Application of Charge-Sensitive Preamplifier for the Calibration of Partial Discharge Calibrators below 1 pC

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***Abstract* — Modern partial discharge calibrators often have their lowest range below 1 pC. However, traceable calibration services below 1 pC charges are not widely available, or their uncertainties are relatively high because of low signal levels. Application of charge-sensitive preamplifier for the calibration of partial discharge calibrators provides a promising solution. This new calibration method both improves signal levels and integrates the partial discharge pulse. The characteristics of the preamplifier can be corrected using a software, but after that the partial discharge calibrator calibration results have good signal level and repeatability. Estimated uncertainty is below 2 % for 0.1 pC.**

***Index Terms* — Calibration, measurement, measurement techniques, measurement uncertainty, partial discharges.**

I. INTRODUCTION

Modern commercial partial discharge (PD) calibrators often have their lowest charge level as 0.1 pC. However, at the moment National Metrology Institutes (NMIs) provide traceable calibration services for apparent charge starting from 0.5 pC and the relative uncertainty at this level is 20 %. This uncertainty is approximately one order of magnitude higher than the uncertainties that are given for the charge levels above 10 pC. [1]

IEC 60270 [2] describes three methods for the calibration of PD calibrators. The reference method is by comparison with a reference calibrator. Second method is to use numerical integration method, where a PD calibrator is connected to a reference resistor. Voltage across the resistor is measured with a digitizer and the measured impulse voltage is numerically integrated with a software resulting the apparent charge. Third approach is the step voltage response method, where a PD calibrator is connected to a measuring capacitor and the voltage is measured over the capacitor using a digitizer. The apparent charge is calculated from the measured voltage and capacitor values.

Common problem for all the presented methods is that when the charge levels are low, also the measured voltage level is low. For example, with the numerical integration method the typical amplitude of the 0.1 pC signal is approximately 1 mV with the highest approved resistor value of 200 Ω. This low voltage level is very difficult to measure accurately with a digitizer.

Hauschild and Lemke [3] have pointed out that on low PD level below 10 pC, use of an electronic integrator will significantly amplify the voltage, and improve signal to noise ratio. Charge-sensitive preamplifiers (CSPs) are integrating devices and they can be used in order to convert charge into voltage. CSPs are commonly available products and their amplifying ratios can be hundreds of mV per pC. This approach will give high enough voltage to be measured accurately with digitizers. This paper studies the possibility to use commercially available CSPs for calibration of PD calibrators, especially with low charge levels (< 1 pC).

II. METHOD

After comparing specifications of a number of different models, the most suitable one was selected for this study [4]. Nominal gain of this device is -0.13 V/pC, equivalent rms noise charge 0.1 fC, and nominal rise time 5 ns. The output droops because the feedback capacitor of the amplifier discharges through the feedback resistor. The nominal *RC* time constant of the CSP is 150 µs, and it can be seen as a decaying tail in raw output voltage in Fig. 1.

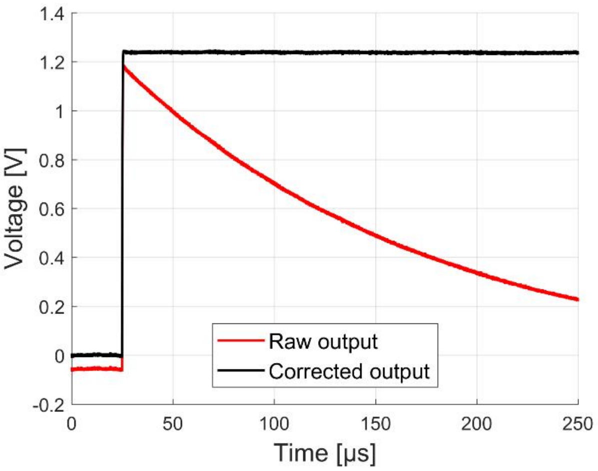

Fig. 1. Output of the charge amplifier for -10 pC charge from reference calibrator, showing the raw data and corrected output after offset and droop corrections. The input signal is a short (<300 ns) -10 pC PD pulse from a reference calibrator.

