Results of an Interlaboratory Comparison of Current Harmonic Measurements Performed According to IEC 61000-3-2

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Abstract – Results of an interlaboratory comparison of current harmonics measurements performed according to the international standard IEC 61000-3-2 are presented. A general description of the activity is provided. The circuit model of the traveling sample is described, and its SPICE simulation is compared with the robust average of measurement results. The reproducibility of this basic electromagnetic compatibility test method is quantified to verify if the reproducibility limits set by the standard IEC 61000-3-2 are met.

1. Introduction

This work is in the vein of others devoted to the investigation of the measurement reproducibility of basic test methods in electromagnetic compatibility (EMC). In particular, papers [1–4] are devoted to the quantification of the reproducibility of radiated emission measurements, [5] analyses the reproducibility of conducted emission measurements of voltage disturbances, [6, 7] are focused on the reproducibility of radiated immunity tests, [8] concerns the reproducibility of immunity tests against currents induced at radio frequency, and [9] deals with the reproducibility of immunity tests to impulse (surge) phenomena.

To our best knowledge, the reproducibility of current harmonics measurement according to the standard IEC 61000-3-2 [10] has never been investigated before. From March to December 2021, a proficiency test through interlaboratory comparison of current harmonics measurements was carried out with the first author as coordinator. Twenty test houses in Europe participated in the exercise. A stable and robust traveling sample was specifically designed and realized, essentially consisting of a relatively low-power, nonlinear load. Here, we report the results of this intercomparison.

In Section 2, we provide a general description of the activity. In Section 3, the robust statistical analysis used for processing measurement results is introduced. Details about the structure and characterization of the traveling sample are reported in Section 4. The measurement results produced by the participants in the interlaboratory comparison are presented and briefly analyzed in Section 5. Finally, Section 6 is devoted to conclusions.

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2. Description of the Interlaboratory Comparison

The interlaboratory comparison included an evaluation of the measurements of a traveling sample provided by the coordinator. Each laboratory made a quantitative examination (measurement) of the traveling sample, thus providing the coordinator with a measurement result. The coordinator designed and assembled the traveling sample.

The coordinator assigned to the traveling sample a reference value and the corresponding uncertainty. The reference value x^* and its standard uncertainty s^* were obtained by the coordinator through the statistical analysis of the measurement results provided by the laboratories during the proficiency test. The reference value x^* and the standard uncertainty s^* were disclosed to participants at the end of the proficiency test, after that, the last participating laboratory submitted its measurement results.

The scheme of participation in the proficiency test was sequential. The coordinator passed the traveling sample to the first participating laboratory. The first laboratory performed the measurement, thus obtaining the first measurement result. The first laboratory passed the traveling sample to the second laboratory, which, in turn, performed the measurement and determined the second measurement result. The second laboratory passed the traveling sample to the third laboratory and so on. The last laboratory returned the traveling sample to the coordinator. The proficiency test was completed when the last participating laboratory submitted its measurement results to the coordinator.

The measurement result provided by each laboratory consisted of the current values x at given harmonic orders (and corresponding frequencies). Harmonic orders were selected by the coordinator. The measurement results provided by each laboratory were compared, harmonic by harmonic, against the reference values assigned by the coordinator.

Participation was open to EMC test laboratories that could perform harmonic currents emission measurements in accordance with the method described in [10, section 6.3], in the frequency range from 50 Hz to 2 kHz (from the fundamental to the 40th harmonic of 50 Hz). Accreditation to ISO/IEC 17025 [11] was not required for admission to the proficiency test. The activity was designed assuming participation of both accredited and nonaccredited laboratories.

3. Statistical Analysis

The measurement result provided by each laboratory was compared against the reference value x^* and its standard uncertainty s^*. The assessment of the performance of the laboratory was based on the z score (symbol z, see [12, section 9.4.1]). The measurement result x_i provided by the ith laboratory ($i = 1, 2, ..., p$, where p is the number of participating laboratories) was compared with the robust mean x^* and robust standard deviation s^* assigned by the coordinator as follows

$$z_i = \frac{x_i - x^*}{s^*} \tag{1}$$

The value of z_i was calculated for each laboratory and for each investigated frequency. Therefore, as many values of z_i were calculated as the number of investigated frequencies (for example, 10 frequencies investigated, 10 values of z_i for the ith laboratory). The measurement result provided by the ith laboratory produced a warning signal if, at least at one frequency, we had z_i less than –2 or greater than +2. The measurement result provided by the ith laboratory produced an action signal if, at least at one frequency, we had z_i less than –3 or greater than +3. If at all frequencies, we had z_i greater than –2 and less than +2, then the measurement result provided by the ith laboratory did not highlight any anomaly (warning signals do not add up to give an action signal).

