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Examination of the Instrument for Power Quality Estimation - Case Study

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Abstract – **Evaluation of measurement properties of digital instrument can be performed in several ways. The calibration procedures relay mainly on the use of one of two standard methods: using the pattern input data set or applying the pattern reference instrument. In paper, the case of measurement experiment with use of ten instruments for electrical power quality assessment is cited. All instruments met the terms of respective standards, and measured this same network voltage. But their indications differed significantly. The question is: what are the reasons of these differences in indications? Case study - based considerations concerning calibration procedures are presented, taking into account the configuration of the measurement channel as well as the way of the measurement information handling in separate parts of measuring channel. The performed methods of the channel calibration or its characteristics verification were presented, along with obtained exemplary results. The conclusions related to the reasons of instruments indications dispersion are formulated. Another approach to measurement characteristics verification, especially performed in software part of instrument, is proposed.**

Keywords **–measurement channel examination, calibration procedures, measurement algorithms, electrical power quality estimation**

I. INTRODUCTION

A core information of this paper is based on previously accepted paper [1], devoted to validation of the measurement algorithms in instrument for power quality estimation. At the same time it should be added, that not only structure of the paper was changed, but also approach towards examine the measurement properties of the instrument for power quality estimation is different and case-study based.

The configuration of analogue quantity measurement channel of most instruments can be illustrated in simplified form as shown in Fig. 1. Two main parts of the channel can be distinguished, the Data Acquisition (DA) and the Digital Data Processing (DDP). The base of such decomposition of measurement channel is the way of measurement information carrying and processing. In the DA part the information is transferred by signals and its processing depends on the analogue hardware characteristics of this part of channel as well as on the characteristics of the ADC (Analogue-to-Digital Converter). The signals, and consequently the carried information are vulnerable to a number of disturbances. In the DDP part the information is represented by a string of numbers, and the influence of any disturbances is significantly limited. The data processing is typically performed in the processor software (although in many solutions the data is processed in hardware, also programmable). The measurement characteristics of the DDP are depended on the software algorithms of processor (in Fig.1: DSP - Digital Signal Processor).

The calibration of an instrument involves checking its characteristics at several points throughout the calibration range of the instrument, while the verification of characteristics is to check the relationship between the result obtained by means of instrument and the expected result. Further considerations apply to both procedures calibration and verification, although it will be invoked only one of them.

For some simple devices, especially where the output information depends linearly from its input, the measurement channel can be treated as "black box" and in effect of calibration procedure the settings of "zero" or "span" of channel characteristics can be adjusted to obtain the expected course. These settings can be changed either in DA or DDP part. For more complicated measurement procedures the better practice is to perform the calibration procedures separately for DA and DDP parts. The evaluation of measurement characteristics of designed instrument was made considering these two parts of track.

The calibration of DA part is usually easy to execute. The measurement information in this part is carried by signals, so the calibration relays on determining of DA actual characteristics. The calibration can cover whole DA or the signal conditioning unit only (Fig. 1). The results can be used for scaling the data processed in DDP part of channel.

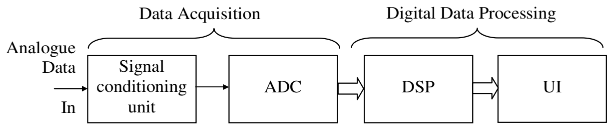

Fig. 1. The simplified block diagram of digital measurement channel

Assuming that the DA characteristics are known, the calibration of DDP can be done in few ways. Some of them are shown in Fig. 2. Further considerations concern the instrument with data processing in program algorithms embedded in processor software. In Fig. 2.a the calibration setup using the set of known digital data is shown. The data are fed directly to the DDP, excluding the DA part of channel. In estimation procedure the actual results from DDP are compared with the expected results. Main disadvantage of this calibration method is the limited set of test data which cannot cover various measurement conditions. This setup is mainly used for testing of the measurement software, during its design. The software can be embedded in DSP on board of instrument as well as outside the considered target circuit. Fig. 2.b shows the calibration setup using the analogue standard test signals. Just as in the previous method the set of testing signals is limited but the calibration procedure refers to both parts of the channel. The calibration setups in Fig. 2.c and Fig. 2.d are free from above mentioned limitations. But other problems concerning different sets of data, used by examined and reference instrument (Fig. 2.c) as well as processed in instrument's algorithms and forwarded for calculation in estimation system (Fig. 2.d), can result in lowering of quality of calibration procedure. This is particularly true for measurement functions where the set of data for calculation of the result is locally, in instrument's procedures, selected from an information stream.

