AN IEC 61000-4-30 CLASS A - POWER QUALITY MONITOR DEVELOPMENT AND PERFORMANCE ANALYSIS

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Abstract: Power Quality assessment is today one of the main ways to improve energy efficiency. International standards tend to restrict the way this assessment is done, by defining the measurements methods that should be adopted by an instrument. This work describes some of the constrictions and requirements assumed for the design of the high performance Power Quality data logger PQ1000, taking into account the international standards IEC 61000-4-30 Class A and the IEC 61000-4-15 published in August 2010. Trough it, the most important demands of the IEC 61000-4-30 class A instruments are exposed. Details of the hardware components are also shown, and the most important points of the signal processing path are explained. The performance in the RMS values determination is given, also the frequency response for harmonics measurement are shown, and a detailed analysis of fulfillment of the tests given in the IEC 61000-4-15 ed. 08-2010 are given in the final section. Before the publication of this ed.08-2010 the Cigrè C4.1.01/CIRED 2 CCO2/UIE WG2 - 2004 protocol was the reference document that in addition with the IEC standard was used for the evaluation of digital flicker meters. This protocol aim is to guarantee a higher degree of compatibility between instruments of different manufacturers and models. The tests here presented intend to submit the equipments to a more real situation, and try to show possible hardware or firmware defects. The results given by the PQ1000 widely surpasses the standards exigencies.

Key words: Power Quality Data Logger, IEC 61000-4-30 Class A, IEC 61000-4-15, Harmonics, Flicker.

1. POWER QUALITY MONITORING

Power Quality assessment in electrical energy distribution obeys to control entities requirements, user complains, and network maintenance schedules. The instruments applied must allow the complete analysis of the supplied magnitudes: Voltage and current, mains frequency, polyphase system unbalance, voltage events as dips, swells and interruptions, harmonic and interharmonic content, flicker and transients.

From several years, the RMS voltage, the spectral content and flicker were defined by the standards, but the absence of a complete set of regulations to describe the whole spectrum of electric magnitudes related to power quality led to differences in the results, depending on the manufacturer of the instrument, and the conditions that were applied. This situation turned the comparison difficult, when not impossible.

During year 2003 the IEC 61000-4-30 Ed.1 was presented and its new edition was released in 2008. IEC 61000-4-30 Ed. 2.0 [2] as its predecessor defines Class A instruments as the ones applied in contractual subjects, standard compliance verification, and disputes resolution. Its main objective is that measurements from different instruments of different manufacturers and models will give identical results within the uncertainty band when connected to the same signal. It defines the measurement methods establishing a guide for results interpretation and a performance specification, not for design of the instrument.

2. IEC 61000-4-30 ED. 2.0 - 2008-10 – MAIN REQUIREMENTS

Table 1 presents the main measurement requirements exposed in the standard for the Class A instrument [2].

Table 1. Ranges and Tolerances.

Parameter	Ranges		Uncertainty Tolerances	
	IEC	PQ1000	IEC	PQ1000
Frequency	50Hz ± 7,5Hz 60 Hz ± 9Hz		± 10mHz	<2,5mHz
Voltage TrueRMS	10 ~ 150 % UDIN	10 ~ 200%	± 0,1%	<0,025%
Current	Acc. Traducer Range		± 0,1% FS	<0,025%
Flicker PST/PLT	0,2 ~ 10	0,2 ~ 20	± 5%	<2,5%
Unbalance u2 y u0	0 ~ 5%	0 ~ 100%	± 0,15%	<0,05%
Voltage Harmonics	0 ~ 200%		± 5%	<1%
Interharm.	ΔV/V @ PST = 2		± 5%	<1%

