WP5 - Task 5.2

Impulse current and short circuit current measurements
Task 5.2 Impulse current and short circuit current measurements

Context

- High-impulse currents occur in high voltage power systems:
  - Lightning strikes
  - Switching operations of circuit breakers
  - Switching manoeuvres in gas-insulated switchgear
  - Electromagnetic pulses

The understanding of higher current events is important for the management of power quality.
Task 5.2 Impulse current and short circuit current measurements

- **Objectives**
  
  ✓ Identify suitable sensors for impulse and fast transient currents up to 60 kA

  ✓ Characterization of the complete measurement system with a target uncertainty of 0.1 %

- **Parameters of 8/20 µs signals**

  Peak value, $U_{\text{peak}} < 60$kA

  Front time, $T_1 : 8$ µs

  Time to half value, $T_2 : 20$µs
Specifying the existing transducers and first selection

Selection of transducers

- Rated current range
- Large bandwidth
- Dynamic performances to accurately capture the short-lived events
- Linearity
- On-site measurements

**Pearson coil**

\[ N_1 I_1 = N_2 I_2 \]

\[ E = \mu_0 NA \frac{dl}{dt} \]

\[ V_{out} = \frac{\mu_0 NA}{C_1 R_0} I \]

- **Pearson**
  - 50 000 A
  - 0.25 Hz to 4 MHz
  - 10 mV/A

- **Rogowski**
  - 50 000 A
  - 0.6 Hz to 1 MHz
  - 0.1 mV/A
Task 5.2 Impulse current and short circuit current measurements

- **Measurement chain**: comparison method

- **8/20 µs Impulse Current Generator**

- **Digitizer**
  - 12 Bit, 100 MS/s

- **2 Current transducers**
  - Different technologies

- **Pass over the generator fluctuations and other common factors**

- **Share the advantage of two different technologies**

- **Rigid bar circuit with modular geometry designed**
Digitizer characterization according to EN 61083-1: 2001

✓ Internal noise level (quantization noise): \( 8 \cdot 10^{-4} \) of FSR
  
  Limits: \( 40 \cdot 10^{-4} \) of FSR

✓ INL - Integral Non-Linearity

\[ \varepsilon_{\text{NLIS}}^{\text{min}} = -1.62 \cdot 10^{-4} \]

\[ \varepsilon_{\text{NLIS}}^{\text{max}} = +1.85 \cdot 10^{-4} \]

Limits:

\[ \varepsilon_{\text{NLIS}} = \pm 50 \cdot 10^{-4} \text{ of } FS \]
Digitizer characterization according to EN 61083-1: 2001

DNL – Differential Non-Linearity

**Static**

\[ \varepsilon_{\text{NLDS}}^{\text{min}} = -0.43 \text{ LSB} \]

\[ \varepsilon_{\text{NLDS}}^{\text{max}} = +0.37 \text{ LSB} \]

Limits: \( \varepsilon_{\text{NLDS}} = \pm 0.8 \text{ LSB} \)

**Dynamic**

\[ \varepsilon_{\text{NLDD}}^{\text{min}} = -0.27 \text{ LSB} \]

\[ \varepsilon_{\text{NLDS}}^{\text{max}} = +0.27 \text{ LSB} \]

Limits: \( \varepsilon_{\text{NLDS}} = \pm 0.8 \text{ LSB} \)
Digitizer characterization according to EN 61083-1: 2001

