THE 8th INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING
May 23-25, 2013
Bucharest, Romania

Aspects of metrological calibration of power quality analyzers

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Abstract- **This paper presents some aspects of power analyzers utilization, related with your calibration by metrological laboratory. The full metrological characterization of power analyzers is a difficult technical process because the specifications in related standard are minimal. After a short presentation of parameters and measurement methods recommended by the important standards in the field of power quality, CEI EN 50160 and CEI EN 61000-4030, study of uncertainty propagation related to test calibration, this document describes the instruments configuration and evaluation of measurement errors and uncertainties for one parameter, voltage in sinusoidal and non-sinusoidal regime.**

***Keywords*: power analyzer, calibration, uncertainty**

I. INTRODUCTION

Power Quality of power supply systems is a recent concept in the history of the development of electrical systems. The phenomenon definitions, studies of related situations and measurement instruments and proposal of new standards in the field by international organizations represent activities with strong development.

The deviations in voltage and frequency in low, medium and high voltage supply systems due to nonlinear loads, non-sinusoidal sources and digital control contribute to undesirable effects, with impact on losses and overheating, reliability and failures of equipments.

Researches in the field of power quality have been conducted in multiple directions. A study direction is represented by the analysis of physical phenomena that lead to alterations in parameters of voltage and current in AC networks [1], [2]. Another direction deals with getting new methods to decrease the negative effects on power quality, especially harmonics, unbalance and reactive power flow [3], [4], and [5].

A continuous activity takes place in the establishment define requirements related to parameters of power quality. The standard EN 50160 [6] defines, describes and specifies the main characteristics of the voltage in low, medium and high voltage electricity networks and the limits imposed and accepted.

The measurement methods and correct interpretation of the results for power quality monitoring analyzers result from EN 61000-4-30 standard specifications [7], the fundamental reference for power quality instrumentation.

This standard requires three classes of instruments for monitoring power quality, where Class A shows peak performances and accuracy.

Note that different organizations have discussed in recent years the limitations of these standards, for example, KEMA and Leonardo Energy [8] or ERGEG [9] and some technical questions hoped to be solved during the meeting of Working Group 9 in Bilbao, Spain, on March 2013.

Important developments were made in the construction of power quality analyzers [10], [11]. We can identify [12] four generations of instruments: online meters, which provides the information without any logging, data loggers, which provide periodic data recording, power quality analyzers with selective data based on events and power quality analyzers with continuous logging of all raw data. All these instruments require regular calibration in order to preserve the quality of measurements and traceability. The calibration performed in authorized laboratories presents some technical problems, arising mainly from the lack of clear theoretical and practical measurement specifications, both in standard as well as in literature [13], [14]. Multitude of specific phenomena requires a significant amount of measurements and processing results; different forms of input signals can lead to the same result; a specific phenomenon can be affected by the presence, at the same time, of many disturbing quantities due to others phenomena. These factors lead to the need for calibration in various possible combinations of events with varying degrees of severity, which increases even more the number of experiments and their technical difficulty.

This paper refers to these measurement issues related to calibration of power quality analyzers and present experimental results for some of the parameters related to the waveform amplitude in steady state regime.

II. STANDARDS, PARAMETERS AND MEASUREMENT METHODS FOR POWER QUALITY

The most influential standards in the field of power quality are EN50160 and IEC 61000-4-30.

They provide some minimum requirements to be met in terms of parameters describing power quality and methods of achieving adequate measuring instruments. Adopted as national standards in many countries, these regulations serve both energy operators as well as metrological laboratories [15], [16].

