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Characterization of Transducers to Measure Voltage and Electric Current AC.

[1]Manuel Águila Muñoz, [2]Manuel Torres Sabino, [3]Mercedes Lázaro Gonzaga
[1, 2, 3]*Instituto Politécnico Nacional, ESIME Zacatenco, México.*
Corresponding Author: Manuel Águila Muñoz.

--ABSTRACT--
This document shows the procedure used to determine the mathematical relationship to characterize the response of LEM® LV 25-P and LTS 25-NP transducers when used to measure AC voltage and current signals, respectively. The transducers and other components were installed on a test stand that facilitates connections and measurements of input and output signals. The tests performed consider electrical signals with a frequency range from 60 Hz to 1500 Hz, with the purpose of knowing the response of the sensors in conditions of the presence of harmonic components. Analog voltage and current signals are generated with PC-controlled test equipment.

KEYWORDS: *Characterization, AC Signals, Transducers, Measure, Harmonics.*

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I. INTRODUCTION

In the current AC electrical networks, there are installed elements, equipment, electrical loads, and some operating conditions that distort the voltage and current waveform: non-linear loads, static compensators, arc furnaces, capacitor banks, power transformers energization, etc. [1,2].

The processes of measuring parameters in voltage and current electrical signals are of vital importance for the recording, billing, control, and management of electrical energy. Thus, it is required the design of instruments that are able to perform measurements with good accuracy and can also make the determination of parameters for A. C. electrical signals with harmonic distortion.

For the measurement of electrical signals, transducer devices are required that allow the indirect measurement of electrical voltage and current signals of relatively high magnitudes, and for a wide range of frequencies. [3,4].

Transducer manufacturers indicate in a mathematical expression the relationship between the output signal versus the measured input signal, however, this information is usually related to the measurement of signals that occur in nominal or general operating conditions and does not establish the necessary certainty for the measured electrical signals are distorted by harmonic components.

II. HARMONIC DISTORTION

Harmonic distortion can explain as the sum of signals with frequencies multiples of the fundamental frequency (f1). [4,5].

Figure 1 shows a distorted analog signal and its harmonic components. The analog signal (left) is composed of the sum of three harmonics:

- **h1** Fundamental component with frequency 60 [Hz], peak value 10 [V].
- **h3** 3rd harmonic with frequency 3 times the fundamental (180 [Hz]), peak value 5 [V].
- **h6** 6th harmonic with frequency 15 times the fundamental (900 [Hz]), peak value 2.5 [V].

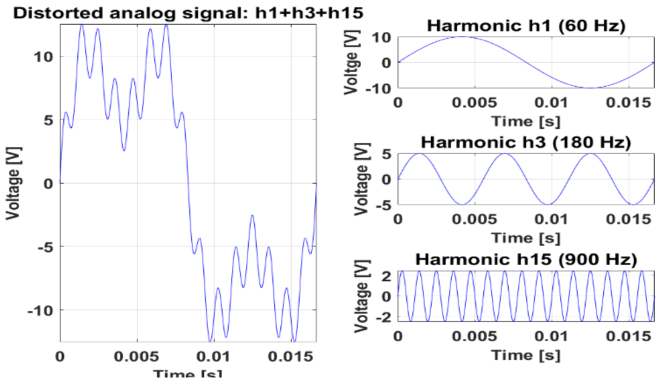


Figure 1. Distorted analog signal (left), and its harmonics components (right).

III. DESCRIPCIÓN DEL SISTEMA DE PRUEBAS.

Figure 2 shows four ***LEM® LV 25-P*** voltage transducers and four ***LEM® LTS 25-NP*** current transducers mounted on a test stand, also showing the connection points: V_{in} (input voltage AC), I_{in} (input current AC), V_{out} (output voltage signals for each transducer), supply voltage ±12 [V] (***LV 25-P***) and supply voltage 5 [V] (***LTS 25-NP***) [6,7].