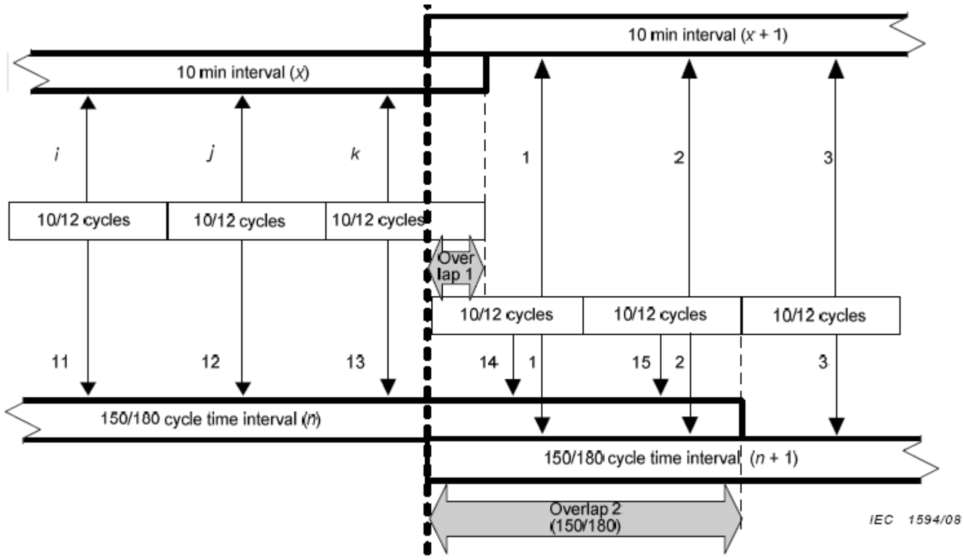

Fig. 1. Time aggregation scheme

Every Class A instrument should give the same results when connected to the same stimulus. The reduced tolerances for magnitudes, the combination of tests, and the unique time aggregation method restricts the performance of this kind of equipment. This normative also defines two additional classes, class S and class B, focused on statistical survey and for preliminary measurement respectively.

Aggregation Intervals: Are the time periods during which the instrument should average measures. The standard defines four basic intervals for 50Hz systems: 10 cycles of fundamental frequency, 150 cycles (aggregated from fifteen 10 cycles intervals), 10 minutes (determined with an absolute internal clock) and a 2 hour interval (aggregated from twelve 10 minutes intervals). All the parameters measured (in exception of mains frequency) should be processed using this time scheme, in real time without samples loss. See Fig. 1.

Time reference: Real time internal clock uncertainty is defined in 20ms for 50Hz mains systems. Periodical re-synchronization is demanded by remote (for example GPS) or local technique, if this external synchronization is not available, time uncertainty should not exceed 1 second each 24hs.

Mains Frequency: Zero crossing technique for periods of 10 seconds is proposed by the standard, but other methods are accepted if the results uncertainty is equivalent. Maximum uncertainty is 10mHz in the range of ±15% of the nominal frequency: 50±7.5Hz and 60±9Hz.

RMS Voltage: Uncertainty of 0,1% of the nominal voltage is required in the range of 10% to 150% of the nominal voltage.

Harmonics and Interharmonics: Class A defines its restrictions based in the IEC 61000-4-7 Class I standard [4] up to the 50° order. The determination of all the spectral components should be done in real time without gaps (continuous sampling).

Flicker: It is defined by the IEC 61000-4-15 standard [3]. The uncertainty required is 5% for PST in the levels of 0,2 to 10. This parameter is further analyzed in detail.

Additional requirements: The normative [2] establishes influence quantities ranges that the instrument should withstand with its results within the uncertainty levels stated in the standard.

3. REFERENCE INSTRUMENT FOR TESTING

The validation of the instrument consisted in hardware, firmware and software tests. The electrical parameters calibrator Fluke 6100A [6] was used in ECAMEC measurement laboratory during the development stage. Preproduction samples were tested in governmental laboratories facilities, testing compliance with measurement techniques and uncertainty levels, electrical safety, environmental and electromagnetic compatibility.

4. IMPLEMENTED HARDWARE IN DATA LOGGER ECAMEC - PQ1000

According to the requirements established in the standard [1], the hardware was developed with suitable capacity for its accomplishment and for future performance upgrades. Fig. 2 presents a simplified hardware block diagram of the PQ1000 [5] components.

