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Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS1-10684

Diagnostic and testing on GIS voltage dividers for HVDC applications

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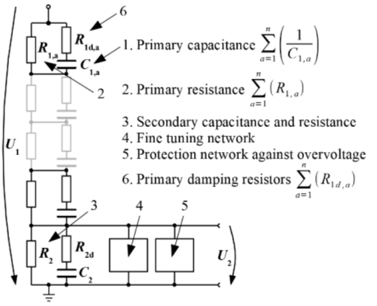
Motivation

- High activities on HVDC GIS development
- High precise measurements on composite voltages for:
  - ± DC & ± LIWV combination
  - ± DC & ± SIWV combination
- International existing standardization IEC 61869-15 does not provide information about composite voltages, how to measure and sufficient accuracy classes. Also, polarity on different test voltages are not in line with D1/B3.57 with TB 842
- Development and special testing of a *universal divider*, type RCR, in GIS design for online diagnostics in operation

Principles of dividers designs

- The Equivalent circuit diagram (ECD) of a *universal divider* needs to include serial damping resistors $R_{1d,a}$ to prevent voltage oscillations
- The identic time constant of primary part and secondary part is vital to obtain the correct mapping of the primary voltage shape



Simplified RCR-divider ECD

- The **identic** time constant relation of the main parallel elements

$$\tau_1 = \tau_2 = R_1 \cdot C_1 = R_2 \cdot C_2$$

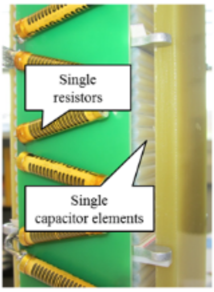
- The **identic** time constant relation of the main serial elements

$$\tau_1 = \tau_2 = R_{1d} \cdot C_1 = R_{2d} \cdot C_2$$

- Individual ratio factor *K* for DC, AC and transient follows according to

$$K = \frac{\underline{U}_1}{\underline{U}_2} = \frac{\underline{Z}_1 + \underline{Z}_2}{\underline{Z}_2}$$

Mechanical design

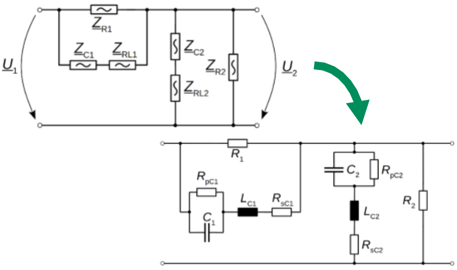


Sectional view of a GIS divider active part

- Parallel resistors: non-inductive type with individual accuracy of 0.2%, a TC with10 ppm/K and VC with 1ppm/V
- Single capacitor elements, type All film, with individual accuracy of 2%, a TC with -250 ppm/K
- Serial damping resistors, non-inductive type with individual accuracy of 1%
- **Several small units** consisting of $R_{1,a}$, $R_{1d,a}$ and $C_{1,a}$ are build and connected in series.

Precise circuit diagram

- Based on impedance view of ECD, an advanced ECD illustrates all significant elements including frequency dependencies



(Upper) Impedance ECD. (Lower) Advanced ECD in element view.

Primary part		Secondary part	
R_1	Main resistance	R_2	Main resistance
C_1	Main capacitance	C_2	Main capacitance
R_{pC1}	Resistive component of tan δ value	R_{pC2}	Resistive component of tan δ value
L_{C1}	Leak inductance	L_{C2}	Leak inductance
R_{sC1}	Serie resistance value	R_{sC2}	Serie resistance value

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- Mathematical discussion can be found in paper D1-11110 “Requirements, design principles and testing experience with composite voltages on a ±550 kV HVDC GIS voltage divider”
- Voltage error ε_U and the phase displacement Δφ follows as

$$\varepsilon_U = \frac{K \cdot U_2 - U_1}{U_1} \cdot 100 \ [\%]$$

$$\Delta\varphi(\omega) = \arctan\left(\frac{\mathrm{Im}\{\underline{F1}\}}{\mathrm{Re}\{\underline{F1}\}}\right) - \arctan\left(\frac{\mathrm{Im}\{\underline{F2}\}}{\mathrm{Re}\{\underline{F2}\}}\right)$$

The impact of leak inductance

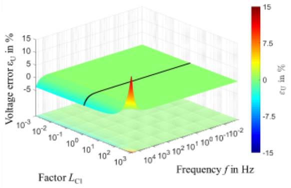
- The primary leakage inductance L_{C1} is measured with a length-dependent value characteristic of 1.5µH/m for GIS solutions
- Inductive ratio $K_L = \frac{L_{C1}}{L_{C2}}$ and must follow K
- Primary and secondary resonance point has an impact on the frequency response behavior in terms of accuracy performance

$$f_{res1} = \frac{1}{2\pi \cdot \sqrt{L_{C1} \cdot C_1}} \qquad f_{res2} = \frac{1}{2\pi \cdot \sqrt{L_{C2} \cdot C_2}}$$

$f_{res1} < f_{res2}$	Primary resonance is dominant, voltage error has a ***positive*** trend
$f_{res1} > f_{res2}$	Secondary resonance is dominant, voltage error has a ***negative*** trend

