DETAILED ANALYSIS OF CLASS F1 / F3 FLICKER METER IMPLEMENTATIONS ACCORDING TO THE RECENT IEC STANDARDS

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ABSTRACT

The paper is concerned with specific problems of flicker-meter implementation in class A and class S power quality analyzers according to the most recent IEC standards, for class F1 and F3 respectively as defined in IEC 61000-4-15 ed.2.0. Test results of designed prototypes are included and compared with our previous implementations. We have focused to introduce the fully compliant correct flicker meters and to thoroughly understand the minimal requirements for such implementation.

INTRODUCTION

Voltage fluctuations are one of the many areas defining the complete power quality monitoring. One of the parameters indicating the voltage fluctuation is flicker. Flicker specification comes from observations of a subjective unpleasant sensation of flashing lights by human eye and brain [1]. Evaluation of the flicker as a power quality index focuses on voltage fluctuations of low frequency from 0.5 to about 35 Hz.

Flicker became observed and monitored because already at voltage fluctuation only a few tenths of a percent causes unpleasant changes in the perception of the light radiation of different light sources and thus adversely affect the human body [2]. Because the human eye is extremely sensitive to flicker voltage, change must be kept within very strict limits. Flickering in power systems is caused by transients (large changes in power consumption) or usage of nonlinear arc furnaces, welding machines etc. (harmonic distortion generally).

The paper follows an implementation of class F1 flicker-meter developed on our own modular ARTIQ platform. This device represents a modular PQ-Analyzer with common low cost 32-bit ARM micro-controller and high quality 16/24-bit AD convertor. We compare this implementation with our previous IEC 61000-4-15 ed.1 [3] flicker meter with simpler analog hardware in a PQ-B analyzer and with more recent class F3 flicker meters (PQ-S1and PQ-S2).

Implementation of flicker-meter is performed according to the standard IEC 61000-4-15 ed. 2.0 [4]. Paper highlights some pitfalls of calculating flicker in a general power quality analyzer. Some partial development achievements were already published in [5].

Hardware Characteristics

The main calculation unit of PQ-A analyzer is ARM STM32 microcontroller, which includes dedicated floating point unit. This makes the floating point calculations much faster and thus it can perform advanced mathematical operations faster. Voltage signals in PQ-A are sampled using a 24-bit sigma-delta AD converter with sampling rate of 256+ samples per period. PQ-B use 16-bit AD converter and PQ-S1 and PQ-S2 use internal 12bit AD converter implemented in microcontroller.

IMPLEMENTATION

Implementation of flicker calculation is performed in accordance with IEC 61000-4-15 Edition 2.0. This chapter describes problems with calculation in the analyzer and also used solutions. The scheme of a flicker meter is shown in Figure 1.

The figure depicts a schematic of the measuring and processing system. It consists of five blocks. The first block normalizes the level of the signal in order to achieve comparable results for various effective values of measured voltage. Purpose of the second block is to recover the voltage fluctuation by squaring the input voltage. Third block comprises several filters in order to remove the second harmonic (present due to squaring the signal) and weight the signal to simulate the human brain sensation and perception. The fourth block squares the signal and applies an averaging filter. The blocks 2 - 4 simulate the perception sequence: lamp –> human eye –> human brain. The fifth block performs statistical analysis of the measurement.

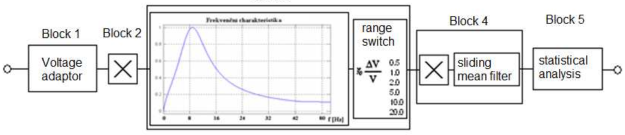

Figure 1: Block diagram of flicker-meter

Our solution

An AD converter on our platform samples the input signal at 14 kS/s on a 50 Hz network. Our previous experiments have shown that a lower sampling rate is actually optimal to reduce the overall computational load of the controller. For this reason it is recommended to perform resampling. In our solution the output sampling rate of 400 kS/s has been used.

