



20 September 2018

Workshop: HVDC GIS PROMOTioN WP 15
HVDC GIS prototype installation test

Arnhem, The Netherlands

RC divider for HVDC applications

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PFIFFNER

Current and voltage – our passion

Presentation overview

1. Introduction
2. Theoretical discussions
3. Performance
4. Technical design
5. International standards
6. Special tests
7. Impressions

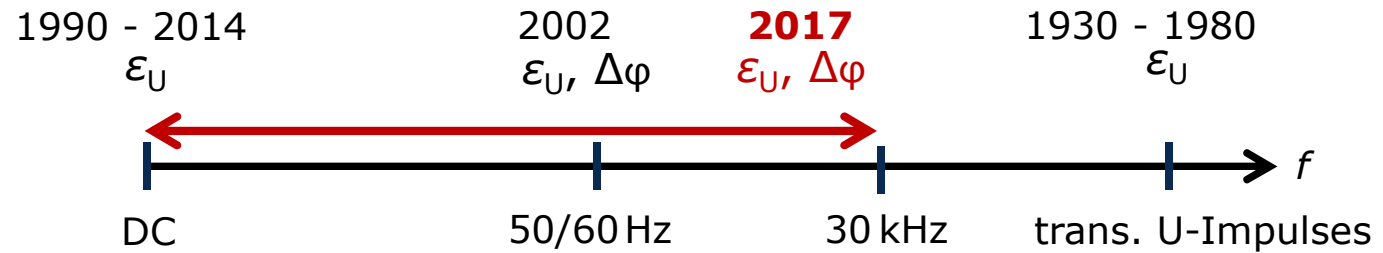


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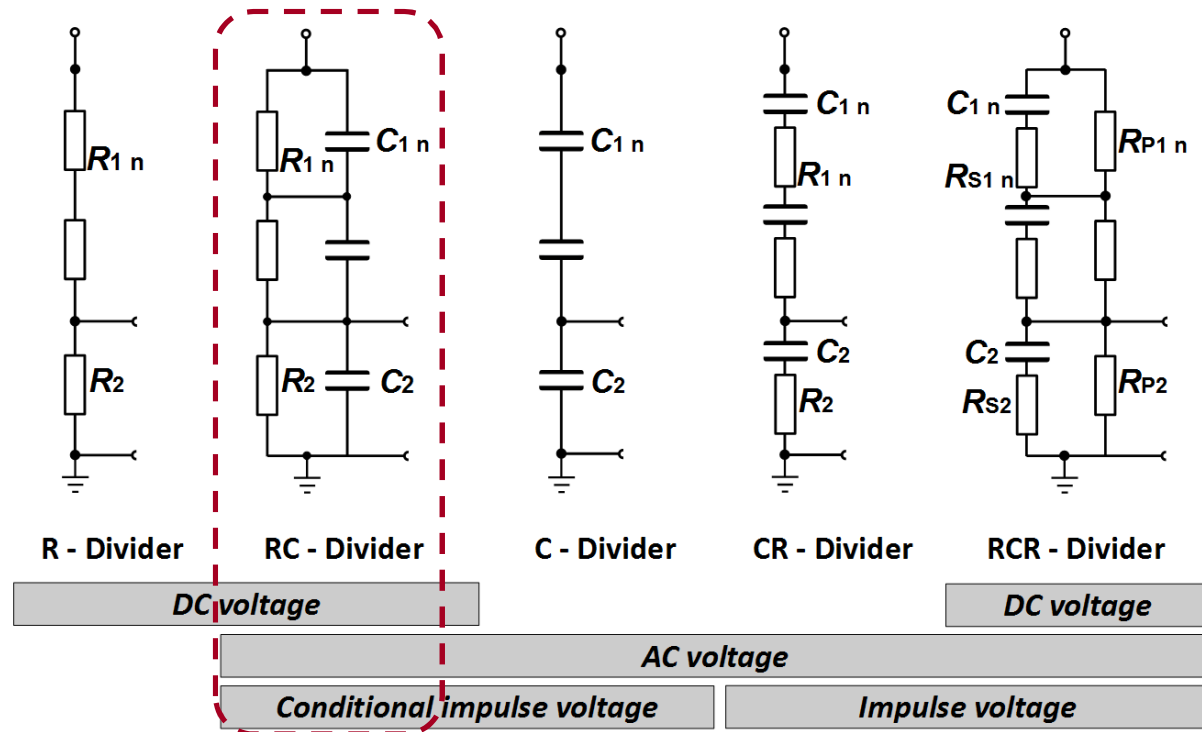


Introduction

Publikationen about
Voltage dividers



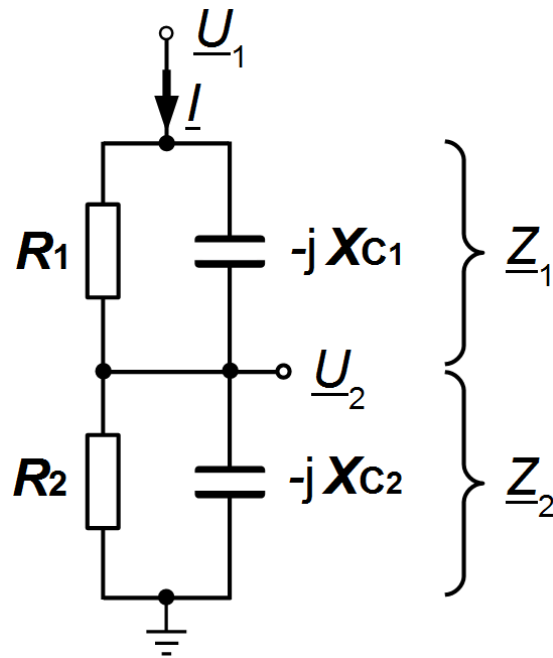
Field of applications



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Theoretical discussions RC-divider