European Standard 50160:2010 “Voltage characteristics of electricity supplied by public electricity networks” characterized the supply voltage in terms of variations on the following parameters: amplitude, frequency, wave form and symmetry of voltages system and sets the voltage characteristics in three-phase systems with various limits for transient, overvoltages and voltage imbalances

Table I presents the main voltage characteristics for European LV and MV electrical networks and their limits accepted

TABLE I
EN 50160 SETS LIMITS

	LV (<1 kV)	MV (< 35 kV)
Frequency	± 1 % for 99.5% of week - 6% / + 4% for 100%	± 1 % for 99.5% of week - 6% / + 4% for 100%
Voltage Magnitude	±10 % for 95% of week, 10 min. rms	±10 % for 95% of week, 10 min rms
Rapid voltage changes	5 % normal 10 % infreq. $P_{lt} < 1$ for 95 % of week	4 % normal 6 % infreq. $P_{lt} < 1$ for 95 % of week
Temporary overvoltage	< 1,5 kV	170% (solidly or impedance earth) 200% (unearthed or resonant earth)
Transient overvoltage	generally < 6 kV occasionally higher	
Voltage unbalance	2 % for 95 % of week 10 min. rms 3 % in some locations	2 % for 95 % of week 10 min. rms 3 % in some locations

The IEC standard 61000-4-30:2008 defines the measuring algorithms for practical implementation of the requirements for power quality parameters measurement.

The standard requires a division into three classes according to performance monitoring and measurement insured:

- Class A: the highest performance and accuracy, different instruments connected to the same signals will produce the same results;
- Class S: instruments used for statistical surveys;
- Class B: instruments used for qualitative surveys and applications where low uncertainty is not required.

Standard specifications require a series of influence quantities to be taken into account. For example, for Class, 0.1% uncertainty must be maintained in the presence of harmonics and flickers. Table II presents the influences quantities and their limits of variation.

III. CALIBRATION METHOD

The calibration procedure requires several steps: establishing a measurement circuit etalons and test procedure, input quantities required, amplitude variation limits and limits errors. Parameters needed for Class A results in Tables I and II.

The IEC 61000-4-30 standard specifies the steps to be followed to assess uncertainty testing instrument for any input quantities applied. For Class A and Class S:

- select measured quantity and maintaining other quantities in testing state 1 (Table III);
- uncertainty checking for five points approximately equally spaced throughout the measurement range of this quantity;
- repeat the test with other quantities in testing state 2;
- repeat the test with other quantities in testing state 3.

TABLE II
STANDARD 61000-4-30 DEMANDS PARAMETRIC TESTS
IN THE PRESENCE OF INFLUENCES QUANTITIES

Parameter	Class	Influence quantity range
Frequency	A	42.5-57.5 Hz
	S	42.5-57.5 Hz
	B	42.5-57.5 Hz
Voltage magnitude	A	10%-200% U_{din}
	S	10%-150% U_{din}
	B	10%-150% U_{din}
Flicker	A	0-20 Pst
	S	0-10 Pst
	B	N/A
Unbalance	A	0~5% u2,0~5% $u0$
	S	0~5% $u2$
	B	SBM
Voltage harmonics	A	200% of Class 3 of IEC 61000-2-4
	S	200% of Class 3 of IEC 61000-2-4
	B	200% of Class 3 of IEC 61000-2-4

TABLE III
UNCERTAINTY STEADY-STATE VERIFICATION (CLASS A & CLASS S)
FOR SOME OF THE PARAMETERS

Influence quantities	Testing state 1	Testing state 2	Testing state 3
Frequency	fn ∓ 0.5 Hz	$f$nom-1Hz ∓ 0.5Hz	fn + 1Hz ∓ 0.5Hz
Voltage magnitude	U ∓ 1%	Determined by flicker, unbalance, harmonics, interharmonics	Determined by flicker, unbalance, harmonics, interharmonics
Flicker	Pst < 0,1	Pst=1∓0.1 rectangular modulation at 39 changes per minute	Pst=4∓0.1 rectangular modulation at 110 changes per minute
Unbalance	100% ∓0.5 % of U on all channels. All phase angles120°	73% ∓ 0/5 % of U Channel 1 80%∓ 0.5 % of U Channel 2 87% ∓0.5 % of U Channel 3 all phase angles 120°	152% ∓0.5 % of U Channel 1 140%∓ 0.5 % of U Channel 2 128%∓ 0.5 % of U Channel 3 all phase angles 120°
Harmonics	0% to 3 % of U	10 % ± 3 % of U 3rd at 0° 5 %± 3 % of U 5th at 0° 5 % ± 3 % of U 29th at 0°	10 % ± 3 % of U 7th at 180° 5 %± 3 % of U 13th at 0° 5 % ± 3 % of U 25th at 0°

