Behavior of Current Transformers Under Distorted Waveforms

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***Abstract*— The use of nonlinear loads connected to the power networks that produce distorted currents has been increased in the last years. At the same time, distributed generation has also been increased. It uses power electronic devices to inject the energy to the network, generating harmonic currents that flow though the networks. Being current transformers key elements for measuring electric power and energy, is it very important to know their precision performance under distorted waveforms. This paper analyzes the errors of typical current transformers used in power networks from a theoretical and experimental point of view. Errors with different distorted waveforms are measured, and several proposed testing methods are evaluated.**

***Index Terms*—Current transformer, smart grids, harmonic, standard, calibration, uncertainty, distortion.**

I. INTRODUCTION

The increase of the price of fossil fuels and technological developments have led to the use of wind turbine generators with high power per unit, resulting in a lower cost of wind based power generators. For this reason, the presence of wind farms has been increased in electricity transmission networks. The effect of harmonic distortion that has this type of generator in the waveforms of the current and voltage in power transmission networks is well known. Additionally, the use of non-linear loads whose currents have high harmonic components has also been increased. There are several studies which examines the behavior of current transformers (CT) under distorted waveform, but their conclusions are not consistent. In some ones, it is concluded that the behavior of the CT is linear [1. 2], but in others the results indicate that CTs are not linear and frequency sweep tests cannot be applied to conclude the behavior with distorted waveforms, with multiple simultaneous harmonic components applied [3].

In the following sections the effect of distortion on the errors of the transformer and its capacity to measure currents at frequencies above the fundamental component is investigated. Nowadays, this problem gets special attention since new regulations that include distributed generation have a section on power quality, establishing limits based on the current harmonic distortion. The results presented in this paper were conducted on a laboratory class 0.2 CT, but more CTs will be analyzed in the final paper.

II. TESTS

The tests were based on a power quality standard system [4, 5] composed by two digital multimeters (DMM) Agilent 3458, a Fluke 6100 current programmable generator, and a PC with software for data analysis. Additionally, we used two shunt resistors as current to voltage transducers. Fig. 1 shows the connection diagram. The programmable generator is responsible for creating the distorted current waveform. This current is applied to the primary winding of the transformer and a shunt connected in series. In the secondary, another shunt resistor is used to measure the secondary current. Both DMMs take samples of the voltage drop on the shunt, synchronously. The control, storage and data processing are carried out by a program on the PC. For communication between the PC and the DMMs a GPIB bus is used. Data are processed by algorithms that estimate the harmonic content [6].

The tests can be classified into three types. First, tests of single tones where only one sinusoid waveform at different frequencies is generated. This test is typically called frequency sweep. The error of the transformer under the classic definition of error [7] is calculated for each of the frequencies. In (1) this definition is shown. Parameter k is rated ratio and subscripts p and s indicate primary and secondary, respectively.

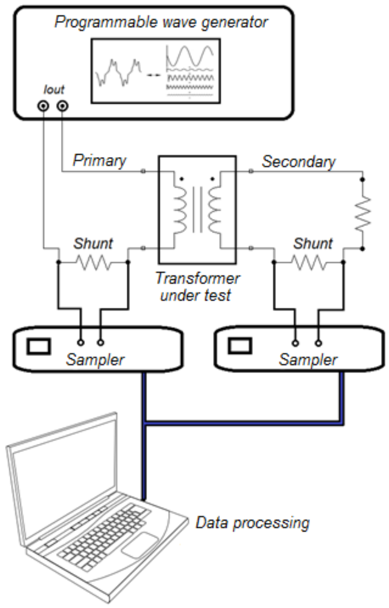

Fig. 1. Connection diagram for basic tests.

$$\varepsilon = \frac{kI_S - I_P}{I_P} \tag{1}$$

The second type of test consists in the superposition of the fundamental component with one harmonic component. We call this type of test "quasi-swept frequency". It is important to note that the definition of error remains similar to the one defined for pure tones (2).

$$\varepsilon_n = \frac{kI_{Sn} - I_{Pn}}{I_{Pn}} \tag{2}$$

The subscript n indicates the index of the harmonic. Note that the error is defined based on the harmonic values and does not involve the fundamental component. Finally, the third test overlaps all harmonics and the fundamental component at the same time, keeping the same definition of error (2) for each of the harmonics component.

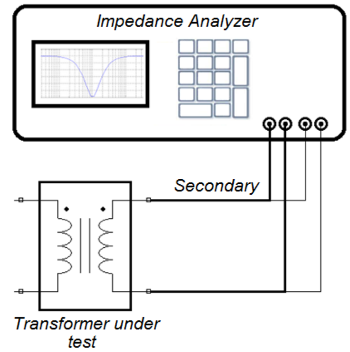

Fig. 2. Connection diagram for the additional tests.

In addition to the previously described tests, a no-load-test was done from the secondary winding in order to measure the value of magnetizing impedance. This information allows to estimate the errors of the transformer at different frequencies. Two testing equipments were used for this purpose: a Quad Tech 7600 impedance analyzer and a Frequency Response Analyzer (FRA) Double M5200. The latter is an equipment designed for field tests which allows to perform the test on CT installed in the network. Fig. 3 shows the value of the magnitude and Fig. 4 the value of the impedance angle.