The measurement functions performed in DDP part of channel are often performed in very sophisticated numerical algorithms. Although they are numerous methods for its calibration the problem is not closed.

In [2] the results of interesting experiment relating to power quality parameters designation were shown. Ten instruments used in the experiment, owned by different institutions, measured the same set of parameters describing the electrical power quality. "Own design" means the prototype instrument, developed in the scientific institution, participating in the experiment. The subjects of the measurements were, among others, network frequency, voltage rms values, total harmonic distortion, dominant harmonics, voltage fluctuation parameters: short and long term flicker severity.

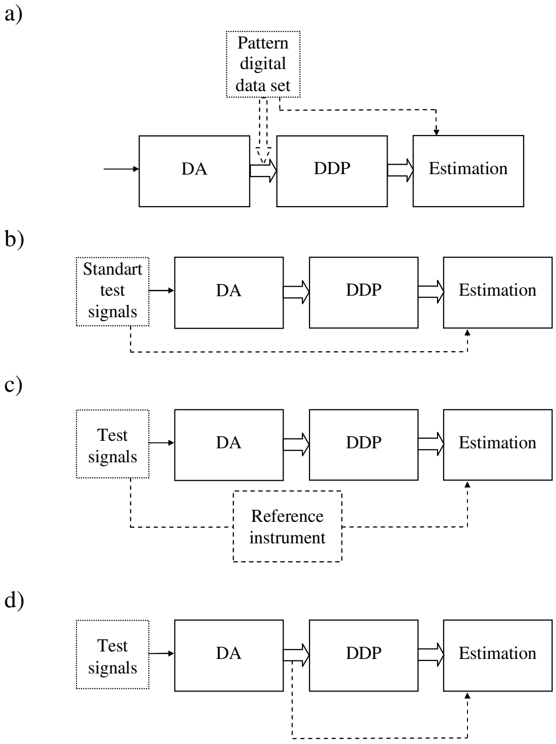

Fig. 2. The exemplary layouts for calibration of digital channel for measurement of analogue quantity : a) using pattern digital data set, b) using standard analogue test signals, c) with reference system, d) using collected digital data

All measurements were carried out at the same point of supply network. They were held at the same time and in the same of time period. All measuring instruments used in the experiment were declared by the manufacturers or designers as complying with terms of respective standard. Although the instruments were measuring the same voltage signal at the same time, their indications differed significantly [2].

For user of specific instrument it is difficult to assess the correctness of the instruments indications. He can only relay on the declarations of the instrument manufacturer.

In [3, 4, 5], some aspects concerning configuration and functioning of measurement track of "estimator/analyzer" (E/A) instrument for designation of electrical power quality coefficients, especially for ship power network estimation, were considered. Further detailed considerations are based on the given designed and constructed instrument, i.e. case study in the area under consideration.

This work is focused on the method of reliable verification of characteristics implemented in the software included in the DDP part of the E/A measurement channels. Main goal of this paper is concentrated on the calibration methods used to the developed instrument.

The measurement functions as well as the basic measurement algorithms implemented in the instrument are shortly presented in section II. Section III describes the calibration procedures applied during examination of instrument. The limitations of used procedures are discussed. Section IV presents the proposal of reliable method of calibration of measurement algorithms implemented in the instrument measurement functions as embedded processor software. This work is concluded in Section V.