The exact sampling rate is varying and dependent (phase locked) on the measured frequency of the fundamental harmonic component of signal. Such sampling method is needed for the correct operation of the power quality analyzer. But for evaluation of the flicker indices it is not suitable and without appropriate resampling one can introduce significant errors to the result. The resampling process is therefore a complicated process. Solving this problem will be described in further detail elsewhere.

First the digital signal from AD converter is squared and then is resampled to lower sampling rate but before resampling it needs to be filtered with a low-pass filter to prevent aliasing. For filtering it would be appropriate to use higher-order IIR filter (at least 5thorder). This filter is extremely susceptible on calculation accuracy and the 32-bit floating point arithmetic proved insufficient. Also the 64-bit/double precision could not have been used as on the platform as its calculation was too slow (approximately 10x slower). This problem was solved by a combination of four simpler 2nd order filters. Comparison of 3rd order filter computed using 32-bit values and 64-bit values and combination of simpler filters are shown in the Figure 2. It shows curve of the maximum current flickering P_{inst} in time with voltage fluctuations of 0.25% and a modulation frequency of 8.8 Hz. In this setting should be $P_{inst,\ max}$ = 1 ± 8 %. After the filtering, signal can be resampled to 400 kS/s for further processing without a significant aliasing effect.

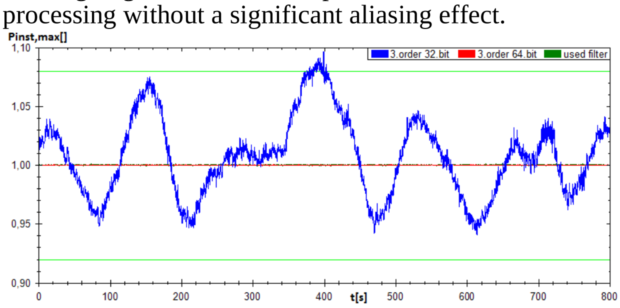

Figure 2: Comparison of filters

Resampled signal is normalized in order to achieve comparable results for various effective values of measured voltage.

Next step is series of filters, squaring signal and averaging filter defined in [4] and described in previous section. Last step is statistical analysis. It is also constructed by [4] and there is used 220 (380 for PQ-A analyzer) classifiers with levels given by expression: $Level = 0.004 \times w^{order}$ where w=1.07 (1.04 for PQ-A)

THE MEASURED RESULTS

This chapter describes the measured results of the flicker meter tests given in [4]. The measurement was performed on the new ARTIQ (PQ-A), PQ-S1 and PQ-S2 hardware platforms. Results for an outdated PQ-B platform designed according to [3] are also given. $P_{inst,max}$ for PQ-B was taken from [6]. Some tests from the standard ([4], ch. 6.4, 6.7 and 6.9) could not be performed because the testing signals required could not be generated by our FLUKE 61000A signal generator.

Used symbols

P_{st} - short-term flicker severity
P_{inst} - instantaneous flicker sensation
$P_{inst,max}$ - peak value of the instantaneous flicker sensation P_{inst} measured during the observation period
T_{short} - short time interval for P_{st} evaluation (10 minutes)

In the tests, $P_{inst,max}$ or P_{st} is measured. The first quantity is easily corrupted by noise coming from the used AD converters. Figure 3 shows temporal evaluation of $P_{inst,max}$ for ARTIQ and PQ-S1 devices. The input signal was 230 V with its amplitude varying by 0.25 % with frequency 8.8 Hz ([4], table 1). For this kind of signal, $P_{inst,max}$ should equal to 1 ± 8 %. Figure 3 reveals that high end devices perform with much lower noise than PQ-S1. Because of high noise level, the values of $P_{inst,max}$ are locally averaged in the figure.