Simplified equivalent circuit diagram



Transmission ratio function $\underline{u}(\omega)$

$$\underline{u}(\omega) = \frac{U_1(\omega)}{U_2(\omega)} = \left| \frac{\underline{Z}_{ges}}{\underline{Z}_2} \right|$$

Complex transfer function $\underline{k}(j\omega)$

$$\underline{k}(j\omega) = \frac{U_2(j\omega)}{U_1(j\omega)} = \frac{\underline{I} \cdot \underline{Z}_2}{\underline{I} \cdot \underline{Z}_{ges}} = \frac{\underline{Z}_2}{\underline{Z}_{ges}}$$

$$\frac{\underline{Z}_2}{\underline{Z}_{ges}} = \frac{R_2}{R_2 + R_1 \cdot \left(\frac{1+j\omega C_2 R_2}{1+j\omega C_1 R_1} \right)} = \frac{\underline{U}_2}{\underline{U}_1} = \underline{k}_R(j\omega)$$

Voltage error

$$\varepsilon_U = \frac{\ddot{u}_r \cdot U_2 - U_1}{U_1} \cdot 100 \quad [\%]$$

Phase displacement

$$\Delta\varphi_R(\omega) = \varphi_2 - \varphi_1$$

Theoretical discussions RC-divider

Boundary conditions

Pure resistive divider $\ddot{u}_R(\omega)$	$\omega \rightarrow 0$	$\frac{Z_2}{Z_{ges}} = \frac{R_2}{R_2 + R_1}$	$\omega = 2\pi \cdot f$ (angular frequency)
Pure capacitive divider $\ddot{u}_C(\omega)$	$\omega \rightarrow \infty$	$\frac{Z_2}{Z_{ges}} = \frac{C_1}{C_1 + C_2}$	

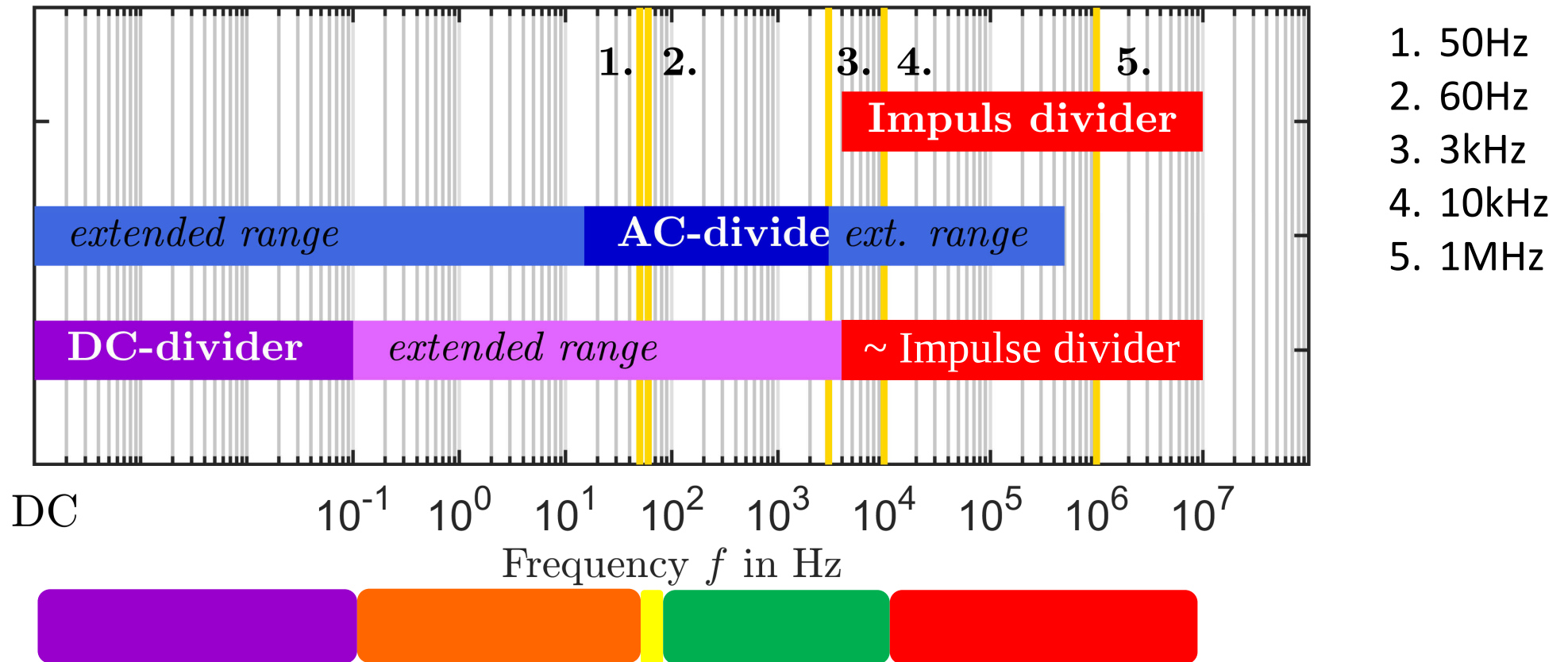
Temperature dependency $R(T)$ & $C(T)$

$R(T) = R_{\vartheta}[1 + \alpha_R(T - \vartheta)]$	$\omega \rightarrow 0$	$\frac{Z_2}{Z_{ges}} = \frac{1}{1 + \frac{R_{\vartheta 1}[1 + \alpha_{R1}(T - \vartheta)]}{R_{\vartheta 2}[1 + \alpha_{R2}(T - \vartheta)]}}$
$C(T) = C_{\vartheta}[1 + \alpha_C(T - \vartheta)]$	$\omega \rightarrow \infty$	$\frac{Z_2}{Z_{ges}} = \frac{1}{1 + \frac{C_{\vartheta 2}[1 + \alpha_{C2}(T - \vartheta)]}{C_{\vartheta 1}[1 + \alpha_{C1}(T - \vartheta)]}}$