II. MEASUREMENT FUNCTIONS

The hardware configuration of instrument is shown in Fig. 3. The voltages from electrical network (3- or 4-wires) and phase currents from up to three generating sets are fed to the inputs of ADCs, where they are sampled and converted into the stream of digital words. The designation of coefficients describing the electrical power quality is carried out in ADSP-TS201 TigerSHARC, embedded DSP processor on the DSM STSL module (Kaztek Systems) [6]. There is also located Xilinx Spartan-3 FPGA (Field Programmable Gate Array), used for data exchange between the DSP and other systems of instrument. The user interface, designed for control and selection of measurement functions of instrument, is supported by general purpose processor (GPP). This processor also controls the indication and registration of data.

In Fig. 4, the main operations carried out in measurement track of instrument, connected with data processing, are shown. They differ in rate of sampling of electrical network signals as well as in set of measured quantities and designated coefficients.

The algorithms of digital data processing for determining the value of individual parameters of electrical power quality are based on common application of DWT, FFT, DFT or chirp CZT, performed in a complementary way. In particular, the wavelet coefficients after respective levels of wavelet decomposition are used as the input data to various procedures of calculation of rms values, coefficients in Fourier series concurrently with transient monitoring algorithm. These operations are carried out in DSP (Fig. 3) [5].

Design and preliminary verification of algorithms embedded in software of E/A was performed using the startup system EVAL-TS201S-EZKIT Analog Devices [7], equipped with two TigerSHARC processors, the same as in the E/A device. Due to the different configurations of peripheral circuits of DSP processors in the startup system and in the E/A device, the preliminary verification included only selected parts of the measurement algorithms.

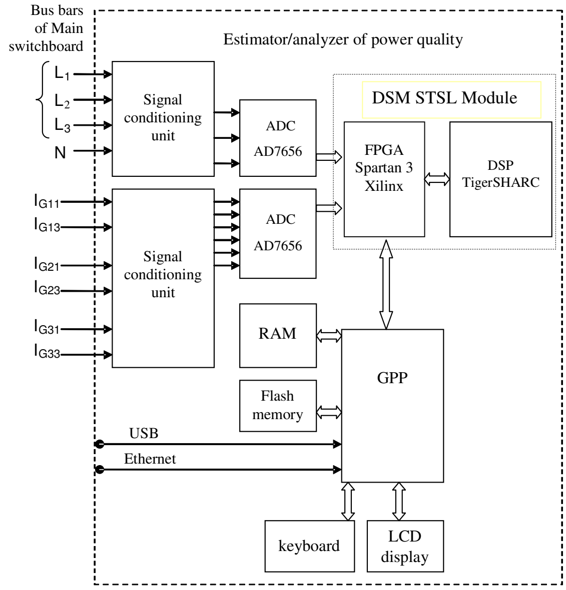

Fig. 3. The hardware structure of instrument [5]

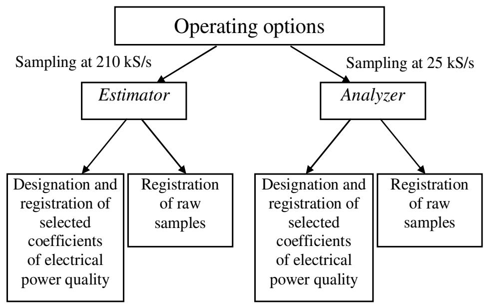

Fig. 4. Main operations performed in instrument

III. ASSESSMENT THE CHARACTERISTICS OF MEASUREMENT CHANNEL

The goal of experiments is most of all the examination of software algorithms, embedded in DSP.

As shown in Fig. 3, the DA part (Fig. 1) of measurement channels includes the circuits from the instrument inputs to the ADCs outputs. The calibration of DA part, starting from voltage dividers (for three voltage channels) and Rogowski coils (for six current channels) to ADC's (Fig.1), was performed using the pattern sources of alternating voltage and current. In Fig. 5, the exemplary characteristics obtained in calibration of one of used current probes, together with designated its trend line, is shown (different than the probe 1 analyzed in [1]). The equations of the trend lines, obtained in calibration procedures of acquisition part of measurement track (Fig. 5), were used in the software part (data processing) of measurement track for scaling of digital data in corresponding channels.