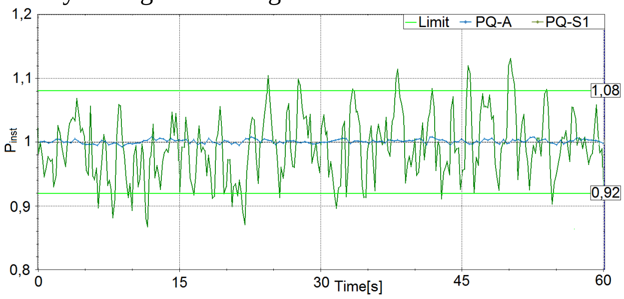

Figure 3: P_{inst} depending on the time

The noise however, due to averaging and statistical evaluation, does not influence P_{st}. This means that the device can be used conveniently to measure this quantity.

Sinusoidal voltage changes ([4], ch. 6.2)

This test verifies the overall response of the measuring chain from input signal to output P_{inst} for the input signal with a sinusoidal voltage fluctuation. In this test the value $P_{inst,max}$ = 1,00 ± 8 % should be achieved. Figure 4shows that the new solution fully complies for all measured frequencies. The obsolete flicker meter PQ-B fails this test for the highest frequency. The test also reveals outstanding performance of the ARTIQ platform.

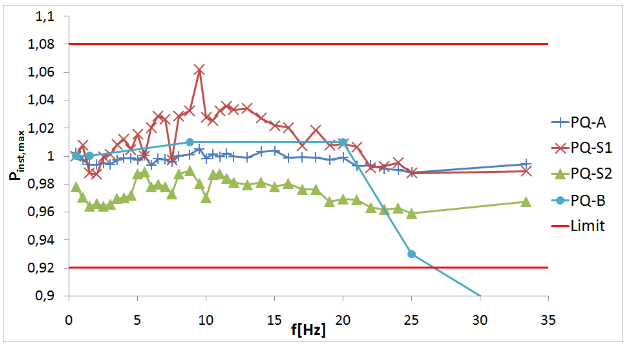

Figure 4: Sinusoidal voltage changes

Rectangular voltage changes ([4], ch. 6.2)

This test is similar to the previous one, only the rectangular voltage fluctuation is used as an input signal. Figure 5 shows compliance with the required limits of the new solution and failure of the obsolete implementation PQ-B for higher frequencies.

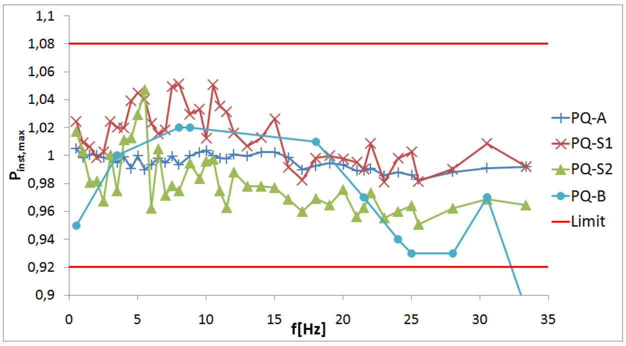

Figure 5: Rectangular voltage changes.

Bandwidth test using harmonic and inter-harmonic side band modulation ([4], ch. 6.6)

In this test the input signal is composed from a fundamental harmonic, a higher harmonic and an inter-harmonic whose difference in frequency is 10 Hz (e.g. 140 and 150 Hz) and is thus detected in the frequency range of the meter. Measured $P_{inst,max}$ should be equal to 1.00 ± 8 %.

Figure 6 shows that only the high end PQ-A platform fully conformed the test within a wide range of frequencies up to 6750Hz. PQ-S1 complied only in range up to 450 Hz and PQ-S2 only below 250 Hz. High frequency attenuation is caused by analogue antialiasing filter. The impact of the filter gain is amplified by double squaring of the signal. Thus 50 % filter attenuation results in 93.75 % attenuation of expected P_{inst}. PQ-B platform completely failed the harmonic test. However, this test is not required for class F3 devices according to [4].

