Calibration of Power Quality Instruments (PQI) for harmonic distortion measurements in Colombia

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Abstract

This article describes the process that the National Institute of Colombia - INM has established to obtain the technical infrastructure to calibrate power quality instruments (PQI) under the IEC 62586: 2017 standard for the measurement of harmonic distortion in Voltage and Electric Current that ensures the traceability of the measurements of the spectral components made by the Colombian electricity sector and allowing it to comply with the provisions of the Energy and Gas Regulation Commission. The project was established in three phases: harmonic distortion calibration and future proposals for self-traceability, instrument design and construction.

Keywords - Measurement, harmonic distortion, measurement uncertainty

1 Introduction

The quality of electrical energy is found within the measurements of electromagnetic phenomena as a study and evaluation of the behavior of electrical voltage, electric current and frequency over a period of time, these parameters are defined in the IEEE 1159: 1995 standard.

Currently the power quality instruments (PQI) used in Colombia for the measurement of harmonic distortion in Voltage and Electric Current and other parameters of the quality of power, are not calibrated by the metrological network of Colombian laboratories since none of these laboratories have the necessary technical infrastructure, for this reason traceability must be obtained abroad, generating increased costs and, in some cases, the scope of measurement and calibration does not meet the metrological needs of the industrial sector. For this reason, the National Institute of Colombia - INM establishes the project of guarding and preserving patterns that ensure the traceability of harmonic distortion measurements in Voltage and Electric Current to the International System of Units (SI).

In this process, the INM consolidated the inter-institutional project proposal in the context of strengthening the National Metrology Institutes (NMI) belonging to the Inter-American

Metrology System (SIM) in support of the Organization of Emerging Technologies of the American States (OAS): "Metrology for Sustainable Energy Technologies and the Environment in the Americas (M4SET)", a project carried out by different INMs in America, which allowed recognizing similarities and differences in the needs of the industrial sector of each country to improve the technical competence of each of its participating NMIs. In particular, as a result of this project, the INM of Colombia defined the technical infrastructure necessary to provide the calibration service of the power quality instrument (PQI) under the IEC 62586: 2017 standard for the measurement of harmonic distortion in voltage and current. Electrical.

2 Quality Metrology of Electric Power: Harmonic Distortion

2.1 Calibration method

The National Institute of Colombia - INM calibrates the harmonic distortion of instruments using a FLUKE brand electric power calibrator, model 6105A (see Figure 1), which offers different generation functions, these functions are predefined in order to obtain the best possible representation of the measurements to be made (distortions and signal variations). In addition to accurate voltages and currents, this type of calibrator can add precise harmonic distortion independently to voltage and current outputs. The generated waveforms are specified according to national and international standards.

The Power Quality Instruments - PQI are calibrated in voltage harmonics and current harmonics by the direct comparison method (see Figure 2): the values indicated by the power quality instrument - PQI are compared with the values of the signals generated by the FLUKE 6105A electrical power calibrator. These signals are configured with spectral components of different amplitudes with a phase angle equal to zero with respect to the fundamental for each harmonic according to Table 3 (test points P4 and P5) of the IEC 62586-2: 2017 standard, to guarantee compliance with the PQI to the IEC 61000-4-30: 2012 Standard.

Figure 1: FLUKE 6105A Calibrator

Figure 2: Calibration of Power Quality Instruments (PQI)
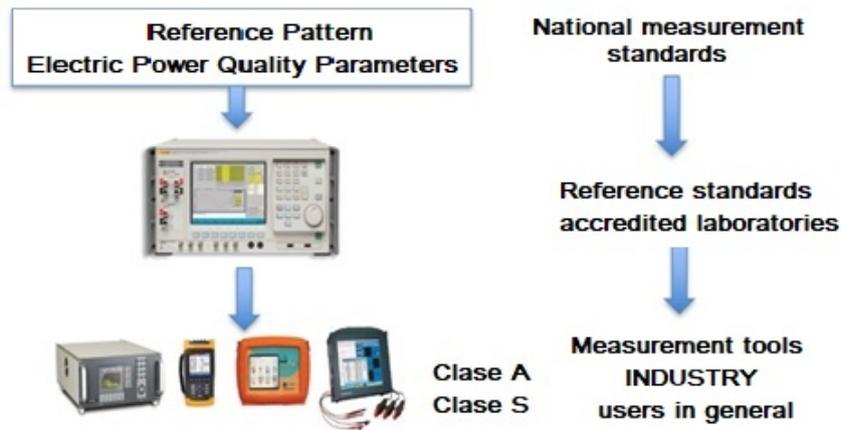
The FLUKE 6105A electric power calibrator is controlled with LabView® software, and in this way, the laboratory can configure and generate different waveforms, the scope of the calibrator allows generating distorted signals up to the 50th harmonic, with a fundamental frequency of 60 Hz; With this system a measurement range is established applied to the instruments under industry calibration of class A and S.