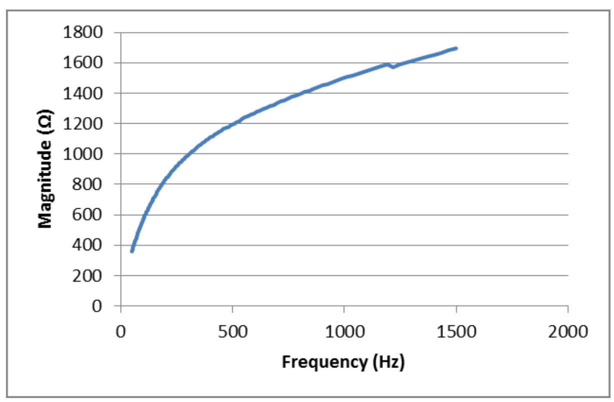

Fig. 3. Magnitude of the CT magnetizing impedance.

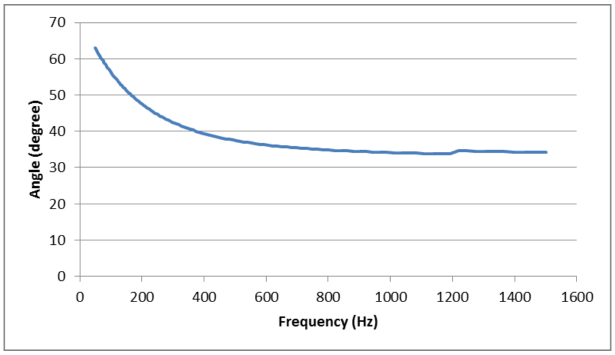

Fig. 4. Angle of the CT magnetizing impedance.

Errors at different frequencies were estimated using the transformer model shown in Fig. 5. For this calculation, it was assumed that the transformer has a resistive load of 0.20 Ω, equal to the value of the shunt resistance used in the first test. The internal resistance of the secondary winding was assumed equal to the dc resistance. This resistance was measured and its value was 0.11 Ω.

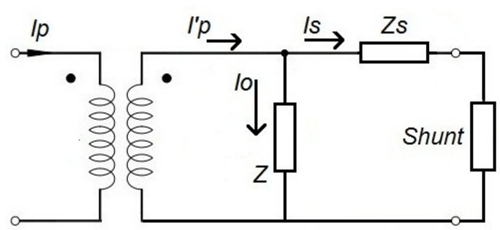

Fig. 5. CT model.

From (1), the error ε is

$$\varepsilon = \frac{I_S - I_P/k}{I_P/k} = \frac{I_S - I'_P}{I'_P} \quad . \tag{3}$$

On the other hand, the secondary current can be calculated as

$$Is = \frac{Z.I'_P}{Z+Zs+Shunt} \quad . \tag{4}$$

Then, the error can be expressed from the impedances as

$$\varepsilon = \frac{Z}{Z+Zs+Shunt} - 1 \quad . \tag{5}$$

This error is a complex number, where its real component corresponds to the error in magnitude, and the imaginary component to the phase error.

III. Results

Table I shows the errors computed from the model. Columns 2 and 3 show the computed errors, and columns 4 and 5, the measured errors according to the first method. The differences are small so that the estimated method based on the impedance measurements is useful to quickly determine the behavior of the CT at high frequencies. It is important to note that this test cannot verify the characteristics of linearity of the transformer; that is the behavior of the CT under a waveform that includes overlapping of several harmonics. To evaluate this, a test was performed by superimposing different harmonics at the same time.

Table I.

	Estimated error		Measured error	
f (Hz)	ε (ppm)	δ (μrad)	ε (ppm)	δ (μrad)
53	-382	732	-281	588
106	-297	431	-130	619
159	-266	323	-117	420
212	-248	262	-110	316
265	-237	228	-102	258
371	-220	184	-95	183
477	-207	160	-91	141
583	-198	146	-89	110
689	-190	136	-87	88

Table II compares the errors of the transformer at pure tones (columns 3 and 4) versus the errors when all harmonics are injected at the same time (columns 5 and 6).

Tabla II.

		Errors with pure tones		Errors with all harmonics at the same time	
f (Hz)	Amplitud	ε(ppm)	δ (μrad)	ε (ppm)	δ (μrad)
53	8 A	-274	606	-311	589
159	1 A	-116	420	-155	-380
265	1 A	-102	258	-148	-201
371	1 A	-95	183	-100	-137
477	1 A	-91	141	-81	-102
583	1 A	-89	110	-69	-78
689	1 A	-87	88	-64	-59
795	1 A	-84	71	-51	-24
1113	1 A	-80	34	-46	-1

It is shown that errors change between both cases. Phase errors significantly change when applying a pure tone and when the transformer is subjected to multiple harmonic components simultaneously. On the other hand, errors in magnitude do not have large differences. The fundamental current does not show appreciable differences. It can be concluded that the CT has a non-linear behavior and the superposition principle is not valid. This result is consistent with some publications [3] concluding non-linearity, but disagrees with other publications that proposed the sweep frequency method to evaluate the distorted errors with multiple harmonic [1, 2].

Tests on more transformers will be presented at the conference.

IV. Conclusions

This work discussed different methods for the evaluation of errors of a laboratory CT for measuring distorted currents. It was noted that as a first approximation is it useful to perform a characterization of the magnetizing impedance to estimate the error at frequencies higher than the nominal one. On the other hand, it was observed that the behavior of the transformer is non-linear. This was checked comparing errors when harmonics were applied one by one and when all harmonics were present at the same time. That means that the superposition principle is not met. Further results of testing many substation CTs will be presented at the conference.

V. References

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