COMPARISON OF MEASUREMENT METHODS FOR DETERMINING ELECTRICAL HARMONIC DISTORTION.

Artur Augusto Martins [1], **Regis Renato Dias** [1]

[1] Instituto de Pesquisas Tecnológicas do Estado de São Paulo S.A. - IPT

E-mail: arturm@ipt.br

Abstract: This work shows the comparison between a harmonic meter based on a digital multimeter digitizing function and a comercial electricity harmonics standard. Details of the algorithm with remarks about how signal processing techniques were applied to avoid some pitfalls and improve results reliability are shown. Some techniques used to achieve better spectrum resolution and a method to measure harmonic phase will be also shown, with graphical visualizations and algorithm description.

Keywords: THD, signal processing, Power Quality, Harmonics.

1. INTRODUCTION

The present work focus on data visualization and comparison of the developed method with a high-end harmonic analyzer. Importance of evaluating the harmonic distortion on power signals were already explained by other publications[1]. Other papers with similar objective of the present one was already presented[2].

Some standard waveforms will be used as a test-case to the developed method, demonstrating how in some circumstance many harmonic analyzers may fail to correctly measure those signals harmonics.

Also, an approach to determine the harmonic phase relative to its fundamental will be shown. This is a common parameter available on many commercial power analyzers, but it was hard to find some information on how it could be estimated.

2. DEVELOPED SYSTEM

Composed by a HP 3458A digital multimeter (DMM) and a software developed using Python 3.4 programming language, the system can be run headless, writing results direct to a file system or a WEB interface.

2.1. Software

The system relies on many mathematical, data visualization and data acquisition libraries for Python. Featured ones are “numpy”, mainly used to evaluate DFT from waveforms, hence determining the amplitude of harmonic content, “matplotlib” and “seaborn” to graphic visualize the results and “pyVISA”, to perform the DMM data acquisition.

2.2. Hardware configuration

The DC voltage range with digitizing configuration (DCV) was used on the DMM. This configuration provides lowest noise level with high resolution (up to 28 bits)[3]. The trade-off between low noise and low bandwidth, compared to others available configurations is not a issue, since current work focus on analyzing low frequency signals with higher harmonics about 2.4 kHz, much lower than the 150 kHz limit.

2.3. Materials and methods

The signal source Fluke 5520A multifunction calibrator with the Power-Quality optional installed, is used as the distorted signal generator. Two preinstalled waveforms were used, the "IEC A" and "NRC7030".

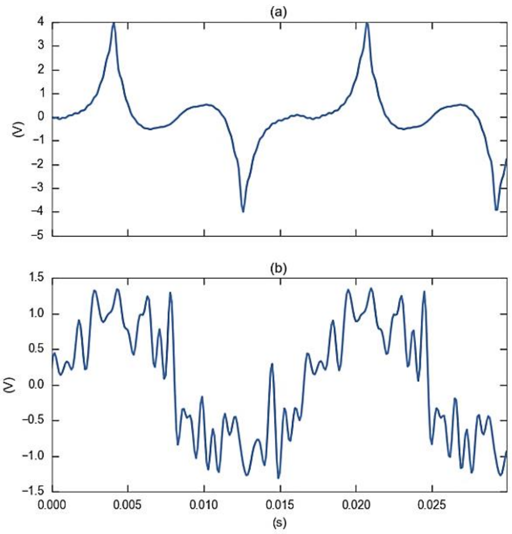

Figure 1- Signal with high harmonic content. In (a) is shown "IEC A" waveform and in (b) "NRC 7030".

Those waveforms provides a good test-case for the evaluation of waveform analyzers, as it has up to 40 defined harmonics with both phase and amplitude distortion, comprehensively generating a good test coverage[4].

After acquiring the signal using the DCV configured to digitize 10000 samples at 20 kHz sample rate, the data is processed by the developed algorithm as follow:

1. Apply harmonic product spectrum (HPS);
2. Interpolation of fundamental peak on spectrum;
3. Frequency estimation;
4. Applying a rectangular window to an integer number of signal periods;
5. Estimate harmonic parameters.

This study focus on three parameters: Harmonic amplitude, phase and Total Harmonic Distortion (THD).