The Power Quality Instrument - PQI is calibrated with two (2) distorted voltage and current signals, configuring waveform 1 and 2 (Figure 3 and Figure 4 respectively) the capacity of the instrument to measure the signals is evaluated with low and high spectral content.

Figure 3: Waveform according to IEC 62586-2: 2017. (P4 test point described in the standard)
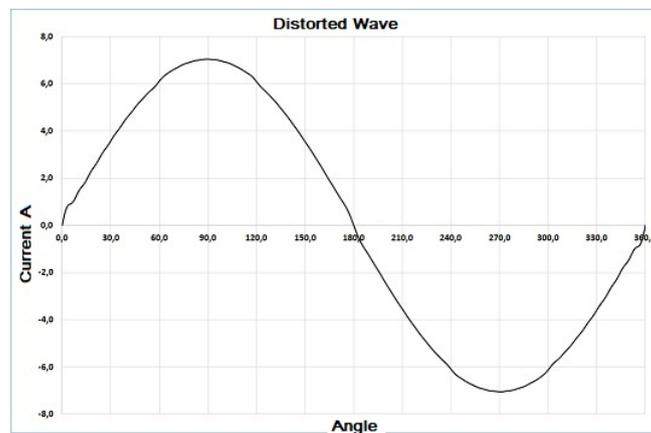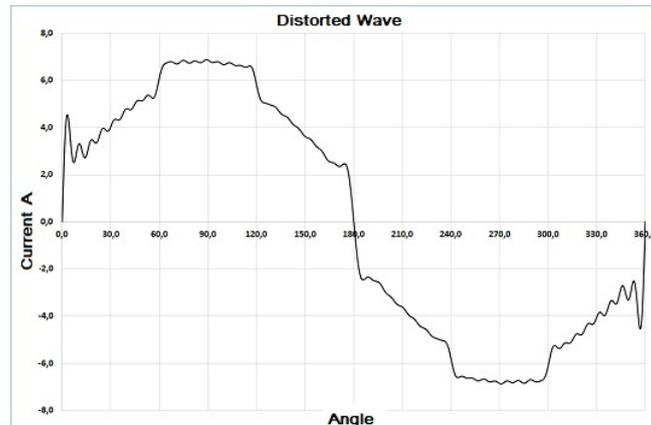
Figure 4: Waveform according to IEC 62586-2: 2017. (P5 test point described in the standard)

The voltage signals use the values of 120 V and 240 V, for Colombia they are normalized nominal voltage values for single-phase two-conductor systems framed in level I of systems with nominal voltage less than 1 kV. In the case of current signals, values of 1 A and 5 A apply, standard values for direct connection systems and connection systems with transformers respectively.

In figure 5, the connections of the system implemented in the INM are presented. The time interval for recording each measurement of the Power Quality Instrument (PQI) is 10 minutes, the measurements are performed automatically and are subsequently downloaded with the instrument manufacturer's software, to be processed in individual formats of voltage and current. For three-phase PQI Power Quality Instruments the calibration is performed phase by phase.

Figure 5: Electrical Power Quality Instrument Measurement System (PQI)

2.2 Uncertainty estimation

The estimation of uncertainty for harmonic distortion in electrical voltage and harmonic distortion in electrical current are described in Tables 1 and 2 respectively.

