Development of a Wideband Current-to-Voltage Transformer Set for Currents up to 2 kA

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Development of a Wideband Current-to-Voltage Transformer Set for Currents up to 2 kA

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***Abstract* — This paper describes the setup and characterization of a set of wideband Current-to-Voltage (C-to-V) transformers equipped with symmetrical primary windings. The objective is to use the C-to-V transformer set to calibrate digital instrument transformer (IT) accurately at power frequency and within a wider frequency range to cover power quality aspects. The errors of the 50 A and the 200 A reference current transformer (CT) were within ±10 ppm and µrad at 50 Hz. The frequency responses of the two CTs up to 12 kHz were below 0.1 % and 0.2 crad.**

***Index Terms* — Wideband, current transformers, calibration, measurement uncertainty, instrument transformers.**

I. Introduction

According to IEC 61850, digital measurements are gradually coming into use in substations [1]. The European project "FutureGrid II" is aimed at providing hitherto missing solutions for the calibration and timing of the new type of substation instrumentation. One of the objectives of FutureGrid II is to develop new reference standards and calibration systems for the dynamic calibration of digital instrument transformers. For the setup of such a measuring system for calibrating CTs with digital interface and to evaluate its standard uncertainty according to the drafted IEC/IEEE TS 61869-105 [2], wideband reference sensors are required. In this paper, the setup of a set of reference C-to-V transformers and its characterisation up to 2 kA from 16 Hz to 12 kHz is presented.

II. Development of the C-to-V Transformers

The reference C-to-V transformer consists of a CT with a precise measuring resistor connected to the secondary of the CT. A set of four commercial zero-flux current transformers [3], [4] with rated currents of 50 A (CT50), 200 A (CT200), 600 A (CT600) and 2 kA (CT1500) was used to establish the reference transformer set. To convert the different secondary currents of this transformer set into a 1 V output voltage, a resistor box, containing precision resistors [5] from 1 Ω to 20 Ω was built. The ratio $\underline{F}_{IU}$ of the realised C-to-V transformer can be defined according to

$$\underline{F}_{IU} = \underline{U}_S / \underline{I}_P = R_m / K_n \cdot (1 + \varepsilon_m + \varepsilon_i) \cdot e^{j\cdot(\delta_m + \delta_i)} \qquad (1)$$

where K_n is the rated current transformer ratio $I_{P,r} / I_{S,r}$, ε_i and δ_i represent the ratio errors and the phase errors of the CT, ε_m and δ_m represent the error of the of the measuring resistor R_m and its phase error.

A. Setup of the C-to-V Transformers

The usability and expected metrological characteristics of the window type zero-flux transformer were improved by implementing several symmetrical primary windings to the CT. The rated primary currents of the C-to-V transformer set ranges from 8.3 A to 1500 A. As an example, the symmetrical winding configuration of the added primary of the CT200 is illustrated in detail in Fig. 1 (left) from a vertical view. The connection scheme for the different primary windings N_p = 1 to 4 of the CT200 is shown in Fig. 1 (right).

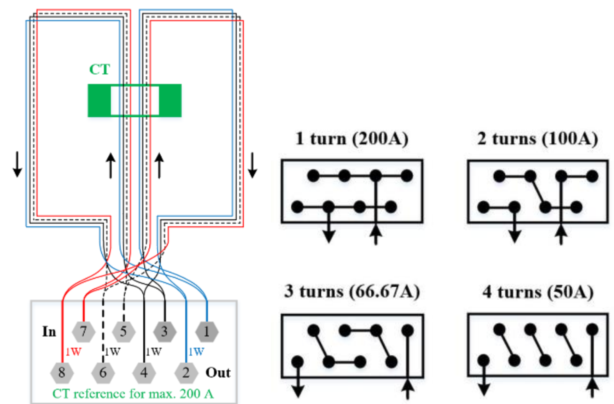

Fig. 1. Scheme of the primary winding arrangement (left) and port connection setups (right) of CT200.

The setup of the improved CT 200 consists of the window type CT itself, several wires for the primary windings, a winding support, fabricated by a 3D printer to fix the geometrical position of the primary wires and a connection box. The symmetry was applied to realise a geometrically fixed measurement environment for the sake of obtaining stable and repeatable CT errors. Additionally, the use of several primary windings allows the realisation of variable transformation ratios K_n. The other CTs (CT50, CT600, CT1500) follow a similar geometrical arrangement.

The conversion of the secondary current to the output voltage for the measuring system was realised with a resistor box, which contains five precision resistors, two power supplies and two separate channels. The nominal values of the resistors (R_1 to R_5) were selected from 1 Ω to 20 Ω. R_1 to R_5 will be realised with two resistors in parallel, and a maximum power of 3 W each [5]. The assembly is currently in process. Therefore, the

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presented measurements were carried out with other precision resistors.