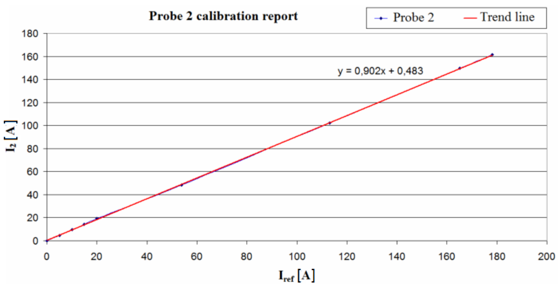

Fig. 5. The exemplary calibration report of current probe No. 2

Assuming proper calibration of input circuits, the accuracy of designation of particular power quality coefficient depends on correctness of algorithms applied in data processing part of measurement channels.

For assessment of measurement characteristics of whole measurement track, the E/A was tested under laboratory as well as in ship environment conditions for several various testing signals. The examination was performed using experimental setup shown in Fig. 2.c. Test signals were provided at the same time to inputs of the examined instrument and to reference PXI system. In Fig. 6, the exemplary results of calibration of the phase voltage channels of instrument are shown. The differences between rms values, measured by the tested instrument and PXI system, are presented.

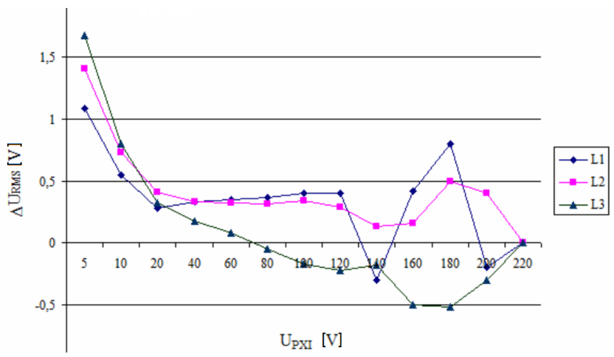

Fig. 6. The calibration results of voltage tracks of instrument

Another way of verification of measurement characteristics of instrument is done using the registered raw samples of electrical network signals. The experimented setup is shown in Fig. 2.d. For stationary test signals, the digital representations of raw samples of these signals were registered. For the same test signals, after change option of instrument operation (Fig. 4), the particular coefficients are registered. In the examination arrangement, based on PC computer with running software separately tested using pattern data, the registered raw samples are processed and calculated coefficients are compared with coefficients obtained from tested instrument. Table I contains the measurement results of 3-phase triangle signal (experimental setup as in Fig. 2.b), generated in Chroma type 6590 Programmable AC Power Source (for standard triangle signal DST017 from its waveforms library) [8], combined with the obtained results in the E/A instrument and as a result of raw samples processing in PC system (experimental setup as in Fig. 2.d).

Table 1. The results obtained in the E/A and in the PC reference system using raw samples of standard signal DST017 from Chroma Programmable AC Power Source.

			L1	L2	L3
E/A	U_{rms}	(V)	220,75	220,56	219,70
	U_1	(V)	219,13	218,93	218,10
	THD	(%)	12,00	10,24	11,97
PC	U_{rms}	(V)	220,80	220,20	220,24
	U_1	(V)	219,23	219,05	218,68
	THD	(%)	12,18	12,23	12,14
DST017	U_{rms}	(V)	220,00	220,00	220,00
	U_1	(V)	218,42	218,42	218,42
	THD	(%)	12,04	12,04	12,04

Concluding, the applied testing methods for assessment of measurement track characteristics are reliable for specified instrument. The obtained results of the experimental verification are positive within acceptable field of tolerance.