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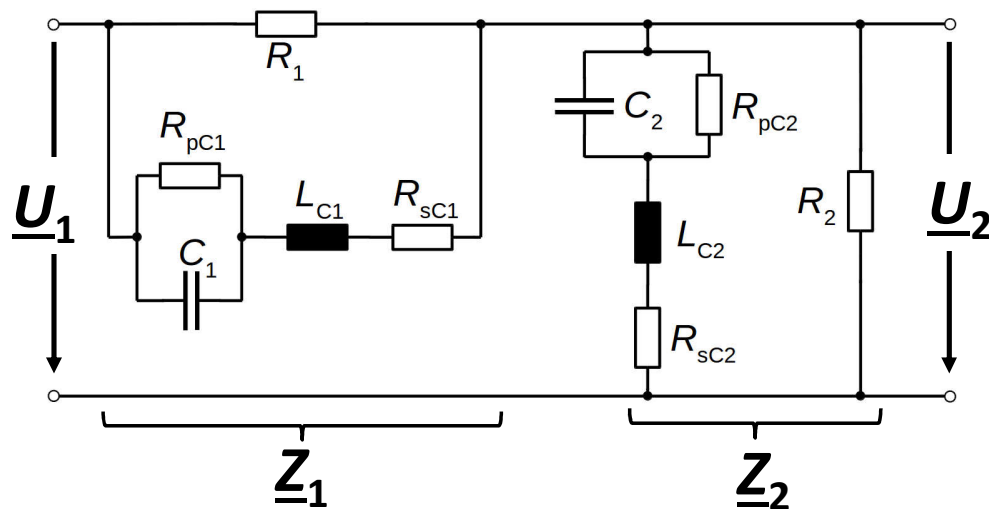
Performance requests



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Theoretical discussions RC-divider

Advanced equivalent circuit diagram



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Transmission ratio function $\underline{\ddot{u}}(\omega)$

$$\underline{\ddot{u}}(\omega) = \frac{U_1(\omega)}{U_2(\omega)} = \left| \frac{\underline{Z}_{\text{ges}}}{\underline{Z}_2} \right|$$

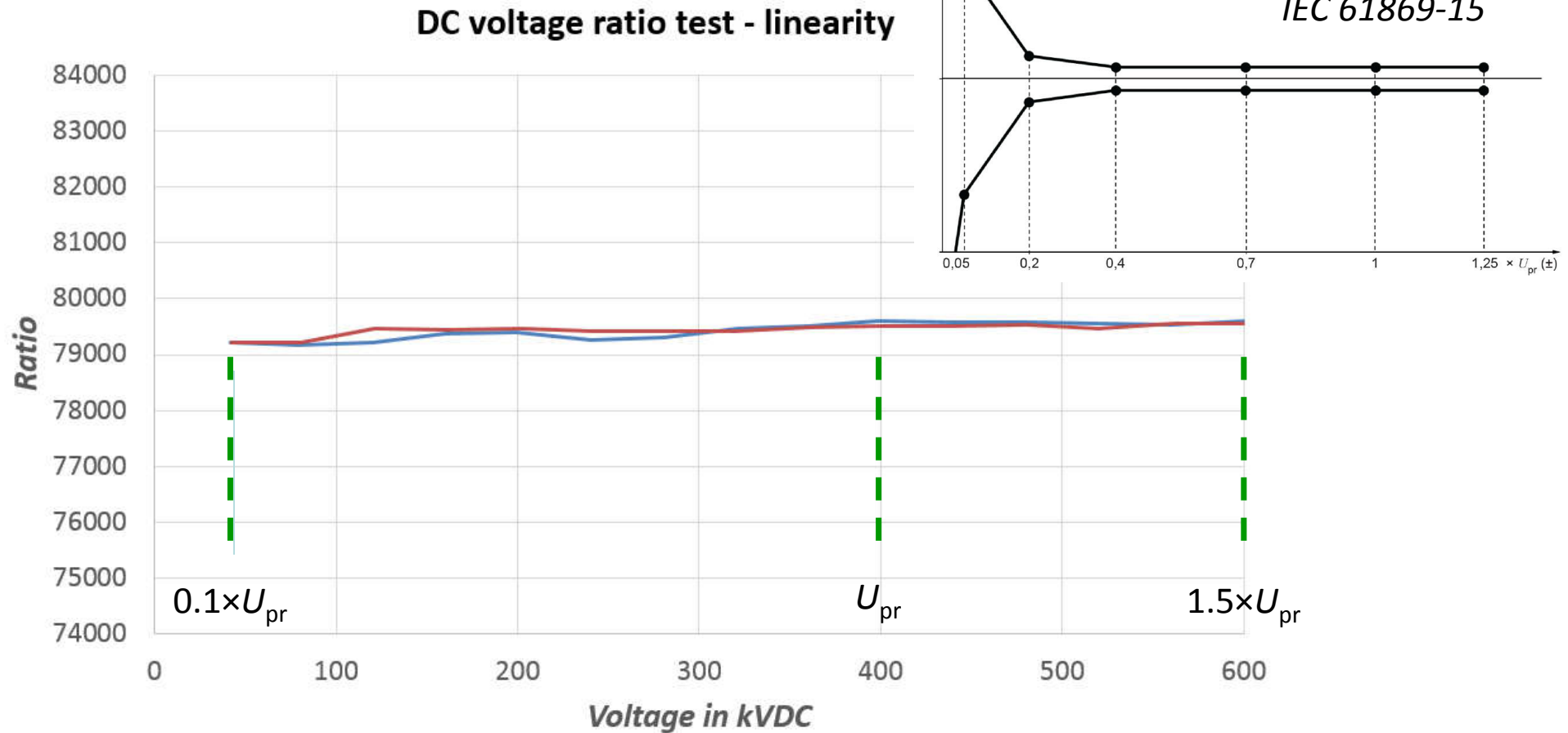
Complex transfer function $\underline{k}(j\omega)$