2.4. Signal processing

The developed algorithm firstly measures the signal frequency from spectrum. This approach avoid erroneous time domain frequency measurement, since the "NRC 7030" test signal present many zero crossing and spikes. However, estimating the frequency from "IEC A" waveform spectrum can also give inaccurate results. The signal has a 3rd harmonic with 100% of fundamental amplitude, creating a pitfall for the proposed method.

So the first step of signal processing is applying HPS. This stage is intended to mitigate the failure of determining the signal frequency as previously described.

By downsampling and multiplying the spectrum, low frequency noise piles up and overwhelms the undesired peaks, as shown on figure 2.

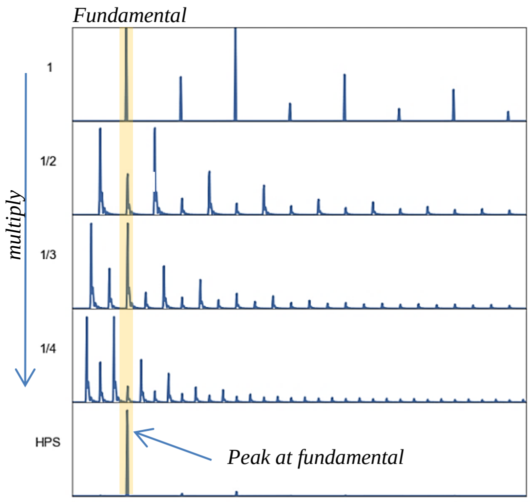

Figure 2- Harmonic Product Spectrum.

After HPS is performed, an estimative of the fundamental frequency is determined. Then, the original spectral lines are interpolated and used to achieve better amplitude accuracy[5], as show in figure 3 for the “IEC A” waveform spectrum.

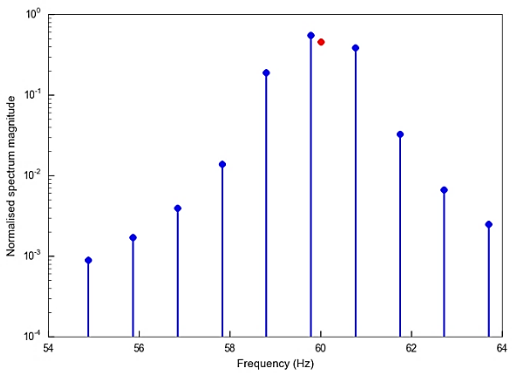

Figure 3 – Spectrum’s region of interest used to estimate fundamental frequency and amplitude. Note the interpolated point precisely positioned near 60 Hz

The same interpolation procedure is applied through higher frequency bins. An array is created containing information for each frequency and amplitude up to 40th harmonic.

To perform harmonics phase measurement, a time domain analysis is performed as follow:

1. Sintetize a pure sine and cosine with same signal fundamental frequency and samples number;

2. Let $corr_{sin}$ and $corr_{cos}$ be the correlation between signal and the synthesized sine and cosine respectively;

3. Let φ_{offset} be the result from the four quadrant arctangent of $corr_{sin}$ $corr_{cos}$;

4. For each harmonic, synthesize a sine and cosine with the proper phase offset, using (1) and (2):

$$sin_i = \sin(2\pi f t + i\varphi_{offset}) \ (1)$$

$$cos_i = \cos(2\pi f t + i\varphi_{offset}) \ (2)$$

Where *f* is the harmonic frequency, *t* is the time array and *i* is the harmonic bin index.

5. Determine phase for each bin, using (3):

$$\theta_i = \arctan 2(corr(cos_i, sin_i)) \ (3)$$

3. RESULTS

For our comparison, “IEC A” and “NRC 7030” waveforms were applied simultaneously to DMM and Radian Standard. Both DMM using the DCV function and Radian Standard (RD) recorded 100 measurements on a one hour period. A side-by-side THD error distribution can be visualized on figure 4.