The values of x^* and s^* were obtained by the coordinator by using the robust analysis (algorithm A) described in [12, Annex C, section C.3.1]. The robust analysis is based on an iterative calculation. At the first step of iteration

$$x^* = \text{median of } x_i \quad (i = 1, 2, ..., p) \tag{2}$$

and

$$s^* = 1.483 \cdot \{\text{median of } |x_i - x^*|\} \quad (i = 1, 2, ..., p) \tag{3}$$

Notably, the factor 1.483 that appears in (3) represents the ratio between the standard deviation σ and the median of the absolute deviations from the median (MAD), assuming normal distribution. It is indeed possible to show that in the case of symmetric distribution $\mathrm{MAD}/\sigma = \Phi^{-1}(3/4)$, where Φ is the cumulative distribution function. In the case of normal distribution $\Phi^{-1}(3/4) = 0.6745$ and therefore $\sigma = 1.4826 \cdot \mathrm{MAD}$.

4. Traveling Sample

The traveling sample (see Figure 1) was a nonlinear device absorbing an active power of nearly 40 W at a rated voltage of 230 V (RMS). It essentially consisted of a full wave rectifier and a resistive–capacitive load. The traveling sample was designed for being powered at the fundamental frequency of 50 Hz and rated voltage of 230 V (RMS). When powered, the traveling sample generated harmonic currents from 50 Hz to 2 kHz at 50 Hz steps; however, only odd harmonics were considered in the interlaboratory comparison. Even harmonics had small amplitude and were neglected.

Figure 1. Picture of the traveling sample.

The coordinator identified the harmonics to be measured (10) and reported through their order. For example, the harmonic current of order five was at the approximate frequency of 250 Hz. The traveling sample required at least 1 min warm up after being powered, and measurements should not have been carried out before the warm up time was elapsed.

The amplitudes of the harmonic currents generated by the traveling sample were stable. Hence, a test observation period T_{obs} of 10 s was sufficiently long to achieve the measurement repeatability specified in [10, section 6.3.3.1].

The diagram showing the main circuit parameters of the nonlinear load is shown in Figure 2. It was essentially a full-wave rectifier formed by a bridge made of diodes D1, D2, D3, and D4 (model 1N5408) and a resistive–capacitive load (series of 47 μF capacitor, and 3.3 Ω resistor). The 2267 Ω resistor was a bleeder for the 47 μF capacitor.

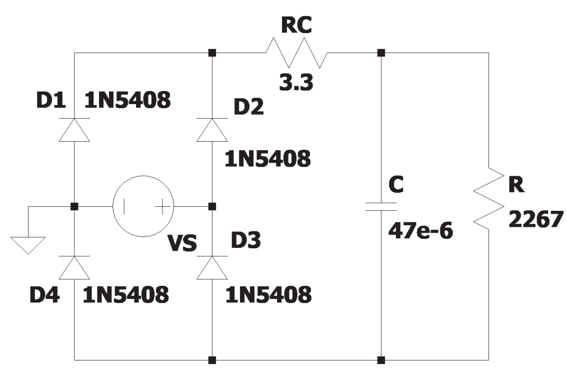

Figure 2. Circuit diagram of the nonlinear load.

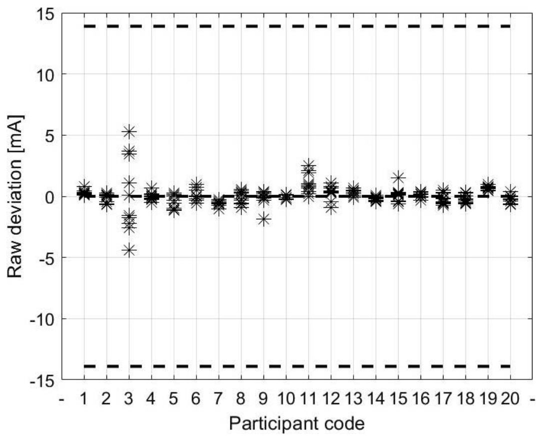

Figure 3. Raw deviations between the measurement results of the participants in the interlaboratory comparison and the reference values. An incremental code from 1 to 20 is associated with each participant. The reproducibility limits set by the standard [10] of ±13.9 mA are represented through dashed lines.

