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Behavior of voltage transformers under distorted waveforms

Daniel Slomovitz [1], Gonzalo Aristoy [1], Alejandro Santos[1], Marcelo Brehm[1], Leonardo Trigo[1]

[1] UTE-Laboratory, Uruguay

E-mail: dslomovitz@ute.com.uy

Abstract: In this work, we present testing results of voltage transformers (VT) errors, under distorted waveforms. Different types of VT used in high voltage power networks were analyzed. This includes inductive as well as capacitive VTs. The main tests were done at nominal voltages, and comparisons with low-voltage testing methods were included.

Keywords: Harmonic, instrument transformer, power network, power quality, high voltage.

1. INTRODUCTION

The continuous proliferation of non-linear loads in power networks leads to increase the harmonic content of the voltage. To mitigate this problem, filters and other devices are used. Anyway, measurements of voltage harmonic distortion are necessary to demonstrate that they are under regulated limits. In high-voltage networks, the voltage measurement is done through voltage transformers (VT) with primary voltages in the range of 6 kV up to 500 kV, or even more. There are different types of VTs. Inductive type (IVT) is based on the same principle than power transformers. They have a magnetic core and primary and secondary windings. Other type called capacitive voltage transformer (CVT) has a high-voltage capacitive voltage divider followed by a conventional medium-voltage transformer. The behavior under distorted waveform is very different for one type, or the other.

International most used standards only propose to test these transformers at power frequency [1, 2]. In this case, the errors at higher frequencies are not known. Additional requirements for harmonic response would be find in other standard [3], but most VT in service were not manufactured to fulfil this standard. Table II of that standard shows the limit ranges for harmonic measurement. They go from 1% and 1° for 1st and 2nd harmonic, and 5% and 5° for harmonics from 3th to 50th. For this work, a high-voltage source with programmable harmonic content was used, as well as a measuring bridge that gives the error in ratio and phase for each harmonic order. They are described in [4].

2. TESTED UNITS

2.1. Inductive type

A low frequency model for inductive voltage transformers (IVT) is shown in figure 1.

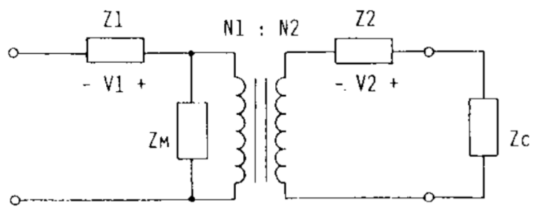

Fig. 1. Model for inductive voltage transformers.

Z_1 and Z_2 are primary and secondary winding impedances. Z_M is the magnetizing branch, modelled by a resistor in parallel with a non-linear inductor. The behavior of this inductor is taken into account modifying its value in function of the applied voltage. At low frequencies, errors in IVTs are due to voltage drops in the series impedance Z_1 and Z_2. We performed two different tests. Low-voltage tests up to 20 kHz, and nominal-voltage tests up to 3 kHz.

A. Low voltage tests

Tests were done with a FRA equipment [5], with voltages around 10 V. Figure 2 to 4 show the behavior of the frequency response of different IVT used in high voltage power networks. Their nominal voltages go from 6 kV up to 150 kV. More results will be presented at the conference.

All curves show a similar behavior up to 2 kHz, corresponding to the 40th harmonic. They remain approximately constant up to 2 kHz. At higher frequencies, some IVTs reduce the ratio voltage, but the 60-kV and 150-kV ones, increase it. The ratio variation at 2 kHz reaches values up to 20% for the 150-kV IVT. Others have lower variations.

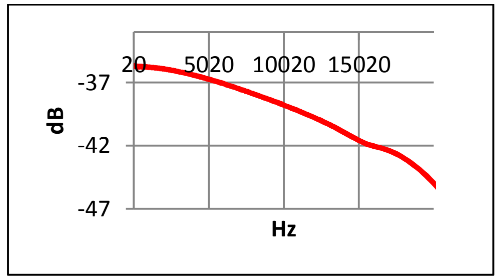

Fig. 2. Frequency response of a 6 kV IVT.

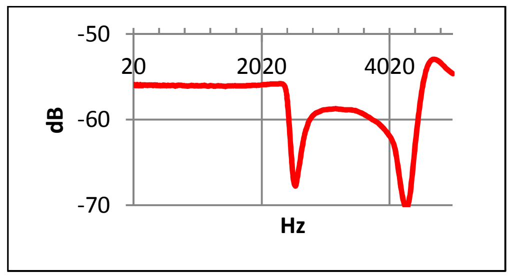

Fig. 3. Frequency response of a 60 kV IVT.