Two operations are performed to the raw output. First, the offset is removed by calculating the level from the beginning of the trace, and subtracting it from the measured voltage curve. The second thing is to remove the decaying effect due to *RC* time constant. This is done with droop-correction in time domain. The first order decay can modelled by

$$U_o(\omega) = \frac{j\omega}{j\omega+\omega_c} U_i(\omega), \quad (1)$$

where U_i and U_o are the input and output voltages, and $\omega_\mathrm{c}=1/RC$. The corresponding inverse filtering is performed by

$$U_i(\omega) = \frac{j\omega+\omega_c}{j\omega} U_o(\omega) = 1 + \frac{\omega_c}{j\omega} U_o(\omega), \quad (2)$$

and it can be represented in time domain by

$$U_i(t) = U_o(t) + \omega_c \int_0^t U_o(t)\,dt. \quad (3)$$

The integration is easy to implement into software. Using the nominal value of 1/(150 µs) for ω_c already leads to good cancellation of the droop effect. In Fig. 1 the integration constant ω_c is adjusted to provide flat response, according to the known characteristics of the reference calibrator. This adjusted value was used for the following measurements.

Now the gain of the CSP can be calibrated traceably by using a reference charge method. In this method, a calibrated reference capacitor connected to the input of the CSP is charged to a known voltage, which is then shorted to ground by using a mercury-wetted relay. Reference charge can be calculated as

$$Q = CU, \quad (4)$$

where U is the charging voltage of the reference capacitor C.

Software calculates the apparent charge using the average of output voltage from 1 to 3 µs after the beginning of the step. This method was chosen because PD calibrators should have a step voltage duration longer than 5 µs [2]. By discarding the first and last µs of the step voltage, possible transients caused by the sudden change of charge are neglected. Reference capacitor (or injection capacitor of PD calibrator) affects to the gain of the CSP [5]. However, the effect of the reference capacitance was found negligible in this case. Voltage linearity was also tested and the effect was also negligible. Estimated uncertainty for the CSP gain calibration is less than 1 % ($k = 2$).

III. RESULTS

CSP was used for calibration of commercial PD calibrator. PD calibrator was connected to the input of the CSP using a BNC connector and the output of the CSP was connected to the reference digitizer input. The digitizer measured the impulse voltage and the evaluation was done with a software. Calibration result with estimated uncertainty is presented in Table 1. Result is an average of 12 individual pulses.

Table 1. Example of calibration result with CSP.

Nominal value [pC]	**Measured with CSP [pC]**	**Standard deviation**	**Estimated uncertainty (*k* = 2)**
-0.1	-0.0969	0.6 %	< 2 %

Estimated uncertainty consists of the uncertainty of the digitizer and CSP gain drifts and standard deviation. Output voltage of the CSP for -0.1 pC charge is presented in Fig. 2.

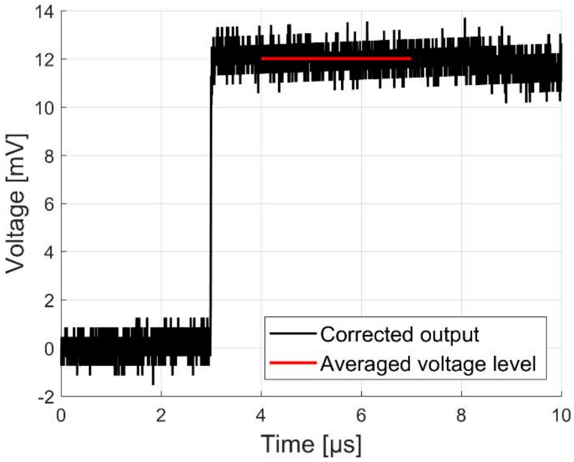

Fig. 2. Single shot trace of the charge amplifier output for -0.1 pC charge from a commercial PD calibrator after offset and droop corrections. Oscilloscope (8-bits, 1 GHz bandwidth) was used with 1 MΩ input and 500 MS/s sample rate.

IV. CONCLUSION

Charge-sensitive preamplifier is promising way to calibrate PD calibrators below 1 pC because it offers a higher signal level and good repeatability together with low noise level. Tested preamplifier can be used for calibration of higher charge levels up to 20 pC. Estimated uncertainty for measurements down to 0.1 pC is below 2 % ($k = 2$), which is at least one order of magnitude lower than currently available from National Metrology Institutes.

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