$$\underline{k}(j\omega) = \frac{U_2(j\omega)}{U_1(j\omega)} = \frac{\underline{I} \cdot \underline{Z}_2}{\underline{I} \cdot \underline{Z}_{\text{ges}}} = \frac{\underline{Z}_2}{\underline{Z}_{\text{ges}}}$$

$$\underline{Z}_1 = \frac{\underline{Z}_{R1} (\underline{Z}_{C1} + \underline{Z}_{RL1})}{\underline{Z}_{R1} + \underline{Z}_{C1} + \underline{Z}_{RL1}} \quad \underline{Z}_2 = \frac{\underline{Z}_{R2} (\underline{Z}_{C2} + \underline{Z}_{RL2})}{\underline{Z}_{R2} + \underline{Z}_{C2} + \underline{Z}_{RL2}}$$

$$\underline{k}(j\omega) = \frac{\frac{\underline{Z}_{R2}(\underline{Z}_{C2} + \underline{Z}_{RL2})}{\underline{Z}_{R2} + \underline{Z}_{C2} + \underline{Z}_{RL2}}}{\frac{\underline{Z}_{R1}(\underline{Z}_{C1} + \underline{Z}_{RL1})}{\underline{Z}_{R1} + \underline{Z}_{C1} + \underline{Z}_{RL1}} + \frac{\underline{Z}_{R2}(\underline{Z}_{C2} + \underline{Z}_{RL2})}{\underline{Z}_{R2} + \underline{Z}_{C2} + \underline{Z}_{RL2}}}$$

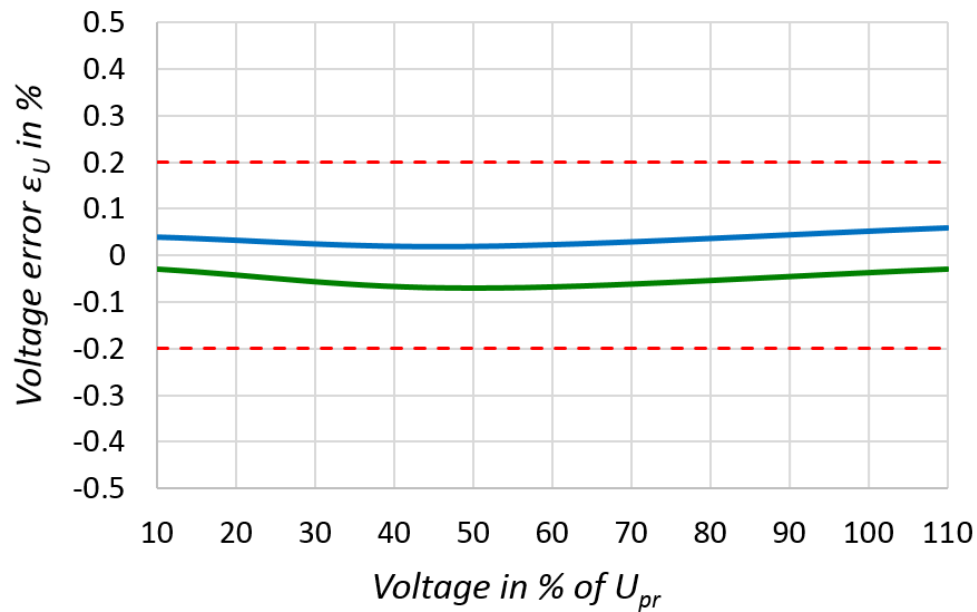
Performance – DC performance



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Performance – AC performance @ f_R

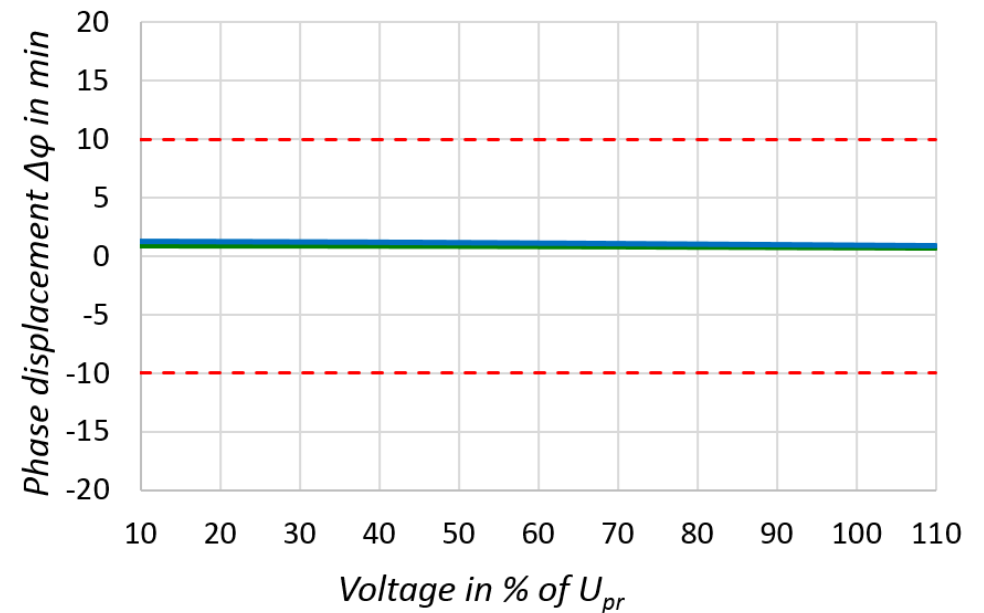
Linearity measurement



Type RGK 320DC;

Serialnumber 1: **Blue** / Serialnumber 2: **Green**

Limits of class: dashed **red** lines.