A selected mathematical method is applied to the selected calibration method to estimate the voltage error of each harmonic through the indications of the instrument under

Table 1: Estimation of harmonic distortion uncertainty in voltage

VARIABLE	DEFINITION
E_{Vx}	Measurement error rms of the harmonic component of order h in voltage.
V_{IBC}	rms value of the harmonic component of order h indicated by the instrument in voltage.
V_{Ref}	rms value of the harmonic component of order h indicated by the voltage standard.
s_{read}	Standard deviation of readings.
∂_{Resol_IBC}	Instrument resolution under voltage calibration.
$\partial_{Resol\_standard}$	Resolution of the standard instrument in voltage.
$\partial_{Cal\_standard}$	Standard calibration in voltage

calibration and the standard instrument, the measurement error for voltage harmonics is expressed according to Equation (1).

$$E_{Vx} \quad = \quad V_{IBC} + V_{Ref} \tag{1}$$

By including all the variables in Table 1 within Equation (1), equation (2) is obtained.

$$E_{Vx} = V_{IBV} + V_{Ref} + s_{leido} + \partial_{Resol\_IBC} + \partial_{Resol\_Standard} + \partial_{Cal\_Standard} \tag{2}$$

Table 2: Estimate of harmonic distortion uncertainty in current

VARIABLE	DEFINITION
E_{Ix}	Measurement error rms of the harmonic component of order h in current.
I_{IBC}	rms value of the harmonic component of order h indicated by the instrument in current.
V_{Ref}	rms value of the harmonic component of order h indicated by the current standard.
s_{read}	Standard deviation of readings.
∂_{Resol_IBC}	Instrument resolution under current calibration.
$\partial_{Resol\_standard}$	Resolution of the standard instrument current.
$\partial_{Cal\_standard}$	Standard calibration in current

The measurement error for current harmonics is expressed according to Equation (3).

$$E_{Ix} \quad = \quad I_{IBC} + I_{Ref} \tag{3}$$

Including all the variables in Table 2 within Equation (3), we obtain equation (4).

$$E_{Ix} = I_{IBV} + I_{Ref} + s_{leido} + \partial_{Resol\_IBC} + \partial_{Resol\_Standard} + \partial_{Cal\_Standard} \tag{4}$$

The traceability of the FLUKE 6105A electrical power calibrator is performed by digital sampling, a method used by different laboratories that currently provide traceability to the INM in harmonic distortion in voltage and electric current.

3 Experimental Methodology and Results

The measurement system and especially the FLUKE 6105A electric power calibrator has been subjected to different tests to confirm its operating condition and ensure that during measurements it operates within specified intervals in magnitude and phase angle for each of the 50 harmonics applied according to Table 3 (test points P4 and P5) of the IEC 62586-2: 2017 standard.

The results allowed experimentally confirming the good performance and versatility of the measurement system (see Figures 5 and 6) for the calibration of Power Quality Instruments - PQI, the most outstanding results are described below.

3.1 Selected instruments under calibration

The measurement system was tested with three instruments under calibration of different brands and models: FLUKE brand type 435 II [1], ZERA brand type COM 3003DC [2] and ZERA brand type MT3000 [3]; all three instruments have the function of measuring harmonics in voltage and current, and are instruments classified as Class A - (PQI-A) or Class S - (PQI-S) power quality instrument according to IEC 61000-4 -30: 2012.

3.2 Experimental measurement system

Figure 6 shows the assemblies made. For the tests, 120 V was considered as the fundamental voltage and 1 A as the fundamental current, with four different time periods for recording the measurements: 1 s, 1 min, 5 min and 10 min.

Figure 6: Assemblies made

In the tests carried out, the measurement uncertainty is estimated verifying that the results obtained do not exceed the limits established in Table 1 of the IEC 61000-4-7: 2012 standard, the measurement uncertainty is expressed with a normal distribution, with a factor of coverage k = 2, and a probability coverage level of 95.45

Given the number of tests carried out, it is selected to present the results obtained for the calibration of harmonic distortion in current applied to a PQI-A, brand FLUKE type 435 II; Table 3 presents one of the test points performed and the associated conditions.

This instrument has inputs to make a three-phase connection, which implied defining some operating conditions of the measurement system, because the standard calibrator only provides a single-phase output; In this way, the measurements were made phase by phase respecting the direction of flow of the circuit current and guaranteeing a reference voltage in the measurement circuit of 120 V.