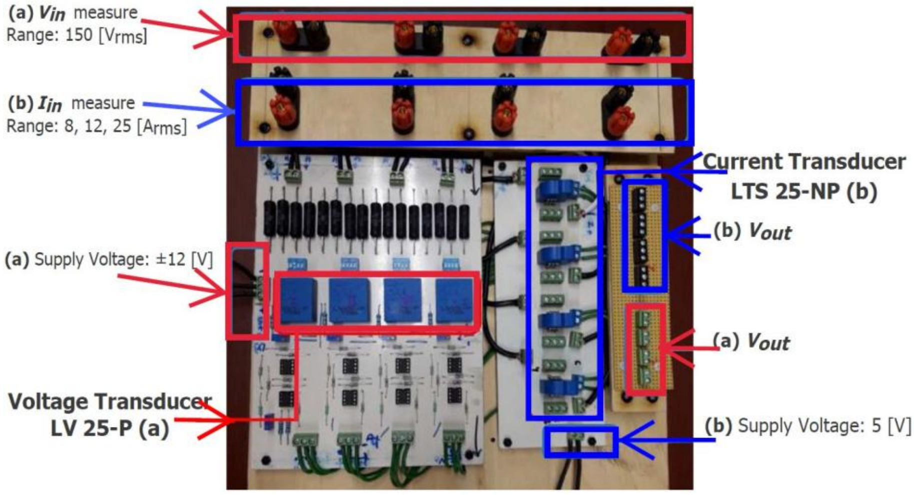
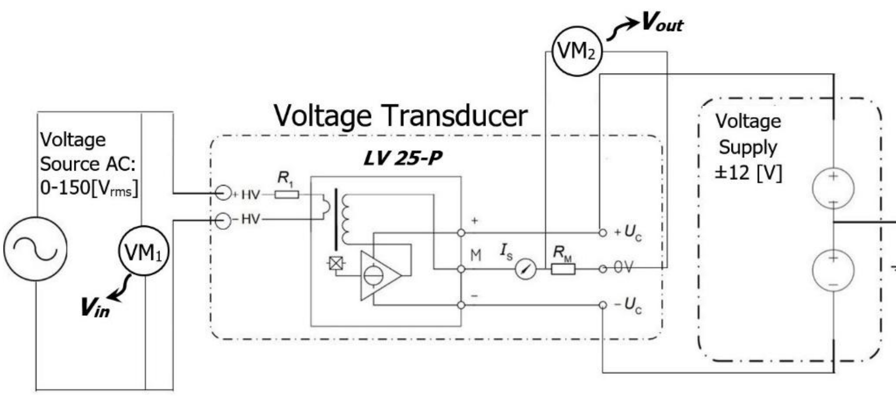


Figure 2. Mounting transducers: ***LV 25-P*** and ***LTS 25-NP*** [6,7].

Figure 3 shows the electrical circuit of the test system implemented to measure the output voltage V_{out} of the ***LV 25-P*** voltage transducer; this signal is a function of the input voltage V_{in}. The equipment and measuring instruments used are shown on the right.

Figure 4 shows the electrical circuit of the test system implemented to measure the output voltage V_{out} of the current transducer ***LTS 25-NP***, this signal is a function of the input current I_{in}. The equipment and measuring instruments used are shown on the right.

Figure 5 shows the test system implemented for the transducers: ***LV 25-P*** and ***LTS 25-NP***, here are the equipment and measuring instruments from which the readings were taken for recording and further processing.



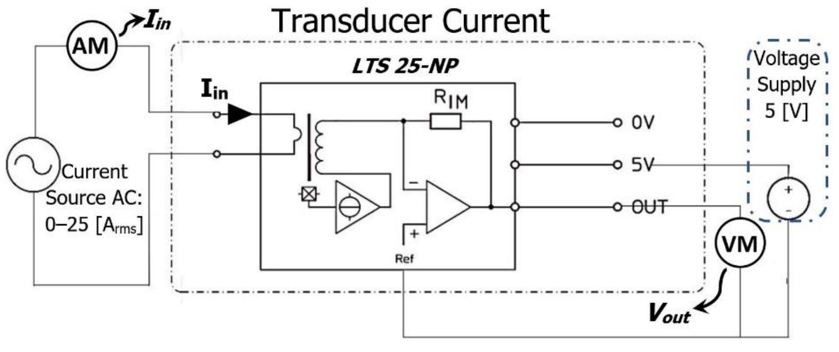
Equipment
Voltage sourse AC:
KoCos® Artes 300

Voltage supply:
AEMC® AX 503

Measuring instruments
VM1, Voltmeter AC:
BK Precision® 5390

VM2, Voltmeter AC:
BK Precision® 5390

Figure 3. Electrical circuit for voltage transducer ***LV 25-P*** [6,8].



Equipment
Current sourse AC:
KoCos® Artes 300

Voltage supply:
AEMC® AX 503

Measuring instruments
AM, ampmeter AC:
BK Precision® 5390

VM, Voltmeter AC:
BK Precision® 5390

Figure 4. Electrical circuit for current transducer ***LTS 25-NP*** [6,9].