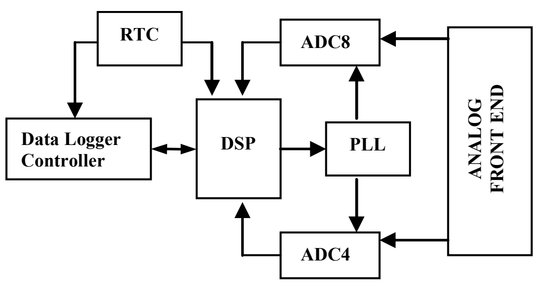

Fig. 2. Hardware block diagram

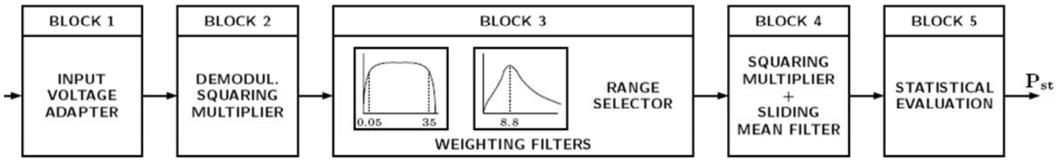

Fig. 3. Flicker Meter block diagram

Data logger controller: This stage controls the data memory and the communication interface for data to be read from a PC. ***RTC:*** Is the time reference for the 10 minutes interval required. Its uncertainty is better than 2 ppm, giving a stability better than 0,2 seconds a day. ***DSP:*** The measurements algorithms are implemented by this stage. It is a 32 bit floating point architecture, with maximum capacity of 1.2 Gflops. ***PLL:*** Phase Lock Loop programmable oscillator that provides the sampling frequencies for the two ADCs. It is feed backed with the mains frequency value. ***ADC8:*** 24 bit, 8 channel analog to digital converter. Except Flicker and mains frequency, all the other magnitude measurements are accomplished with the samples provided by this stage. ***ADC4:*** 24 bit, 4 channel analog to digital converter. It provides the samples for the flicker measurement process and for the mains frequency calculation used to feedback the PLL stage. ***Analog Front End:*** Operational amplifiers arrange that conditions the analog signal prior to the sampling process.

Figure 2 shows the analog stage plus the sampling stage performance. The FFT of the signal acquired by the ADC8 stage is shown. Note that the noise floor is below –100dB, see Fig. 4.

5. ALGORITHM STRUCTURE

The measurements and calculations are structured in two main sections: ADC8 and ADC4. The ADC8 which has 8 simultaneous acquisition channels processes the voltage and current signals, obtaining the RMS values and electric power magnitudes measured by the PQ1000. Fig. 5 shows the accuracy and stability of voltage measurements obtained for each channel from 10 cycles buffers through a period of ten minutes.

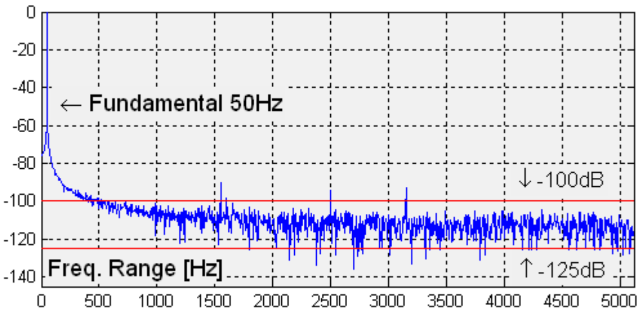

Fig. 4. SNR ADC8 in voltage channels

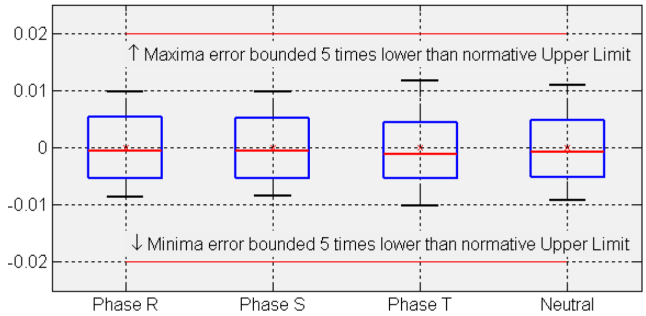

Fig. 5. Maximum relative error ±0.01%.