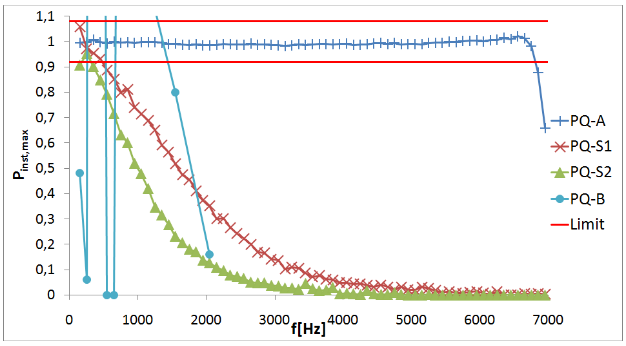

Figure 6: Bandwidth test using harmonic and inter-harmonic

Rectangular voltage changes and performance testing ([4], ch. 6.3)

In this test the total response for rectangular voltage fluctuations is measured. Also the overall range of the flicker meter is determined. The input signal is sinusoidal with a rectangular voltage fluctuation ([4], table 5). The fluctuations magnitude is multiplied by the k-factor. Range of the meter is determined by such value of k, for which the achieved accuracy is $P_{st} \pm 5$ % or 0.05 (whichever is greater). Figure 7 summarizes results of this test for all PQ analyzers.

The first graph shows summary of the PQ-A analyzer used as a leading implementation in our evaluations. It achieved great results high above the required flicker range. Thanks to this performance the ARTIQ range of flicker meter is declared as 0 – 20Pst. This device meets the requirements for class F1 according to [4] as well as the class A according to [7]. The graph shows that in measuring small flicker affects the use of better AD converters.

The second graph shows the results for the device PQ-S1. Achieved measuring range is 0.2 - 20, worse accuracy for smaller values is mostly caused by the noise of used analog components.

Next graph shows the results for the device PQ-S2. That reached a little better result and reached the range of 0.1 - 20. It also shows that the accuracy of the third phase is significantly worse than the first two phases yet still compliant. This is probably due to the design of hardware and will be addressed in its future edition.

The last graph shows the results of the PQ-B device. It still gives acceptable results for small values but it does not meet limits for higher values. Values for 1CPM are caused by the use of a shorter averaging in block 1 of the measurement chain. The contrary, smaller values for 4000CPM (33,3Hz) are caused by the use of inaccurate evaluating filter that attenuates frequencies over 30Hz. These weaknesses, however, in an earlier version of the standard [2] were not reflected, because at that revision the test required only the lower frequencies. So this instrument is complaint only according to the version 1.0 of the IEC flicker standard and will need an update for the actual version.

