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CONSIDERATIONS ON THE COMPARISON OF TWO MOST ACCURATE SAMPLING METHODS FOR MEASURING HARMONIC PARAMETERS AT LOW FREQUENCIES

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Abstract

Two methods for the estimation of the harmonic parameters at low frequencies based on digital sampling voltmeter data were compared: (1) the synchronous synthesizing and sampling and (2) the optimized asynchronous sampling. It was verified that they agree within less than one part in 10^6.

Introduction

The synchronous sampling technique reached its current high accuracy with the development of a system for synthesizing and measuring electric power where the timing of the digital signal generator is obtained from the time base of a digital sampling voltmeter (DSV) [1]. The system uses one DSV that is synchronously switched between the voltage and current channels. Several technical details about the synchronous synthesizing and sampling are discussed in [2] and in the references therein.

An optimized algorithm based on asynchronous sampling that uses two commercial DSVs in a master-slave configuration for accurately measuring the magnitudes and phase shifts of the harmonics of two arbitrary voltage signals at low frequencies was published recently [3]. Several technical details about the optimized algorithm are discussed in [4].

The algorithm described in [3] was simplified for one-channel measurements and the simplified version was sent by Inmetro to PTB as an executable software (referred to in the sequel as 'asynchronous software'). The objective was to compare the synchronous and asynchronous sampling techniques for measuring harmonic voltages. The methods and results of the comparison are discussed in this paper. Due to limited space, we describe only the configuration of the measurement systems as well as the results obtained when the asynchronous software was installed in an independent system.

Independent asynchronous sampling system

Two separate systems (one synchronous and the other asynchronous) were used to measure the signal harmonics. A 55.5-Hz, half-wave rectified signal containing 18 harmonics was synthesized by the digital generator of the PTB synchronous system. The signal was sampled by both the PTB synchronous system and an independent system that comprised a non-synchronized DSV controlled by a computer. The PTB synchronous system ran its own software. The independent system ran the asynchronous software. Both systems were at first configured to measure $m = 25$ harmonics.

The PTB system reported a THD of 43.42876%. The algorithm was configured to sample 10 periods with 50 samples per period ($N = 500$) spaced by $t_{samp} = 0.000360$ s (with $t_{aper} = 0.000335$ s). The ac and the fundamental rms values reported were 5.5234665 V and 5.0663223 V, respectively.

The independent system controlled by the asynchronous software reported a THD of 43.42880%. The algorithm selected $n = 100$ bursts of $N = 199$ samples spaced by $t_{samp} = 0.0003622$ s (with $t_{aper} = 0.0003322$ s). The fundamental ac rms value (5.066309 V) was measured with an uncertainty of 3.7 μV V^{-1}. The harmonic magnitudes as a percentage of the fundamental were measured with an uncertainty of less than 6×10^{-7}.

Table I. Harmonic magnitudes (m = 25).

Harm .No.	Inmetro (%)	$u(d_i)$ (10^{-6})	PTB (%)	$u(d_i)$ (10^{-6})	Error (10^{-6})
1	100	-	100	-	-
2	42.36267	0.6	42.36264	0.4	0.3
3	0.00071	0.5	0.00073	0.3	–0.2
4	8.45477	0.5	8.45477	0.4	0.0
5	0.00034	0.5	0.00038	0.3	–0.4
6	3.60485	0.5	3.60487	0.3	–0.2
7	0.00037	0.5	0.00040	0.3	–0.3
8	1.98579	0.5	1.98576	0.4	0.3
9	0.00026	0.5	0.00030	0.3	–0.4
10	1.25647	0.5	1.25651	0.3	–0.4
11	0.00019	0.5	0.00026	0.4	–0.7
12	0.85684	0.5	0.85684	0.4	0.0
13	0.00016	0.5	0.00016	0.4	0.0
14	0.61829	0.5	0.61829	0.4	0.0
15	0.00031	0.5	0.00029	0.4	0.2
16	0.46826	0.5	0.46821	0.4	0.5
17	0.00043	0.5	0.00056	0.4	–1.3
18	0.35957	0.5	0.35952	0.5	0.5

The results obtained for the harmonic magnitudes as a percentage of the fundamental are listed in Table I. The results above the 18th harmonic are negligible and were not listed. The results obtained with the independent system controlled by the asynchronous software are listed in the 'Inmetro' column. The third column lists the corresponding standard uncertainties as evaluated by the asynchronous software. The results obtained with the PTB synchronous system are listed in the 'PTB' column. The fifth column lists the corresponding standard uncertainties as evaluated by PTB. The differences between the two methods are listed in the 'Error' column. The results for the phase angles relative to the fundamental are listed in Table II.

Table II. Harmonic phase angles (*m* = 25).

