Calibration system for voltage transformers under distorted waveforms

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Abstract. In this work, we describe a programmable high-voltage source to test the behaviour of voltage transformers under distorted waveforms at nominal voltages, as well as the measurement system for computing their errors at each harmonic component.

1. Introduction

Measurements of voltage harmonic distortion in power networks require of voltage transformers (VT) to reduce the high-voltage level of the lines to a low-voltage level according to the measurement instrument specifications, around 100 V. Their primary voltages are in the range of 6 kV to 500 kV, or even more. Conventional tests are done only at power frequency, but if they are intended to use under distorted waveforms, it is necessary to test them under this condition. Even more, as they are not linear devices, the errors they have under distorted waveform must be tested at nominal voltages [1] [2]. For this reason, a programmable high voltage source was developed. It has the possibility to program any harmonic content, up to the 50th order of the power network frequency. Additionally, the same system allows to measure the errors of the VT under test, for each harmonic component. The following sections describe the developed system.

2. High voltage source

The voltage source comprises three main parts: an arbitrary waveform generator, a power amplifier and a step-up transformer, which are described in the following paragraphs.

2.1. Waveform generator

The waveform generator is based on a digital-to-analogue converter (DAC), with a resolution of 16 bits [3], and a PC running a LABVIEW [4] based software developed for this application. The software has six screens: Generation, Measurements, Secondary, Primary, Ratio and Configuration. The first and the last ones are used to configure the waveform and generate it. In these screens (see figure 1), the fundamental frequency (50 Hz to 60 Hz) and the percentage and angle of each harmonic, up to the 50th order, are entered. The software calculates the values of the data vector and finally loads this vector into the DAC. The output signal of the DAC has a range of ±10 V. A voltage divider attenuates this signal to values compatibles with the input of the power amplifier (0.5 V). There are buttons to record and load distorted waveforms, buttons to load waveforms into the card and to null the output voltage.
2.2 Power voltage source
The power voltage source has two main blocks. The first block is the dc power supply (see figure 2). It uses a 20 kVA, 220 V /110 V, 50 Hz three-phase transformer with two secondary windings, one in delta and the other in star connections. A 12 pulse rectifier converts ac to dc. It has two three-phase full wave rectifiers each. At its output, there is a bank of capacitors (15 mF in total) for filtering. The second block includes a 50-kW class-D audio power amplifier and auxiliary devices, as a 13-V–dc voltage source for the internal signal stage of the amplifier, multi-function meter for monitoring the power factor, current transformer, etc. The amplifier is energized with 300 V generated by the dc power supply. This amplifier can manage signals of 0.5 V, from 50 Hz to 3 kHz. These signals are amplified to values near 200 V rms, with currents of tens of amperes. Additionally, the system uses a series resistor at the output to increase the power factor (not shown in figure 2). Figure 3 shows the arrangement of the different parts of the system in the rack.

2.3 Step-up transformer
The third part of the source comprises a set of step-up transformers with secondary nominal voltages of 6 kV, 15 kV, 30 kV, 60 kV and 100 kV. Their bandwidths depend on the transformer. For the lowest voltage, it covers the range 50 Hz to 3 kHz. As the nominal voltage increases, the bandwidth decreases, attenuating the highest harmonics. Then, to get the required harmonic amplitude at the VT under test, larger values must be set in the waveform generator. This is not a problem, because the actual harmonic content is measured by standard voltage dividers and a harmonic meter. Although the maximum voltage is limited to 100 kV, even up to 500 kV capacitive-VTs were tested, as it is detailed in [1].

Figure 1. Waveform generation screen
Figure 2. Power voltage source block-diagram.

Figure 3. Panel and internal view of the power voltage source.
3. Measurement system

The measuring system comprises high and low voltage dividers, a harmonic measurement standard meter and software to process the data. In this way, the primary and secondary voltages are measured, and their harmonic contents are compared. Figure 5 shows a general diagram.

3.1 Voltage dividers

The primary and secondary voltages of the transformer under test are scaled down by voltage dividers (see figure 6). The primary voltage is scaled down by a capacitive-type-divider made by a 100-pF-SF6.
high voltage capacitor in series with an array of low voltage capacitors of 2 \( \mu \)F. The divider constant has a value of 20 000. The secondary voltage is scaled down by a resistive-type-divider made by a set of high thermal stable resistors (Vishay, Z201). Its input impedance is 20 k\( \Omega \). The arrangement of these resistors has been constructed in such a way that it is possible to obtain two output values. The first one has a divider constant value of about 20 and the second one, a divider constant value of about 40. These two ratios are enough to cover a large range of VTs.

The outputs of the voltage dividers are sent to the harmonic measurement standard meter block.

![Figure 6. High-voltage and low-voltage dividers.](image)

### 3.2 Harmonic measurement standard meter

This block has two analogue-to-digital converters (ADC) that are part of the same card of the DAC [3]. These ADCs have a resolution of 16 bits in 8 differential inputs with ranges: 0.2 V, 1 V, 5 V and 10 V. Our system only uses two of those inputs. Both input channels are digitized synchronously, to allow the phase measurement between them, and the data is sent to the PC.

An Interpolated Fast Fourier Transform algorithm reconstructs the two signals obtaining information about the harmonic content of each one. It includes the amplitude and the phase for each harmonic component. There is a screen of the software for entering the actual ratio values of the voltage dividers (module and phase), and the nominal ratio of the transformer to be tested.

The resulting ratio and phase shifts errors for each harmonic are computed and shown in the Ratio Screen (figure 7). It includes type-A uncertainties. Type B uncertainty was estimated based on the accuracy of the voltage dividers, the ADCs and the harmonic estimation software, around 0.05% in phase and quadrature.
Figure 7. Ratio Screen.

Figure 8 reproduces the Primary Screen that shows the measured waveform of the primary voltage of the transformer under test and its harmonic content (bar graph and table). A similar screen exists for the secondary voltage.

Figure 8. Primary Screen.
4. Conclusions
A system that generates and measures distorted voltage waveforms was described. It can calibrate voltage transformers determining the errors in amplitude and phase for each harmonic, up to the 50th component. It was used for voltage transformers from 6 kV up to 500 kV.

References
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