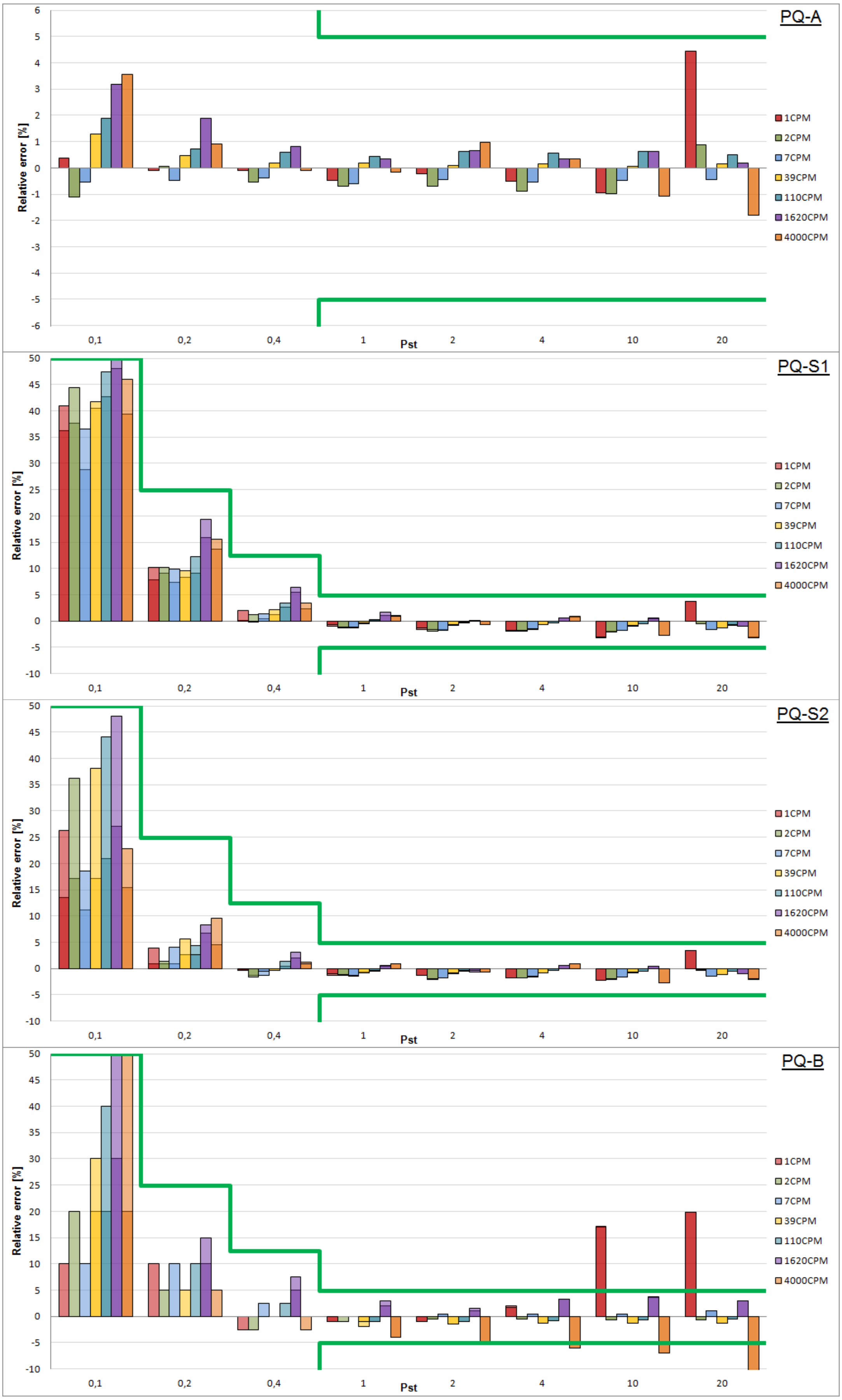

Figure 7: Rectangular voltage changes and performance testing.

CONCLUSION

The tests indicate that a sufficiently accurate result can be achieved in all the performed tests with both high end hardware platform (ARTIQ) and with several low-end, low-cost platforms. Results of ARTIQ comply with all limits required by the ed.2.0 of the IEC flicker standard for the highest class F1. Tested PQ-S were sufficient for class F3 requirements. Results from all the tests were also significantly better than our previous implementation of a flicker meter which failed some of the newly required tests. Some of the tests given by [4] could not have been performed for this report as the signal generator used in the experiments cannot provide the necessary signals. Results for the ARTIQ platform were surprisingly good, especially the frequency range and measurement range test.

Even better results might still be achieved by optimizing the statistical analysis block. This does not fall in the scope of this paper, though. Also, it is possible to improve results for lower values by subtracting the noise that would be determined during calibration. The platform is also overall sufficient for implementation of other flicker and RVC related evaluations. In the following work we plan to use it also for evaluation of flickering of LED lights supplied by both AC and DC power supplies.

ACKNOWLEDGEMENT

This work is co-financed from the student grant TUL 78000 Progressive mechatronics, control and measurement systems with application of advanced simulation methods.

Authors would also like to thanks for support and for instruments provided by the KMB systems company.

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