Type RGK 320DC;

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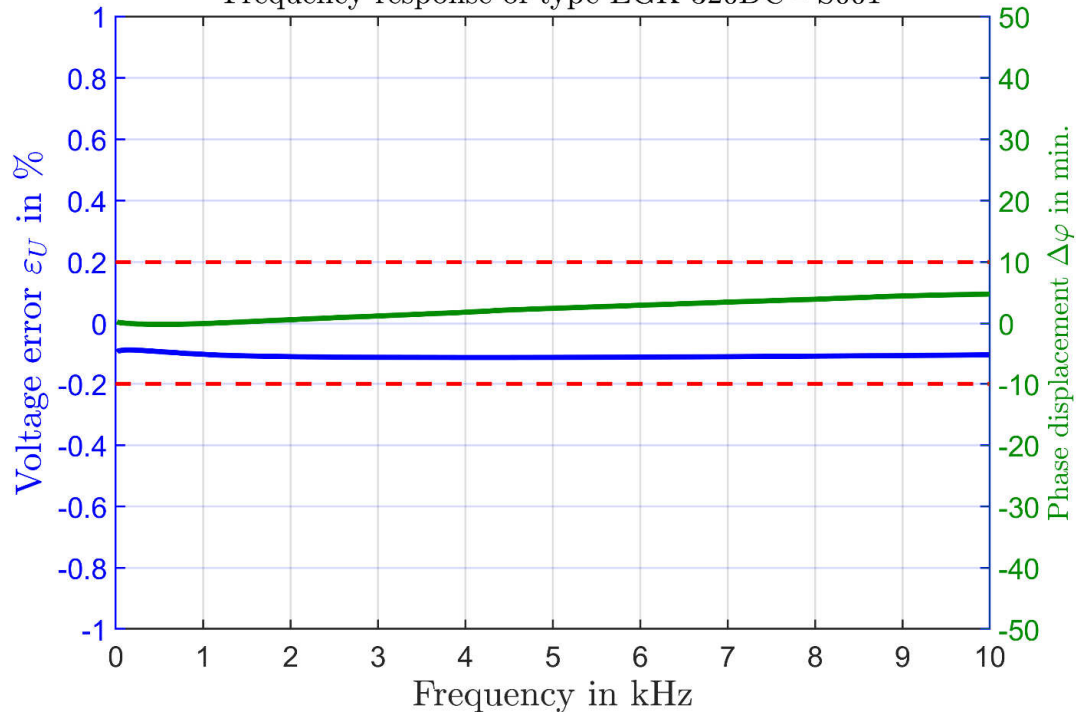
Limits of class: dashed **red** lines.



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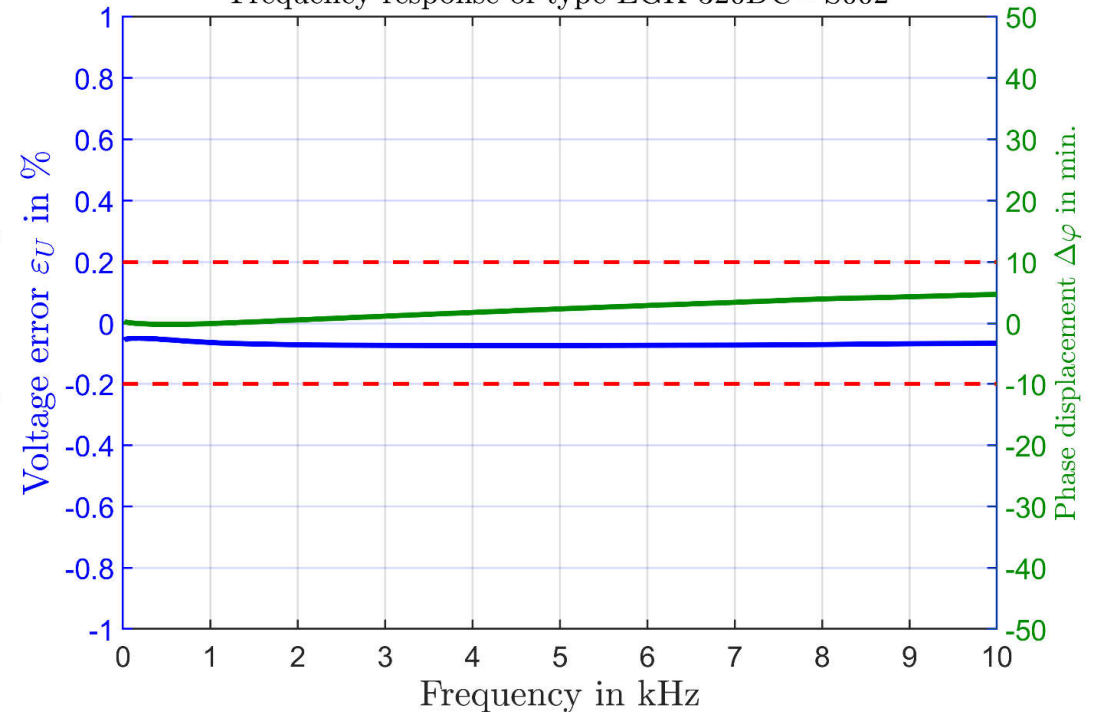
Performance – AC performance @ $f < f_R$ & $f > f_R$