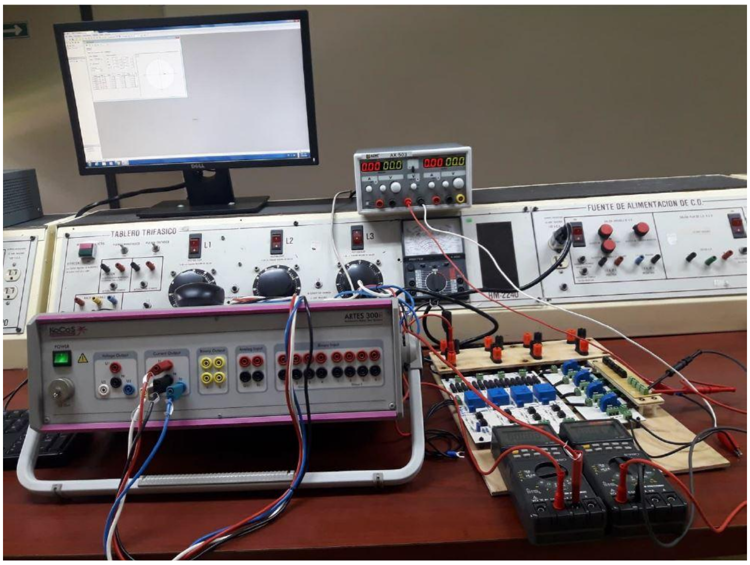


Figure 5. Test system for transducers: ***LV 25-P*** and ***LTS 25-NP*** [6].

IV. PROCEDURE

The characterization of the transducers consists of determining a mathematical expression that relates the output voltage (***V_{out}***) versus the magnitude of the input voltage or current signal (***V_{in}*** o ***I_{in}***), this mathematical expression is a first-order polynomial, that is to say:

For voltage transducer ***LV 25-P.***

$V_{in}(V_{out}) = b * V_{out} + a$ ……………eq. 1

$\therefore V_{out}, output\ voltage\ AC$

$V_{in}, input\ voltage\ AC$

$a\ \&\ b, first\ order\ polynomial\ coefficients$

For current transducer ***LTS 25-NP.***

$I_{in}(V_{out}) = b * V_{out} + a$ …………….eq. 2

$\therefore V_{out}, output\ voltage\ AC$

$I_{in}, input\ current\ AC$

$a\ \&\ b, first\ order\ polynomial\ coefficients$

To determine the coefficients ***a*** and ***b***, the numerical method called first order least errors squares (*LES1*) is used, for this the matrix system eq.3 must be solved. In figure 6, the scattered points x_i & y_i are shown, for them *LES1* coefficients are determined as ***a*** and ***b*** in ***y(x)***.

$$for\ y(x) = b * x + a$$

$$\therefore \begin{bmatrix} a \\ b \end{bmatrix} = \begin{bmatrix} n & \sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x_i^2 \end{bmatrix}^{-1} * \begin{bmatrix} \sum_{i=1}^{n} y_i \\ \sum_{i=1}^{n} x_i * y_i \end{bmatrix} \dots eq(3)$$

The magnitudes x_i & y_i, are obtained from the measuring instruments (figure 3 and 4).

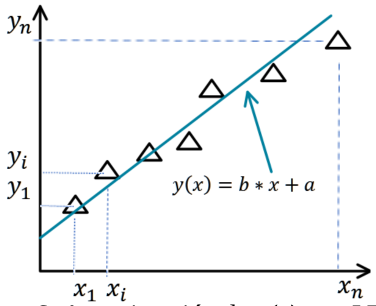


Figure 6. Aproximación de ***y(x)*** con *LES1*.

For the ***LV 25-P*** voltage transducer, AC voltages with magnitudes 0-150 [V_{rms}] were applied. For the ***LTS 25-NP*** transducer, tests were performed for three ranges (8, 12 and 25 [A_{rms}]), thus the respective magnitudes of currents are: 0-8 [A_{rms}], 0-12 [A_{rms}] and 0-25 [A_{rms}].

To know the response of the transducers when there are harmonic components in the AC voltage and AC current signals, tests were carried out with frequencies: 60, 120, 180, 240, 600, 900, and 1500 [Hz].

V. RESULTS

Figure 7 shows the graphical results obtained for the ***LV 25-P*** transducer when AC voltage signals with different frequencies are applied. The straight lines correspond to the adjustment of the scattered points by *LES1* for the different frequencies indicated.