What is the reason of the phenomenon described in [2]? The problem is that the instrument under test and the testing arrangement operate indeed on different set of data. Because the individual coefficients are calculated using samples of signals from electrical network, collected in the time windows approx. 200 ms, the sets of the source data can differ. The procedures for selecting the data set, within the selected measurement window, are running independently for each instrument. For some specific measurement conditions, the small inaccuracy of measurement algorithms may result in large difference of instrument's indication compared to other instruments. Imperfection of measurement algorithms is often the result of used rounding, simplifications and approximations. The optimization of algorithms can help to improve the properties of the measuring instrument. This phenomenon can not be avoided, so the instrument's characteristics accuracy can be improved only by patient verification of software algorithms for calculation of individual coefficients.

IV. RELIABLE VERIFICATION OF MEASUREMENT ALGORITHMS

The idea of reliable verification of measurement algorithms, applicable for E/A instrument (and for another devices also, probably) is based on assumption that the set of data used for calculation of coefficients in examined instrument is the same as used in reference system.

This assumption is fulfilled if the measurement data processed in DSP for coefficients calculation are stored and further used for calculation of respective coefficients in verified reference system (Fig. 7). This configuration differs from the configuration shown in Fig. 2.d that the evaluation of the measurement algorithm performed in reference system is based on the same data set that was used in the E/A for calculation of individual coefficients.

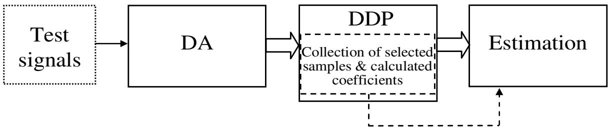

Fig. 7. The experimental setup for verification of measurement algorithms using selected samples and corresponding to them coefficients calculated in the E/A

Fig. 8 shows the resources of the DSM STSL module applied in instrument (Fig. 3). The module is equipped with 128 MB SDRAM additional memory. This memory was not used in instrument operations, because of sufficient capacity of internal memory of DSP (24 Mb) for calculation of adopted coefficients of electrical power quality.

The proposed idea of measurement algorithms verification assumes using of SDRAM memory (marked block in Fig. 8) for storing the selected samples from ADC, but these only, that were used by DSP for coefficients calculation, together with corresponding calculated coefficients. The capacity of SDRAM enables to accumulate the data from several processing cycles, corresponding to measurement windows, approx. 200 ms. For example, for "estimator" operating option (Fig. 4), for memorising the data collected from samples from the three voltage channels, converted in ADC at the rate of 210 kS/s, no more than 256 kB is needed.

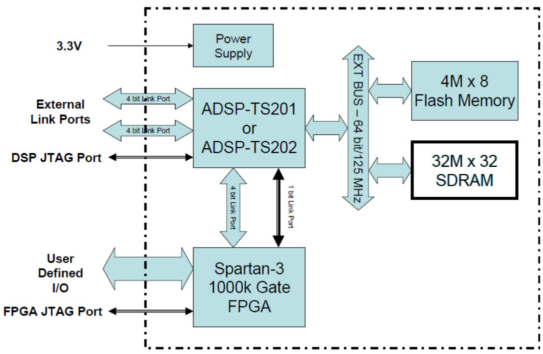

Fig. 8. The block diagram of DSM STSL module [6]

To perform the verification of embedded algorithms the original source data, together with DSP processing results, are sent to external reference system. This way it is possible to asses the real characteristics of data processing, embedded in software of DSP. The implementation of proposed method in instrument is not connected with any hardware modifications. The software changes are needed only to obtain the set goal. The results, shown in [2], indicate that the other methods of verification of the sophisticated algorithms, even using reliable examination systems, not always are sufficiently correct.

V. CONCLUSIONS

In the paper an idea of verification of measurement algorithms embedded in software of instrument for designation of coefficients of electrical power quality, as well as its application using available resources onboard of DSP module of elaborated E/A instrument, are discussed. Case study - based considerations concerning calibration procedures are presented, along with obtained exemplary results.

Another approach to measurement characteristics verification, especially performed in software part of instrument, is proposed. Applying of proposed method of measurement algorithms verification certainly can not solve all problems concerning the measurement result accuracy but it allows the assessment of the method for data processing using the built-in DSP software and identifying errors causing worsening of accuracy.

The research is in progress and the further results will be presented.

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