Frequency response of type EGK 320DC - S001



Serialnumber 1

Frequency response of type EGK 320DC - S002

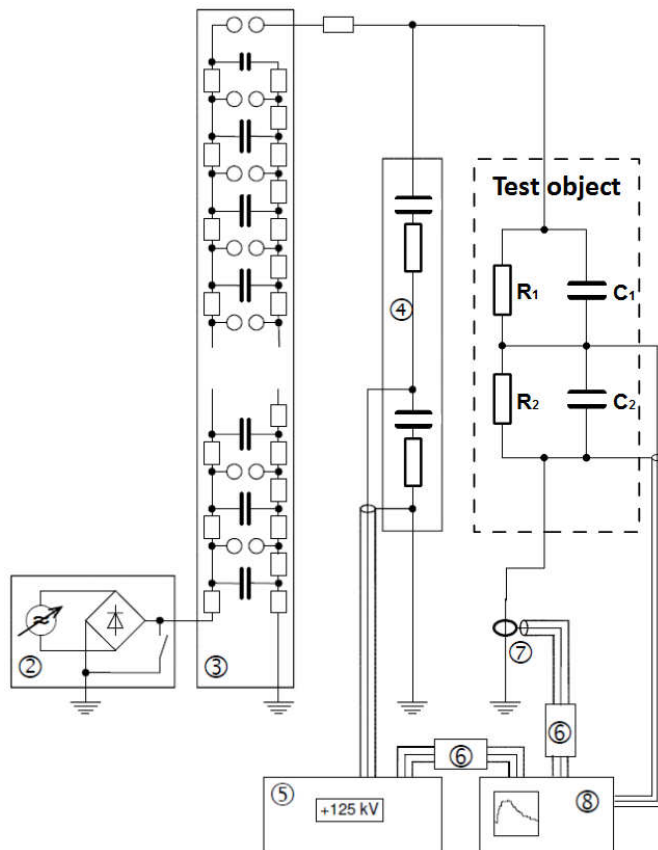


Serialnumber 2



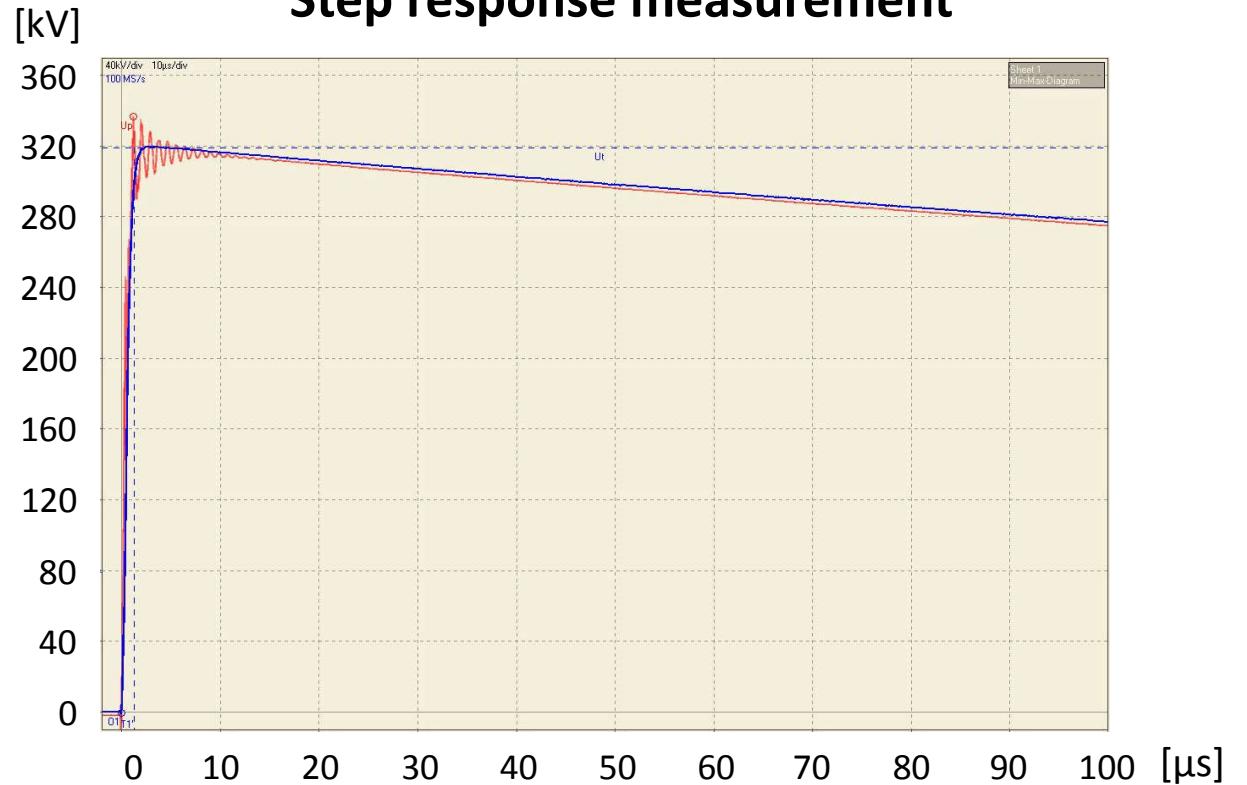
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Performance – Transient performance @ $f > 800\text{kHz}$