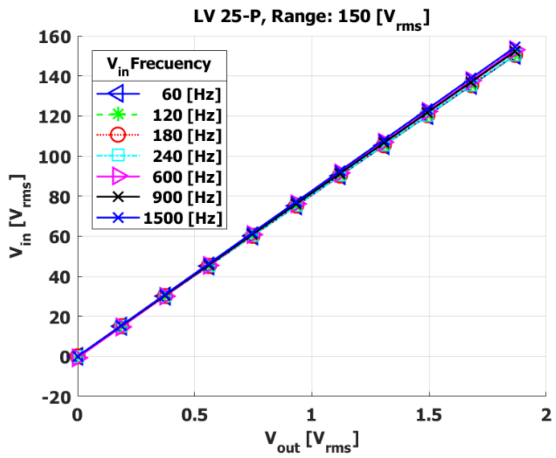


Figure 7. Frecuency response.

In plots 8, 9, and 10, the results obtained for the ***LTS 25-NP*** transducer when AC current signals with different frequencies are applied to it are shown graphically. The straight lines correspond to the adjustment of the scattered points by *LES1* for the different frequencies indicated.

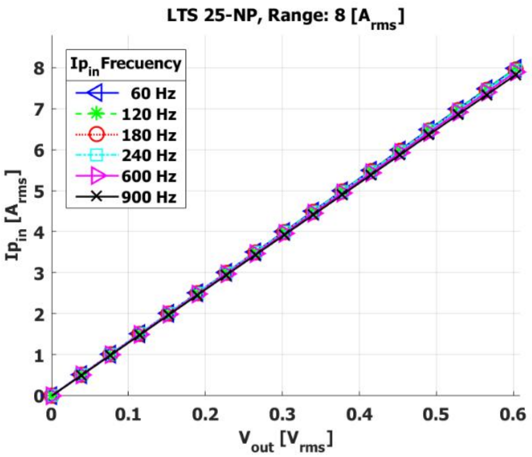


Figure 8. Frecuency response transducer**.**

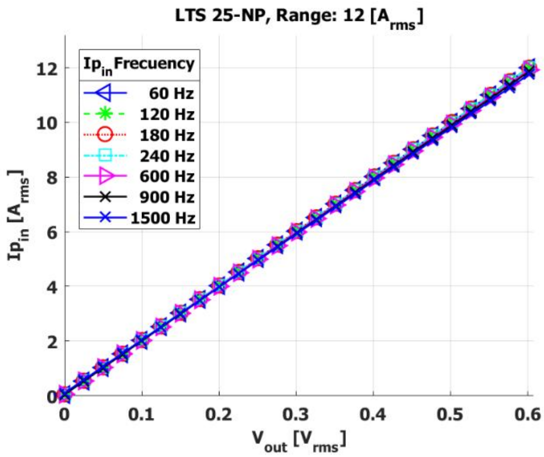


Figure 9. Frecuency response transducer.

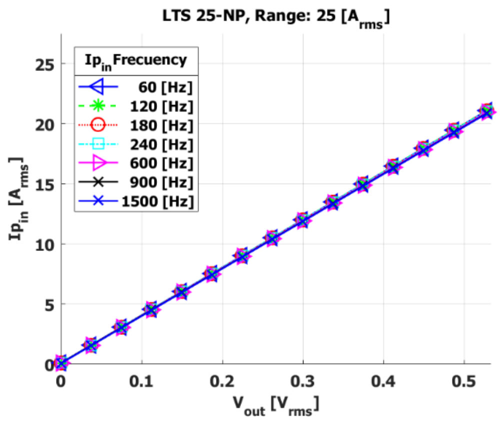


Figure 10. Frecuency response transducer.

As can be seen in the graphs in Figures 7, 8, 9, and 10, there is no great variability in the straight lines fitted for each frequency, for this reason, it is proposed to determine a single straight line to represent them.

For the ***LV 25-P*** transducer, figure 11 shows the average of the measurements and the straight line fitted by *LES1*. Eq. 4 is the first order polynomial determined by *LES1* for the ***LV 25-P*** transducer with 150 [V_{rms}] range.

For the ***LTS 25-NP*** transducer, figures 12, 13, and 14 show the average of the measurements and the straight line fitted by *LES1*. Figs. 5, 6, and 7 are the first-order polynomials determined by *LES1* for the ***LV 25-P*** transducer with ranges of 8, 12, and 25 [A_{rms}], respectively.