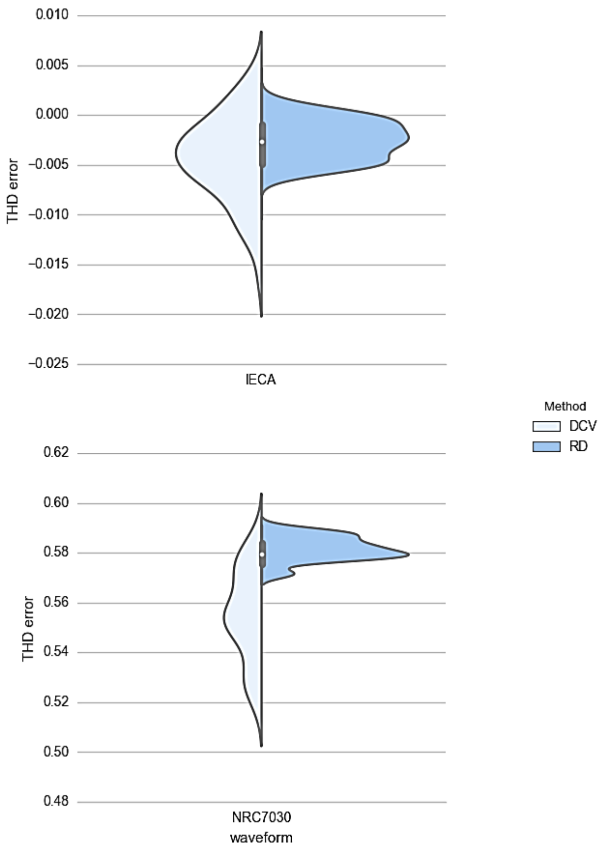

Figure 4 – THD error distribution comparison.

The THD was estimated by (4):

$$THD = \frac{\sqrt{\sum_{i=2}^{n} V_i^2}}{V_1} \quad (4)$$

Where V_i is the amplitude for the harmonic number i and V_1 is the fundamental amplitude.

By visual inference, both DCV and Radian errors distribution behave similar to a normal distribution.

On table 1 is presented the uncertainty budget for test case with worst error (NRC7030). All uncertainties have normal distributions. Note that DMM "calibration" component is the worst case reported on calibration certificate for the 1000 V DC range.

Table 1. Uncertainty budget

quantity X_i	**estimate** x_i	**contribution** $u_i(y)$
Variability From RD	49.5712 %	0.0097 %
Variability From DMM	49.545 %	0.036 %
DMM 1000 V DC calibration	0 V	0.15 %
RD THD range calibration	0 %	0.030 %
Error (DMM - RD)	-0.026 %	0.16 %

For a 95% confidence interval, the direct comparision error, given by the difference from developed method and Radian readouts is (-0.026 ± 0.31) %.

Radian is calibrated by Radian, with standards traceable to the National Institute of Standards and Technology (NIST) and 3458A DMM is calibrated by IPT, with standards traceable by Inmetro.

4. CONCLUSION

The experimental results show that developed system uncertainty is limited by the 1000 V DC range. A better accuracy could be achieved by the DMM, if the measured signal had lower amplitude, suitable to measure at lower ranges. For instance, the 10 V DMM range has better offset voltage uncertainty compared to the 1000 V range used at this work[3]. Also, Radian is not capable to measure signal with RMS voltage lower than 30 V, as stated on its user manual[6].

By acquiring a greater number os samples and cycles instead of faster sample rate also contributed to recduce the total variability. This was stated empirically during our experiments during the development process.

The signals used as test-case at this work, present an unusual THD and harmonic composition. Therefore, those waveforms demonstrated how unexpected results can be if one decides to roll your own harmonic analyzer based on some data acquisition hardware, or even when a comercial meter is not well chose and calibrated. The development of a harmonic analyzer must consider many concerns to ensure it’s robustness and feasibility for a large range of input signal characteristics.

7. REFERENCES

[1] Franco A M, Tóth E and Debatin R M *Influência dos harmônicos na medição da Potência* 2002 Seminário Internacional de Metrologia Elétrica

[2] Pinto M V, Foiatto N and Augusto M S 2013 *Calibration system developed to the harmonic measurements with DFT techniques* 16th International Congress of Metrology

[3] HP3458A Multimeter *Operating, programming and Configuration Manual* 1994 Keysight

[4] 5520A Calibrator *PQ Option Operators Manual* 2001 Fluke

[5] Gasior M, Gonzalez J L *Improving FFT Frequency Measurement Resolution by Parabolic and Gaussian Interpolation* 2004 *CERN-AB-Note-2004-021-BDI*

[6] RD-33 Portable Three-phase Electricity Standard *Operations Manual* Radian Research