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Step response measurement



Blue curve: Impulse reference divider,

Red curve: RC-divider RGK 320DC

Technical design

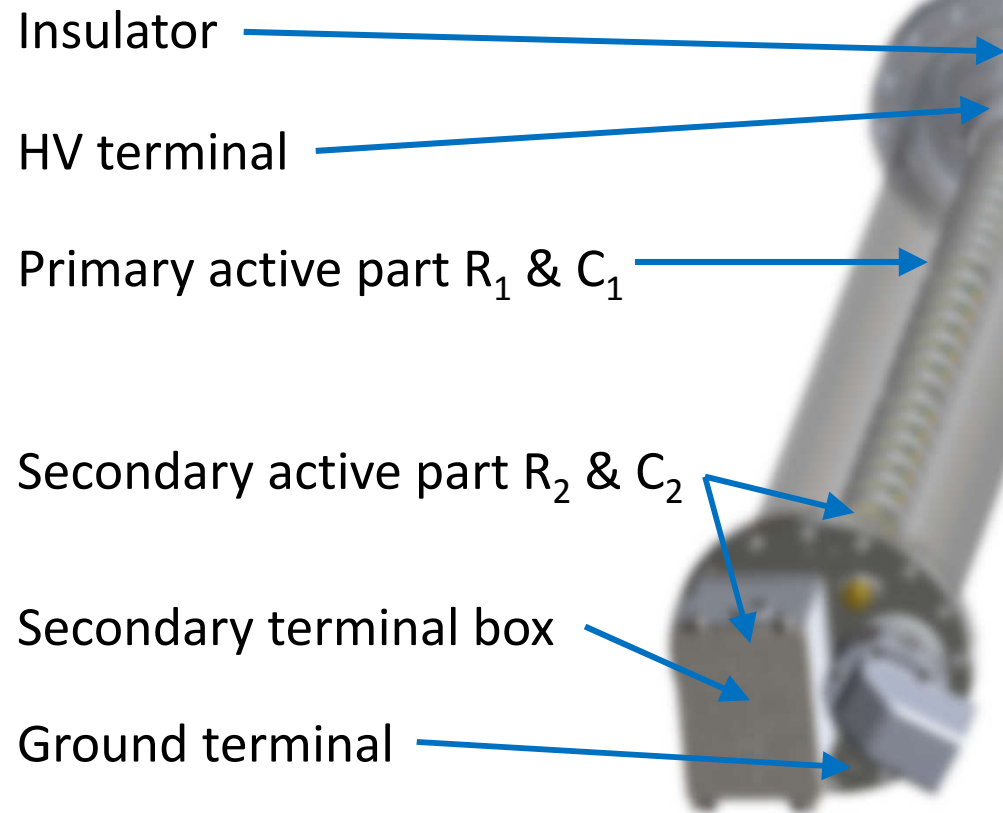


RGK 400DC, Switzerland



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Type RGK



International standards

Non-conventional type



Since summer 2018, special product standards for AC/DC RC-divider are available

Instrument transformers (TC38)

- **IEC 61869 – 1** GENERAL REQUIREMENTS
- **IEC 61869 – 6** ADDITIONAL GENERAL REQUIREMENTS FOR LOW-POWER INSTRUMENT TRANSFORMERS
- **IEC 61869 – 11** ADDITIONAL REQUIREMENTS FOR LOW-POWER PASSIVE VOLTAGE TRANSFORMERS
- **IEC 61869 – 15** ADDITIONAL REQUIREMENTS FOR VOLTAGE TRANSFORMERS FOR DC APPLICATIONS

Coupling capacitors and capacitor dividers (TC33)

- **IEC 60358 – 1** General rules
- **IEC 60358 – 4** AC or DC single-phase capacitor-divider and RC-divider connected between line and ground



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International standards

Tests	Subclause	Comments PFIFFNER
Type tests	7.2	
Temperature rise test	7.2.2	OK
Impulse voltage withstand test on primary terminals	7.2.3	OK
Wet test for outdoor type transformers	7.2.4	OK
Polarity reversal test with partial discharge measurement	7.2.1501	excluding PD measurement
Electromagnetic compatibility tests	7.2.5	OK
Test for accuracy	7.2.6	OK
Test for accuracy versus harmonics	7.2.1502	Frequency response measurement This is a routine test
Verification of the degree of protection by enclosures	7.2.7	OK
Enclosure tightness test at ambient temperature	7.2.8	OK
Pressure test for the enclosure	7.2.9	OK
Low-voltage component voltage withstand test	7.2.601	OK
Measurement of the step response time	7.2.1503	This is a routine test

Tests	Subclause	Comments PFIFFNER
Routine tests	7.3	
Power-frequency voltage withstand test on primary terminals	7.3.1	OK
Partial discharge measurement	7.3.2	OK
Power-frequency voltage withstand test between sections	7.3.3	OK
DC applied voltage withstand test with partial discharge measurement	7.3.1501 1h at positive polarity	excluding PD measurement 1h or 2h both polarities
Power-frequency voltage withstand test on secondary terminals	7.3.4	OK
Test for accuracy	7.3.5 from 0.05 to 125 of U_{pr}	OK from 0.05 to 150 of U_{pr}
Verification of markings	7.3.6	OK
Enclosure tightness test at ambient temperature	7.3.7	OK
Pressure test for the enclosure	7.3.8	OK
Power-frequency voltage withstand test for low-voltage components	7.3.601	OK
Measurement of capacitance	7.3.1502	OK
Measurement of resistance	7.3.1503	OK