LV 25-P, Range 150 [V_{rms}], $V_{in}(V_{out}) = 81.300578 * V_{out} - 0.085733$…… eq. 4
LTS 25-NP, Range 8 [A_{rms}], $I_{in}(V_{out}) = 13.161769 * V_{out} - 0.085733$…… eq. 5
LTS 25-NP, Range 12 [A_{rms}], $I_{in}(V_{out}) = 19.739087 * V_{out} + 0.055147$ …….eq. 6
LTS 25-NP, Range 25 [A_{rms}], $I_{in}(V_{out}) = 39.597022 * V_{out} + 0.098918$…… eq. 7

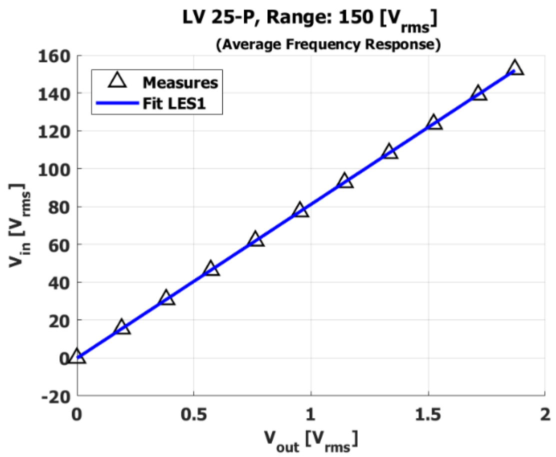


Figure 11. Data fit ***LV 25-P***.

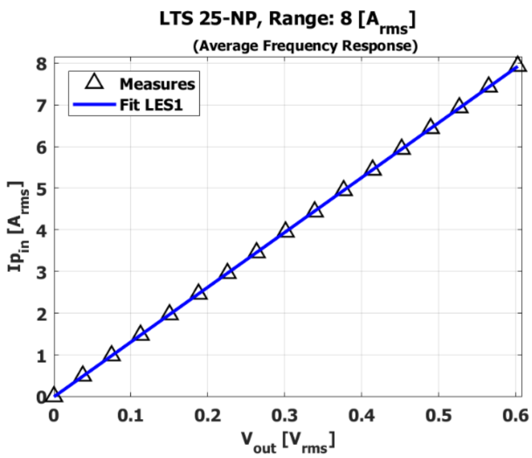


Figure 12. Data fit ***LTS 25-NP***, 8 [A_{rms}].

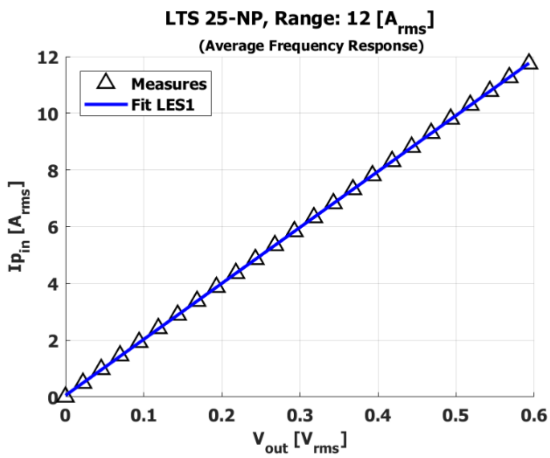


Figure 13. Data fit ***LTS 25-NP***, 12 [A_{rms}].

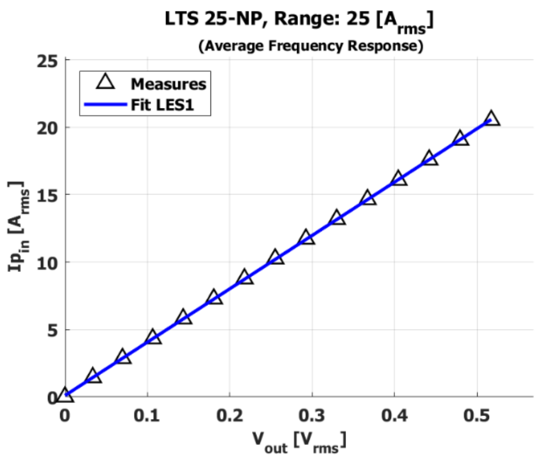


Figure 14. Data fit ***LTS 25-NP***, 25 [A_{rms}].

VI. CONCLUSIONS

Depending on the application of the transducers, in some cases, it is required to perform complementary tests to know their response in conditions not specified by the manufacturers, which will improve the accuracy of the measurements made.

For the development of AC electrical signal measurement instruments, the effects of harmonic components on the response of the transducers used must be considered.

The determination of mathematical expressions, which relate the magnitudes of the input signals versus the magnitudes of the output signals for the transducers, is useful for the development of measurement instruments.

The application of the first-order *LES1* numerical method is of great support for the numerical processing of the obtained measurements.

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