisner[2], Stephan Passon[2], Frank Gerdinand[2], Jussi Havunen[3], Jari Hällström[3], Kari Lahti[4], Frank Böhme[5], Ralf Pietsch[5], Mateusz Kujda[6], Michael Gamlin[6], Andreas Dowbysch[7], Hans-Peter Pampel[7]*

ISH 2023

MEASURING HVDC-IMPULSE COMPOSITE VOLTAGES WITH HIGH-VOLTAGE DIVIDERS: LABORATORY COMPARISON AND ERROR ANALYSIS

Andreas Dowbysch[1], Hans-Peter Pampel[1], Johann Meisner[2], Frank Gerdinand[2], Oliver Pischler[3], Uwe Schichler[3]*

Measurement Campaign
at TU Graz

…completed