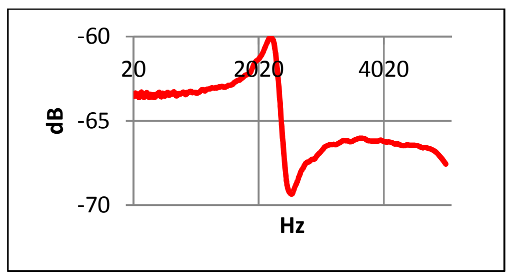

Fig. 4. Frequency response of a 150 kV IVT.

B. Nominal voltage tests

These tests were done at 53 Hz of fundamental frequency, to prevent noise influence from the power network. The voltage at fundamental frequency was set between 80% and 100% of the nominal value. A first test was done adding to the fundamental frequency single tones from 3th (159 Hz) component to 49th (2597 Hz) one. The amplitude of the harmonic components was set around 10%. In this condition, transformer errors were measured for fundamental and each harmonic. A second test was done applying fundamental and all harmonics together. Again, there were measured the transformer error at fundamental and each harmonic component.

Figures 5 to 8 show the ratio error and phase shift with single tones and with high distortion (all harmonic components at the same time). No difference between both tests was detected, which agree with a linear behavior of the tested IVTs.

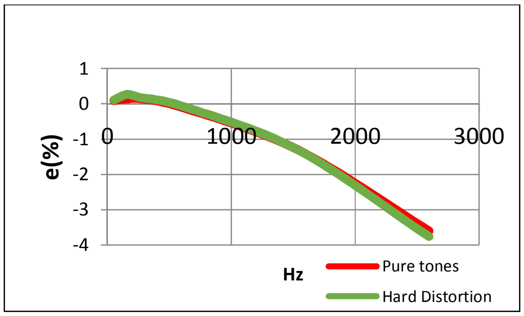

Fig. 5. Ratio error of a 6 kV IVT at 80% of nominal voltage.

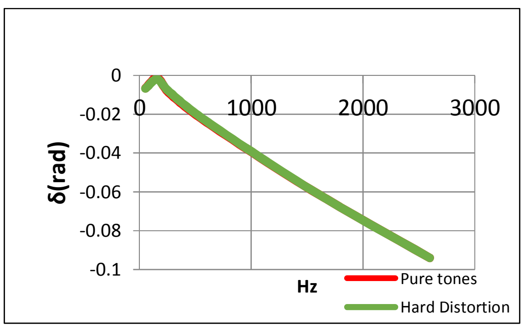

Fig. 6. Phase shift of a 6 kV IVT at 80% of nominal voltage.

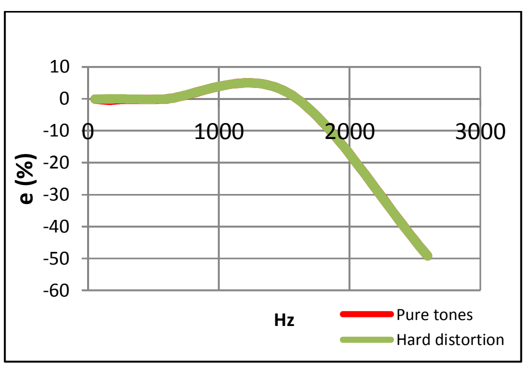

Fig. 7. Ratio error of a 60 kV IVT at 100% of nominal voltage.

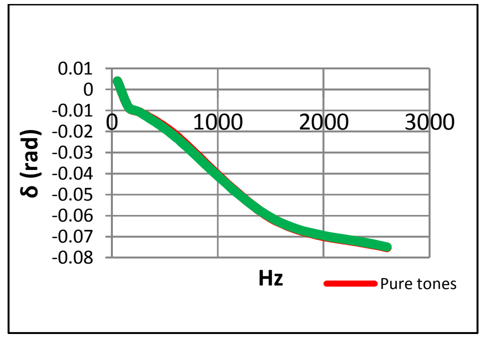

Fig. 8. Phase shift of a 60 kV IVT at 100% of nominal voltage.

The shapes of these curves are very close to those got from low-voltage tests, but the ratio differences do not allow the use of low-voltage tests for error correction. It is good for having a quick view of the frequency response, but if corrective factors are intended to use, tests at nominal-voltage must be done.