5. Measurement Results

The measurement results, in terms of deviation between raw measured values and reference values, are shown through the plot in Figure 3. According to [10, section 6.3.3.2] measurement reproducibility should be better than $\pm(1\% \cdot I_{\text{in}} + 10\,\text{mA})$, where I_{in} is the total input current averaged over the observation period. For the traveling sample $I_{\text{in}} \sim 390\,\text{mA}$, the measurement reproducibility should be within ±13.9 mA. Differences in measurement results that are less than measurement reproducibility are deemed negligible (compare measurement results with the reproducibility limits represented through dashed lines in Figure 3). The relatively large spread of the measurement results provided by participant 3 is probably due to the use of a measurement system requiring an external, large current rated, but low-accuracy, current clamp.

The robust mean x^* and standard deviation s^* at the 10 measurement frequencies selected by the coordinator are reported in Table 1. The current values I obtained from the SPICE (LTspice XVII(x64) (17.0.24.0)) simulation of the circuit model (shown in Figure 2) are reported in the fifth column of Table 1. They do not represent a substitute for the measurement results but a confirmation that the traveling sample behaves as expected and that the measurement method is not affected by a significant bias. The z scores of each participant are finally shown in the plot in Figure 4.

Table 1. Robust mean x* and robust standard deviation s* at the 10 measurement frequencies selected by the coordinator of the interlaboratory comparison[a]

Harmonic number	Frequency (Hz)	x^* (mA)	s^* (mA)	I (mA)
3	150	184.92	0.79	183.1
7	350	144.56	0.65	143.8
11	550	89.69	0.62	90.2
15	750	44.30	0.63	45.4
19	950	29.57	0.49	30.0
23	1150	28.19	0.56	28.4
27	1350	19.91	0.42	20.7
31	1550	12.74	0.30	13.4
35	1750	12.43	0.40	12.6
39	1950	10.59	0.40	11.1

[a] The current calculated through the circuit model in Figure 2 is reported in the fifth column.

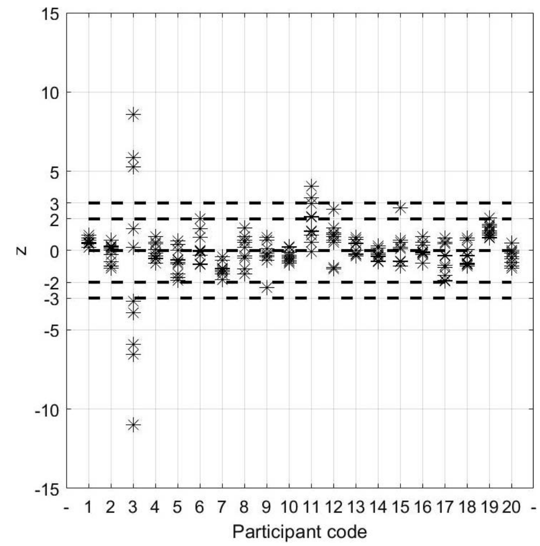

Figure 4. The z scores of each participant in the interlaboratory comparison. The critical threshold levels ±2 and ±3 are represented with dashed lines.

6. Conclusion

The measurement results provided by the 20 participants at the 10 measurement frequencies selected by the coordinator are nearly within –5 mA to +5 mA from the reference values. Most of measurement results are within –1 mA to +1 mA from the reference values. The robust standard deviation s^* is between 0.3 mA and 0.8 mA, a much lower value than the reproducibility limit of 13.9 mA set by [10].

The 200 measurement results were provided by the participants, and 18 signals (eight warning signals and 10 action signals) were issued. Because measurement results are well within the expected reproducibility limits, warning and action signals indicate relative performance of a participant with respect to the average of all participants, and they should not be interpreted as a noncompliance with the IEC 61000-3-2 standard.

7. References

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