3.3   Results

Table 3: Calibration conditions

Magnitude	Alternating Electric Current
Power Quality Parameter	Current Harmonics
Nominal Value Applied	1 A
Reference Waveform	IEC 62586-2:2017 – Testing Point P5 - Table 3.
Reference frequency	60 Hz
Voltage input impedance	1 MΩ
Measurement time	1.5 hours
Time between measurements	30 s
Number of measurements	183 on each harmonic
PQI-A class	I
Measurement class	A
PQI-A reading software	Power Log 5.6
PQI-A Clamp Meter	Fluke i400 en el interval 40 A
Current measurement on the PQI-A	Phase to Phase With 120 V reference voltage

In the different tests applied to instruments (PQI-A), the measured values obtained at different times (for example: 1 s, 10 s, 30 s, 10 min) do not indicate important deviations between the different measurements, so this component (series of measurements) does not contribute significantly to the estimation of uncertainty, a situation that does not happen in the same way in instruments (PQI-S).

The other components of uncertainty are instrumental, for example, the PQI resolution, the stability of the standard and the results obtained in each harmonic from the calibration certificate.

In the current harmonic tests, minimum uncertainty values of ± 17 mA and ± 20 mV were obtained for voltage harmonics.

4 Conclusions

The progress made by the INM in meeting the metrological needs of the industrial sector in quality measurements of electrical power, focused on harmonic distortion with reference to the IEC 62586: 2017 standard, and in particular, configuring the waveforms that meet the conditions established in Table 3 for test points P4 and P5; Measurements were made to the instruments under calibration at operating points of the maximum and minimum harmonic distortion values in voltage and electric current.

The work currently carried out at the INM consolidates the first version of calibration procedures implementing the direct comparison method to calibrate power quality meters in harmonic distortion, and consolidates the mathematical model of estimation of uncertainty that involves different sources of uncertainty associated with the type of non-sinusoidal electrical signals.

The project has established a measurement system to provide a traceability chain for current and voltage harmonic measurements carried out by the industry; Through this measurement system and under stationary conditions with waveform variation, it is feasible for the country to offer calibration services to power quality instruments - (PQI-A) Class A and (PQI-S) Class S, installation fixed (F) or portable (P), according to the classification of the IEC62586-1: 2017 standard.

With the implementation of the measurement system, a new service will be offered in Colombia that will benefit the Colombian electricity market, especially in the design and operation of distribution systems and end-use electrical installations, since the analysis of harmonics and their effects will be made with reliable measurement instruments that ensure their metrological traceability to the international system of units and that with their measurement results allow the electrical risk factors to be adequately identified.

Through the participation of the INM in the initiative "Metrology for Sustainable Energy Technologies and the Environment in the Americas (M4SET)", it was possible to obtain the necessary knowledge to begin the construction of the reference system for the calibration of the FLUKE 6105A instrument; this idea is presented as future work in this document.

5 Future work

The future work of the INM is guided to development and research to cover the metrological needs of the Colombian electricity sector

5.1 Proposal for new services as power

The next stage of implementation of the INM contemplates the design and development of the calibration service in Total Harmonic Distortion (THD), addressing the following categories:

- Calibration of power quality analyzers in Total Harmonic Distortion (THD) voltage at 120 V according to Colombian Technical Standard 5001: 2008.

- Calibration of power quality analyzers in Total Harmonic Distortion (THD) voltage at 240 V, Colombian Technical Standard 5001: 2008.

- Calibration of power quality analyzers in Total Harmonic Distortion (THD) current at 1 A according to Colombian Technical Standard 5001: 2008.

- Calibration of power quality analyzers in Total Harmonic Distortion (THD) of voltage at 5 A according to Colombian Technical Standard 5001: 2008.

5.2 Implementation of a reference system in harmonic distortion for self-traceability of the FLUKE 6105A calibrator

The INM in the electrical power quality measurement process has as its goal the elaboration of the primary system based on synthesis of electrical signals, this system implements the spectral analysis of the digitized signals by means of high resolution and accuracy multimeters, for example, Keysight 3458A multimeters. In this way, multimeters are part of the standard measurement system to provide traceability to an electric power calibrator, for example, to a FLUKE 6105A. [4]

Currently, as a first advance, the INM has implemented a highly accurate sampling system using Keysight 3458A multimeters and a signal analysis algorithm with spectral content. [5]

5.3 Development of laboratory instruments

One of the topics discussed during the development of the M4SET project was the design and implementation of voltage dividers that allow different voltage values to be scaled and current shunts to scale current values. This implementation should be limited to the points required by the Colombian industry within national standards. [6]

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