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Special tests performed on DC dividers



Very fast transient tests

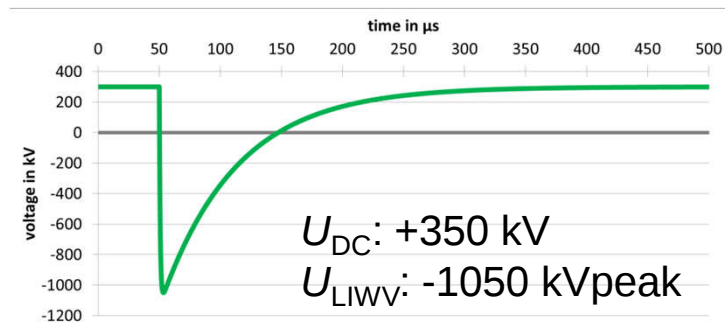
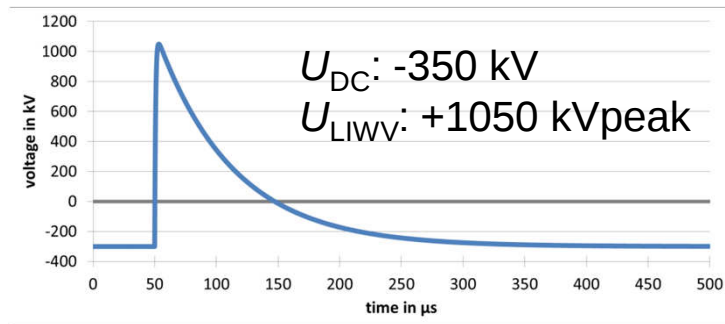
- 200 switching operations
- Check of capacitance values
- 200 switching operations
- Routine test
- Visual inspection



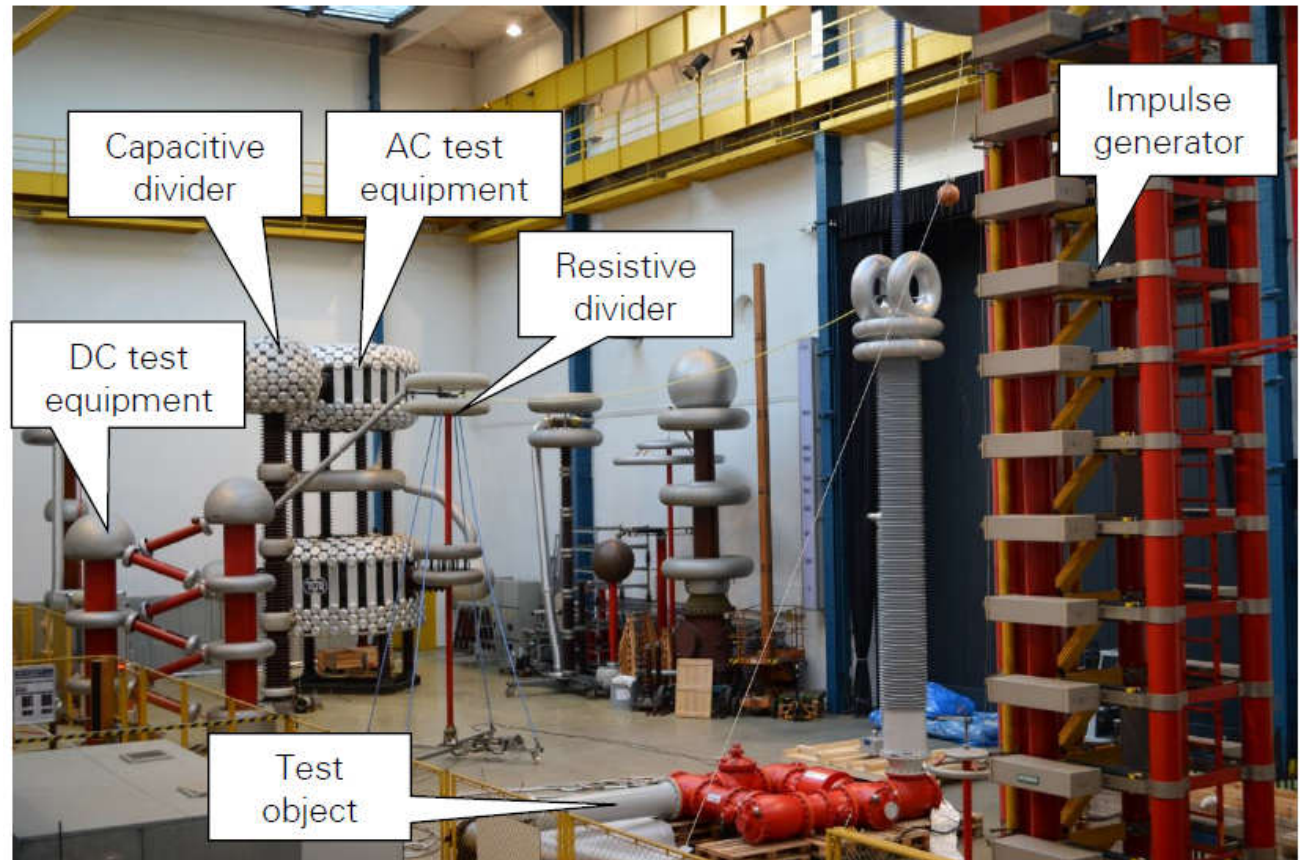
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Special tests performed on DC dividers

Super imposed withstand tests



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Impressions



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Type test approval, University of Karlsruhe / Germany

Impressions



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Long term tests, University of Dresden / Germany

Impressions



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Routine tests, University of Karlsruhe / Germany