2.2. Capacitive type

The simplest model for this type of VT is shown in figure 9.

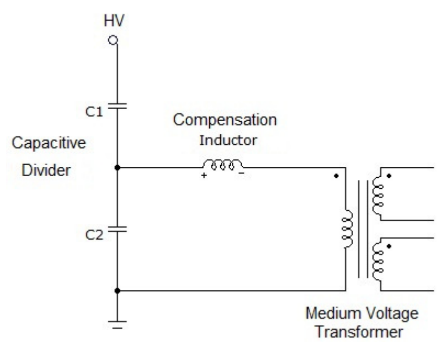

Fig. 9. Simplified model of a capacitive voltage transformer

C1 and C2 form a capacitive divider that is followed by a compensator inductor and a conventional medium-voltage transformer. The inductor is designed to resonate with the capacitors at power frequency, so that the series impedance is nulled. But, at other frequencies, the series impedance increases, so the errors. For the test, it was used the equivalent circuit, shown in [2]. In this configuration, the low terminal of

C2 is disconnected from earth, and connected to the upper terminal of C1. In this way, both capacitors are in parallel, in a Thevenin configuration. The advantage of this testing method is that the value of the applied voltage must be the rated voltage of the medium voltage transformer, around 10 kV, much lower than the nominal voltage of the CVT under test. Many tests were done on different units from 60 kV up to 500 kV. As an example, figures 10 and 11 show the ratio error and phase shift for a 150 kV CVT, 200 VA, class 0.5, at two different voltages: 80% and 120% of the nominal one. The applied voltage had harmonic contents that include many orders from the 3th up to the 49th. The amplitude of each one was around 10%.

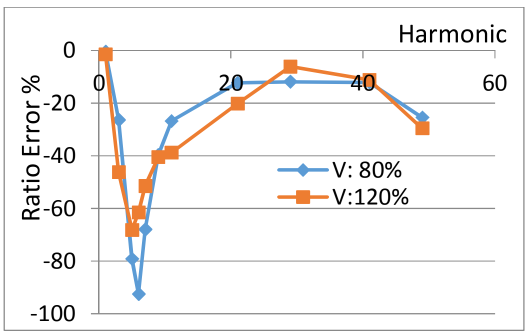

Fig. 10. Ratio error of a 150 kV VCT.

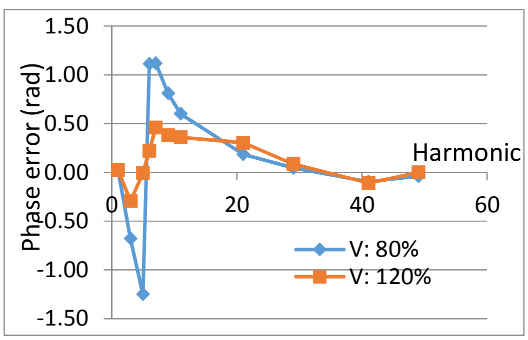

Fig. 11. Phase error of a 150 kV VCT.

The results show that this transformer has very large errors at any harmonic frequency.

Other tests were done varying the burden, and again, a behavior that depends on the burden was detected. This means that in practice it is not possible to use correction factor for using this kind of VT for harmonic measurement.

On the other hand, most of VTs installed in high-voltage power networks are of this type, and it is not practical to change all of them for other types that allow harmonic measurement. It will be presented during the conference some ideas on how to compensate conventional CVTs to reduce their errors to acceptable values.

3. CONCLUSION

Results of VT test under distorted waveform were presented. Low-voltage tests method (FRA) is useful to get a quick view of the frequency response, but to know precisely the value of the errors, tests at nominal-voltage must be performed. IVT errors can be compensated using corrective factors for each harmonic, but this cannot be done for CVT. Their errors are so large that other compensation techniques are necessary.

4. REFERENCES

[1] IEC Standard 61869-3, 2011, "Instrument transformers – Part 3: Additional requirements for inductive voltage transformers."

[2] IEC Standard 61869-5, 2011, "Instrument transformers – Part 5: Additional requirements for capacitor voltage transformers."

[3] IEC IEC/TR 61869-103, 2012, "Instrument transformers - The use of instrument transformers for power quality measurement."

[4] Gonzalo Aristoy, Leonardo Trigo, Marcelo Brehm, Alejandro Santos, Daniel Slomovitz, "Calibration system for voltage transformers under distorted waveforms," this issue.

[5] http://www.doble.com/product/m5400/

ACKNOWLEDGMENTS

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