Theoretical system response by varying L_{Cx} and C_x elements

Element variation		ε_U	Δφ
L_{C1}	↑	+	−
	↓	−	+
L_{C2}	↑	−	+
	↓	+	−
C_1	↑	+	+
	↓	−	−
C_2	↑	−	−
	↓	+	+

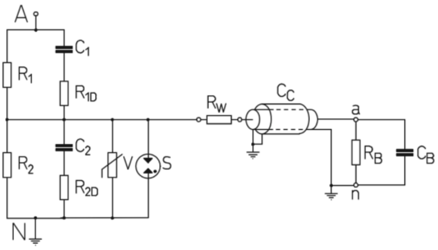


Voltage error by L_{C1} variation

- Stray- or leak inductance elements must be considered to shift the first resonance point > 1.5MHz

Electrical design parameter first performance verifications

- Based on the advanced ECD and under consideration of transmission cable and burden values, the following figure and table provides the final solution

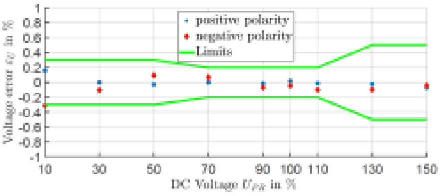


Schematic diagram of the GIS RCR-divider

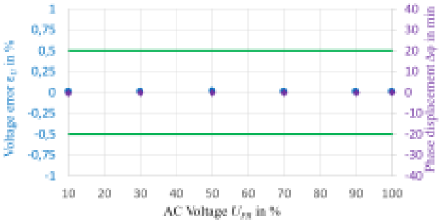
Main element values of the GIS RCR-divider

Primary part		Secondary part	
R_1	2244 MΩ	R_2	28.86 MΩ
C_1	436.8 pF	C_2	518.3 nF
R_{1D}	295 Ω	R_{2D}	258 mΩ
R_W	51 Ω	R_B	2 MΩ
C_C	5.05 nF	C_B	33 pF
V	Varistor	S	Spark gap

- DC accuracy measurement from 10% up to 150% of U_{pr}



- AC accuracy measurement from 10% up to 100% of $U_{pr}/\sqrt{2}$



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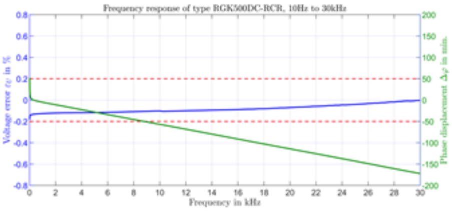
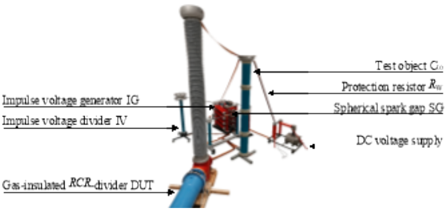
- Frequency response measurements at 250V from 15Hz up to 30kHz



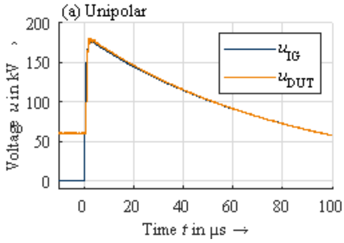
Test setup and results of composite voltage measurements

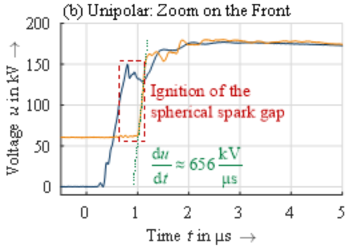
- Principle test setup for the superposition of Impulse voltages and DC voltages. Spherical spark gap was used to decouple DC from LI



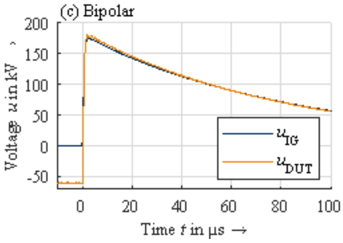
Photograph of the test circuit

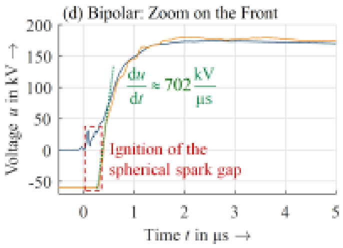
- **Results** Unipolar, both voltages + polarity
- orange DUT: device under test, blue: reference measurement system





- **Results** Bipolar, DC voltages – polarity & LIWV + polarity





- The same test are successfully performed with a combination of DC voltage combined with SIWV. Due to the significant lower frequency content, only the DC + LIWV is shown.

Conclusion

- Missing information in relevant standard IEC 61869-15 must be implemented, based on JWG D1/B3.57. Test voltage levels and polarity as well as accuracy classes for different type of voltage signals.
- When considering stray inductance phenomenon in the design process, the first natural frequency can be moved above 1.5 MHz
- The correct design and accurate calculation of the resistance value of the primary serial damping resistance allows to measure impulse voltages up to a front time of 0.84µs.
- Due to the excellent performance of the discussed type of RCR-divider, following monitoring applications are possible in the future:

  - Condition monitoring of the grid for system reliability and accelerated ageing process detection
  - Measurement of frequency-dependent network impedance
  - Detection of lightning or transient overvoltage
  - Travelling wave applications
  - Monitoring of reignition phenomenon during switching operation of circuit breakers
  - Classical partial discharge measurement in the field