B. Characterization of the C-to-V Transformers

The characterisation of the C-to-V transformers was carried out by separating the behaviour at power frequency and the frequency response. This method allows to split the ratio error ε_i of the CT into two parts: the basic ratio error $\varepsilon_i(f_0)$ at a specific frequency $f_0 = 50$ Hz, and an error difference $\Delta\varepsilon_i(f)$ which describes the frequency response with respect to 50 Hz.

The experiments at power frequency concentrate on two aspects: (i) the error characteristics for different excitation in the different current ranges of each CT; and (ii) the effect of burdening with the measuring resistor. The results for (i) showed that the error variation for currents from 5 % to 120 % of the nominal current range is within ± 1 µA / A and ± 2.5 µrad. The basic errors are practically unaffected by the used current ranges from 50 A ($N_p = 4$) to 200 A ($N_p = 1$). For (ii) the measurements performed with three different burdens from 0 Ω to 5 Ω of the CT proved that the measured errors of CT are almost constant with a variation from (-9.5 to -10.7) ppm and (-4.7 to -6.1) µrad at 50 Hz.

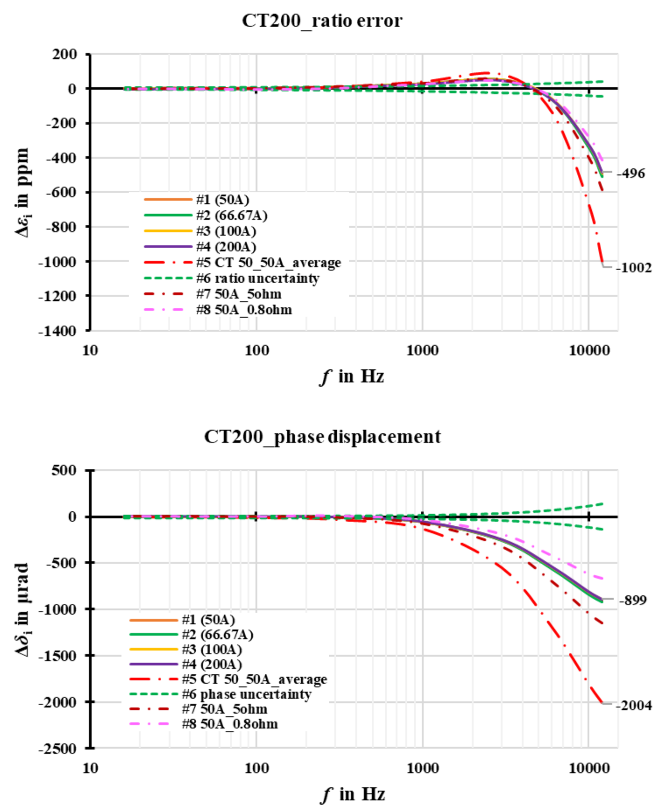

Fig. 2. Frequency response of the ratio errors in the different current ranges of the CT 200 against CT 50.

The evaluation of the frequency response consists of three aspects: the error differences with different current ranges in use, the linearity of the CT at different primary currents and the burdening of the CT. Firstly, measurements of the frequency responses were carried out in the different current ranges of CT200. The CT200 was calibrated with the CT50 [6], which was calibrated before with a set of Fluke A40B [7] and now behaves as the reference. The measured frequency response $\Delta\varepsilon_i(f)$ and $\delta_i(f)$ for the CT200 are displayed by the solid curves (#1 to #4) in Fig. 2. The results show that for all current ranges with a 2.5 Ω measuring resistor, almost identical frequency responses can be obtained. Up to 12 kHz the ratio errors and the phase errors are below 0.05 % and 0.1 crad. For comparison purposes, the averaged frequency response of CT50 is given (curve #5), which clearly shows that the CT200 exhibits approximately half the errors of CT50. Secondly, measurements at rated burden of 2.5 Ω showed that the differences of the frequency responses at test currents 20 % and at 80 % are small and will be used as an uncertainty contribution. Thirdly, the calibration with different burden between 0.8 Ω (#8) and 5 Ω (#7) showed only a small dispersion of ± 100 µA / A for the ratio error and ± 250 µrad for the phase error at 12 kHz.

III. Conclusion

A set of symmetrical C-to-V transformers has been realized as a reference system for calibrating current transformers, as planned in the FutureGrid II project. The rated current ranges are from around 10 A to 1500 A. The errors within the frequency range up to 12 kHz are below 0.1 % and 0.2 crad. The attained expanded uncertainties are below 100 ppm and 300 µrad ($k = 2$). The assembly of the CT1500 is currently in process and calibrations of the whole C-to-V transformer set will be completed in the near future.

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