Har No.	Inmetro (deg)	$u(\gamma_j)$ (deg)	PTB (deg)	$u(\gamma_j)$ (deg)	Error (deg)
1	-90	-	-90	-	-
2	−179.9971	0.0001	−179.997	0.010	0.0001
4	−179.9775	0.0004	−179.978	0.021	0.0005
6	−179.9383	0.0008	−179.939	0.031	0.0007
8	−179.8542	0.0015	−179.854	0.041	-0.0002
10	−179.7402	0.0023	−179.741	0.052	0.0008
12	−179.5624	0.0034	−179.564	0.062	0.0016
14	−179.3095	0.0047	−179.312	0.074	0.0025
16	−178.9915	0.0062	−179.007	0.083	0.0155
18	−178.5956	0.0081	−178.588	0.093	-0.0076

The measurement was then repeated for the same signal but with both systems configured to measure m = 40 harmonics. This was done in order to evaluate the effect of a shorter aperture time t_{aper}.

The PTB system reported a THD of 43.42887%. The algorithm was configured to sample 10 periods with 80 samples per period (N = 800) spaced by t_{samp} = 0.000225 s (with t_{aper} = 0.000200 s). The ac and the fundamental rms values reported were 5.5234871 V and 5.0663392 V, respectively.

Table III. Harmonic magnitudes (*m* = 40).

Harm .No.	Inmetro (%)	$u(d_j)$ (10^{-6})	PTB (%)	$u(d_j)$ (10^{-6})	Error (10^{-6})
1	100	-	100	-	-
2	42.36262	0.7	42.36274	0.5	−1.2
3	0.00075	0.7	0.00070	0.4	0.5
4	8.45477	0.7	8.45481	0.5	−0.4
5	0.00035	0.7	0.00043	0.5	−0.8
6	3.60485	0.7	3.60488	0.5	−0.3
7	0.00038	0.7	0.00038	0.5	0.0
8	1.98577	0.7	1.98576	0.5	0.1
9	0.00028	0.7	0.00028	0.6	0.0
10	1.25647	0.7	1.25641	0.5	0.6
11	0.00019	0.7	0.00017	0.5	0.2
12	0.85683	0.7	0.85688	0.4	−0.5
13	0.00016	0.7	0.00018	0.5	−0.2
14	0.61829	0.7	0.61837	0.5	−0.8
15	0.00032	0.7	0.00034	0.5	−0.2
16	0.46825	0.7	0.46819	0.5	0.6
17	0.00043	0.7	0.00038	0.5	0.5
18	0.35957	0.7	0.35964	0.5	−0.7

The independent system controlled by the asynchronous software reported a THD of 43.42875%. The algorithm selected n = 160 bursts of N = 159 samples spaced by t_{samp} = 0.0002266 s (with t_{aper} = 0.0001966 s). The fundamental ac rms value (5.066324 V) was measured with an uncertainty of 6.0 μV V^{-1}. The harmonic magnitudes as a percentage of the fundamental were measured with an uncertainty of less than 7×10^{-7}.

Table IV. Harmonic phase angles (*m* = 40).

Har No.	Inmetro (deg)	$u(\gamma_j)$ (deg)	PTB (deg)	$u(\gamma_j)$ (deg)	Error (deg)
1	−90	-	−90	-	-
2	−179.9972	0.0001	−179.997	0.010	0.0000
4	−179.9776	0.0004	−180.001	0.021	0.0234
6	−179.9386	0.0010	−179.938	0.031	-0.0006
8	−179.8548	0.0019	−179.855	0.041	0.0002
10	−179.7405	0.0030	−179.742	0.052	0.0015
12	−179.5628	0.0044	−179.564	0.062	0.0012
14	−179.3099	0.0061	−179.313	0.074	0.0031
16	−178.9927	0.0080	−178.993	0.083	-0.0003
18	−178.598	0.010	−178.607	0.095	0.009

The results obtained for the harmonic magnitudes as a percentage of the fundamental are listed in Table III. The results for the phase angles relative to the fundamental are listed in Table IV.

Conclusions

The relative difference between the fundamental rms values measured by the two methods is within the standard uncertainty evaluated by the asynchronous software. The harmonic magnitudes as a percentage of the fundamental measured by the synchronous and the optimized asynchronous methods agree in general within less than one part in 10^6. The differences in the corresponding harmonic phase angles are in general within the standard uncertainties evaluated for both methods.

References

[1] G. Ramm, H. Moser and A. Braun, "A new scheme for generating and measuring active, reactive, and apparent power at power frequencies with uncertainties of 2.5 x 10^{-6}", *IEEE Trans. Instrum. Meas.*, **48**, no. 2, pp. 422-426, Apr. 1999.

[2] W. Kürten Ihlenfeld, E. Mohns, H. Bachmair *et al.*, "Evaluation of the synchronous generation and sampling technique", *IEEE Trans. Instrum. Meas.*, **52**, no. 2, pp. 371-374, Apr. 2003.

[3] G.A. Kyriazis and M.L.R. Campos, "An algorithm for accurately estimating the harmonic magnitudes and phase shifts of periodic signals with asynchronous sampling", *IEEE Trans. Instrum. Meas.*, **54**, no.2, pp.496-499, Apr. 2005.

[4] G.A. Kyriazis, *Bayesian estimation of harmonic components using digital voltmeters with asynchronous sampling*, Ph.D. Thesis, Federal University of Rio de Janeiro (COPPE/UFRJ), (www.pee.ufrj.br/teses/textocompleto/2005062451.pdf), Rio de Janeiro, Jun. 2005, *in Portuguese*.