The Table IV presents the uncertainty requirements for some parameters of power quality.

Calibration can be done by one of the following procedures [17]:

- Using a standard instrument and comparing it with the indications of the instrument under tests;

- Using a precision signal source.

In experiments conducted and presented in this paper, we use the second calibration method. The signal source is the power quality calibrator Fluke 6100A, a programmable source of stable voltage and current waves, distorted by harmonics, flicker, interharmonics and other phenomena (fig.1) [18].

TABLE IV
UNCERTAINTY REQUIREMENTS (SOME OF THE PARAMETERS)

Parameter	Class	Uncertainty
Frequency	A	±10 mHz
	S	±50 mHz
	B	Specif. by Manuf.
Voltage magnitude	A	±0.1% of *U*
	S	±0.5% of *U*
	B	±1% of *U*
Flicker	A	IEC61000-4-15
	S	
	B	N/A
Dips and swells	A	±0.2% *U*
	S	±1% *U*
	B	±2% *U*
Unbalance	A	±0.15%
	S	0.3%
	B	Specif. by Manuf.

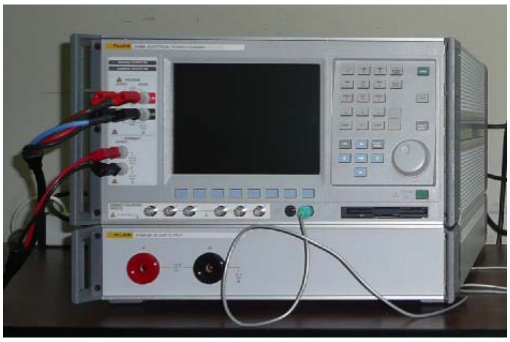

Fig.1. Fluke 6100A power quality calibrator

To estimate the uncertainty of measurement we used the method defined by Guide to the Expression of Uncertainty in Measurement (GUM) [20] and the equivalent Romanian Norm SR ENV 13005:2003.

IV. EXPERIMENTAL RESULTS

We present results obtained from a mono-phase analyzer calibration (fig.2) compared to standard Fluke 6100 calibrator.

Block diagram of the measurement circuit is presented in figure 3. The temperature during the measurements was (23 ± 2)°C, and the relative humidity of the air was (50 ± 10) %.

The 6100A standard was configured to mono-phase voltage and current source. Ten measurements were made for each point set in calibration protocol in order to evaluate the repeatability of the instrument analyzer under test (AUT).

The measurement uncertainty estimation looks into account quantities presented in Table V.

The eq. 1 allows standard uncertainty estimation, where x_i is each input quantity, and $u(x_i)$ is its A standard uncertainty.

Fig.2. Power analyzers tested

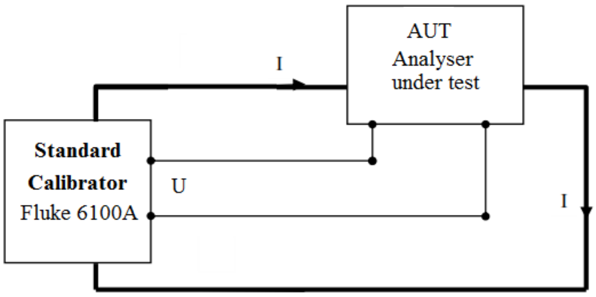

Fig. 3. Block diagram of the direct comparison setup between standard comparator and mono-phase analyzer under test.