## Uncertainty Budget

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Estimated value ( x_i )</th>
<th>Probability distribution</th>
<th>Standard uncertainty ( u(x_i) )</th>
<th>Sensitivity coefficient ( c_i )</th>
<th>Uncertainty contribution ( u_i(y) = c_i \cdot u(x_i) )</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantization error, ( \epsilon_q )</td>
<td>0.4</td>
<td>Rectangular</td>
<td>( \frac{0.4}{\sqrt{3}} )</td>
<td>1</td>
<td>( \frac{1}{2850} )</td>
<td>( 0.8 \times 10^{-4} )</td>
</tr>
<tr>
<td>Integral linearity error (ILE), ( \epsilon_{ILE} )</td>
<td>1</td>
<td>Rectangular</td>
<td>( \frac{0.6}{\sqrt{3}} )</td>
<td>1</td>
<td>( \frac{1}{2850} )</td>
<td>( 1.2 \times 10^{-4} )</td>
</tr>
<tr>
<td>Offset error, ( \epsilon_{off} )</td>
<td>0</td>
<td>Normal</td>
<td>( \frac{0.75}{3} )</td>
<td>1</td>
<td>( \frac{1}{2850} )</td>
<td>( 0.4 \times 10^{-4} )</td>
</tr>
<tr>
<td>Gain error, ( \epsilon_{gain} )</td>
<td>0</td>
<td>Normal</td>
<td>( \frac{0.375}{3} )</td>
<td>1</td>
<td>( \frac{1}{2850} )</td>
<td>( 0.4 \times 10^{-4} )</td>
</tr>
<tr>
<td>Sampling error, ( \epsilon_s )</td>
<td>0</td>
<td>Rectangular</td>
<td>Neglected Since sampling time(10ns)&lt;&lt;Time(( \mu )s) when measured value is constant</td>
<td>1</td>
<td>( \frac{1}{2850} )</td>
<td>0</td>
</tr>
<tr>
<td>Step voltage relative error, ( \frac{u(U_{ref})}{U_{ref}} )</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>1 ( \times 10^{-4} )</td>
<td>B</td>
</tr>
</tbody>
</table>

\[
U_{\text{digitizer}} \left|_{k=1} \right. = 3.2 \times 10^{-4}
\]

Value allowing to maintain the \( 10^{-3} \) targeted uncertainty for the complete measurement system.
Current step generator

- Dynamic characterization of the impulse current sensors and measurement chain

- High level of current (~ 100A)
- Steep falling slope (tens of ns)
- Low parasitic inductance and capacitance
Measurement chain step response

Response parameters for a 50A current step

Pearson coil
Settling time, $t_s = 1.87 \mu s$

Rogowski coil
Settling time, $t_s = 5.59 \mu s$

The attenuation of the step responses in few $\mu s$ indicates no influence on the measure of 8/20 $\mu s$ impulse currents.
Impulse current measurements up to 60 kA (peak value)

Normalised impulse waves, Pearson, Rogowski

Frequency spectra

Site measurements
Results for the impulse currents up to 60 kA

Analysis parameter: the mean value of the difference (absolute value) between the 2 transducers for a set of 10 measurements

✓ Peak Value \(2 \cdot 10^{-4}\)
✓ Front Time \(2 \cdot 10^{-2}\)
✓ Time to Half Value \(5 \cdot 10^{-3}\)

⇒ Reduced dispersion between Pearson and Rogowski coils for the measurement range

⇒ Comparison method validation
Link between measurements of current pulses and calibrations at 50 Hz

Gain $8/20\,\mu s = \text{Gain }^{50\text{Hz}}$ ?

What we know

**Pearson sensor** – 8/20 μs

✓ Designed for pulse currents
✓ Adapted dynamic

**Rogowski coil** – 50Hz

✓ Accept high power frequency currents
✓ Low dynamic

What we need to know

A Sensors performances
  • Linearity up to 60 000 A
  • Frequency response from 50 Hz to 100 kHz

B How does the digitizer influence the dynamic gain to be established?
Link between measurements of current pulses and calibrations at 50 Hz

- Frequency response of sensors and digitizer

**Pearson gain, 200A, sinusoidal**

- GainP [mV/A] vs. f [kHz]

**Rogowski gain, 200A, sinusoidal**

- GainR [mV/A] vs. f [kHz]

**Digitizer Errors [%], Channel 1**

- Digitizer Errors [%] vs. F [kHz]

**Digitizer Errors [%], Channel 2**

- Digitizer Errors [%] vs. F [kHz]
Link between measurements of current pulses and calibrations at 50 Hz

Approach

Sinusoidal regime

8/20 µs impulse

Rogowski coil → GainRogowski_{50Hz,5kA} → GainRogowski_{8/20µs}

Digitizer

Software treatment

Pearson sensor → Corrections_{10kHz} → GainPearson_{8/20µs}

GainPearson_{50Hz}
Results

- [5 kA; 50 kA] the obtained gain for Pearson sensor is constant at ±0.1%
- \( \hat{I} < 5 \text{ kA} \) SNR impact
- \( \hat{I} > 50 \text{ kA} \) Sensors out of range specifications
Conclusions

- Commercial sensors might be used for 8/20µs impulse current measurements with an uncertainty of 0.1% (k=1)
- On-site measurements indicate a reproducibility of $3 \times 10^{-4}$
- Quality of the analysed sensors allows to use them as impulse current standards

![Graph showing Pearson/Rogowski output ratio over time with uncertainty bars.](image_url)
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Thank you for your attention.