TABLE V
INDIVIDUAL CONTRIBUTION TO UNCERTAINTY

Input quantity	Probability distribution
Repeatability	Normal
Resolution	Uniform
Calibration of the standard	t-Student
Drift and temperature error	Uniform

$$u(x_i) = \sqrt{\frac{\sum_{k=1}^{n}(x_i - \bar{x})^2}{n(n-1)}}\,\bar{V}_{ix} \qquad (1)$$

The measurement model of the error E_x of the instrument AUT is defined in eq.2, where: $\bar{V}_{ix}$ - the average value indication of AUT, δV_{ix} - the correction due to the finite resolution of indications, Vs - voltage configured in the standard calibrator corrected by its calibration certificate (δV_s), δV_{sD} and δV_{sT} - the corrections due to drift and temperature.

$$E_x = \bar{V}_{ix} + \delta V_{ix} - V_s - \delta V_s - \delta V_{sD} - \delta V_{sT} \qquad (2)$$

With uncertainties A and B type, determined for each component of eq. 2, complex uncertainty results:

$$u(E_x) = \sqrt{u^2(\bar{V}_{ix}) + u^2(\delta V_{ix}) + u^2(V_s) + u^2(\delta V_s) + u^2(V_{sD}) + u^2(\delta V_{sT})} \qquad (3)$$

1. *Sinusoidal voltage – Testing state 1*

The Table VI presents the results of calibration at point rms voltage Vs = 100V:

Error *Ex* = 0 V;
Expanded uncertainty = 0.1176V.

TABLE VI
CALIBRATION RESULTS – SINUSOIDAL SIGNAL

Quantity	Uncertainty A and B type	Contribution to combined uncertainty
$\bar{V}_{tx} = 100V$	A type	0V
	$u(\bar{V}_{tx}) = 0.058V$	0.058V
$Vs = 100V$		0
	$u(V_s) = 0.0093V$	0.0093V
	$u(V_{sD}) = 0$	0
	$u(V_{sD}) = 0$	0
	Combined uncertainty = 0.05879 V	
	Expanded uncertainty= 0.1176V (k=2)	

Technical characteristics of AUT indicate only maximum error = 0.7V.

2. *Non-Sinusoidal Voltage – Testing state 2*

The methodology used in this situation is similar in non-sinusoidal calibration method indicated in [19]. The waveform is a fundamental component (50 Hz, 100V rms) combined with 3rd harmonic (150Hz, 30V rms). The uncertainty assessment methodology is indicated in [20].

The Table VII presents the results of calibration:

Error *Ex* = -0.003 V;
Expanded uncertainty = 0.1793 V.

TABLE VII
CALIBRATION RESULTS – NON-SINUSOIDAL SIGNAL

Quantity	Uncertainty A and B type	Contribution to combined uncertainty
$\bar{V}_{tx}$ =104.4V	A type	0.001V
	$u(\bar{V}_{tx}) = 0.058V$	0.058V
$Vs = 104.403V$		0
	$u(V_s) = 0.01059V$	0.01059V
	$u(V_{sD}) = 0$	0
	$u(V_{sD}) = 0$	0
	Combined uncertainty = 0.058967V	
	Expanded uncertainty= 0.1793V (k=2)	

These results indicate both the correct choice of calibration method as well as the processing of the results.

V. CONCLUSIONS

This paper analyzes the metrological possibilities to calibrate the power analyzers consistent with the national and international standards in the field. It shows a test regarding the calibration for voltage magnitude the method used is based on the use of a calibrator source.

The calibration methods performed today require a large number of power quality parameters and measurement points. Ensuring traceability of such instruments and reducing the complexity and cost of calibration procedures are elements considered in future research.

ACKNOWLEDGMENT

This work was performed with partially financial support by Project no.30/2012 Romanian Research Authority. This support is acknowledged with thanks.

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