ADC4 stage is aimed to the measurement process of mains frequency and flicker PST-PLT. It has embedded the blocks defined by the flicker meter standard IEC 61000-4-15 [3]. Frequency is measured while the demodulation process is accomplished, through a digital Hilbert Transform.

What follows is an explanation about the functionality of each block according to IEC 61000-4-15 [3] (see Fig. 3), and the implementation details in the PQ1000.

Bock 1: The level of input voltage is adapted with an automatic gain control (AGC) to provide the next block with a constant level input.

Block 2: Demodulation of the signal with a quadratic multiplier according to IEC 61000-4-15 [3]. In the PQ1000 scheme this block is replaced with a Hilbert transform process [7][8][9], giving the amplitude modulation signal of the mains. This process provides information sample by sample of the voltage phasor in the fundamental frequency, in module and phase (see Fig. 6). With this information the AM is obtained and also the frequency of mains is measured with an uncertainty lower than 10mHz (see Fig. 7). The frequency obtained in this stage is then used to shift the sampling frequency for the FFT and RMS applications (ADC8 section).

Block 3: Apart from the AM signal, the demodulation process as not being linear gives several order harmonics

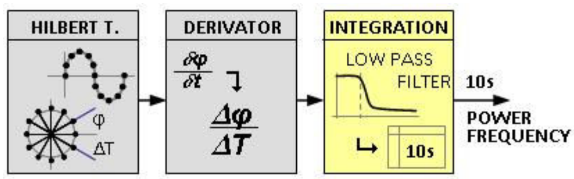

Fig. 6 – Frequency measurement blocks

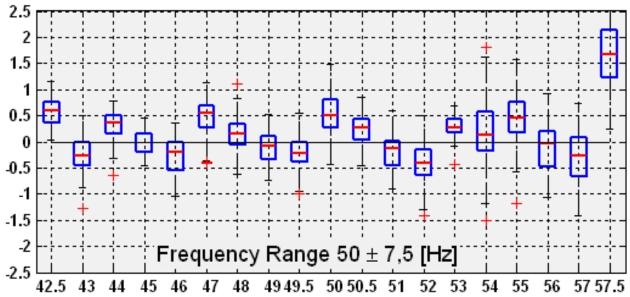

Fig. 7. Frequency relative error < ± 2,5mHz

components, interharmonics, and DC component, which must be removed before the weighing filter applied. This block is accomplished using a high-pass and a low-pass filters with their poles and zeros configuration as established in [3], and for the weighing filter the specification given in table 3 of [3] is used. The digital implementation of the filters designed in the analogical way is modeled with the analog to digital technique of transformation IMPULSE INVARIANT, which in comparison with the BILINEAL technique gives a better adjustment in the frequencies above half Nyquist (see Fig. 8).

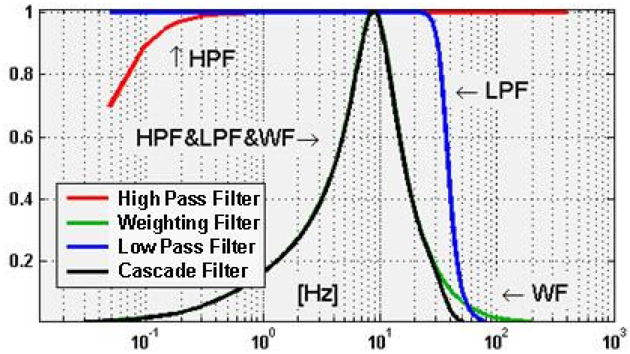

Fig. 8. HPF & LPF & WF: Block 3

Block 4: A quadratic multiplier and a low pass filter models the cumulative disturbance of flickering in an individual brain. The output of this block is instantaneous flicker identified as Output 5 in [3] which magnitude is denominated as perceptibility.

Block 5: Output 5 signal feeds a statistical classifier composed of 512 to 1024 classes. From this resulting distribution percentiles PST is calculated.

6. IEC 61000-4-15 REQUIREMENTS

Standard [3] states design parameters for the equipments intended to measure and quantify line voltage fluctuations as Instant Flicker, Short Term Flicker (PST) and Long Term Flicker (PLT). It establishes the criteria for blocks construction for data acquisition, demodulation, filtering, weighing and statistical analysis for the flicker measurement. The accomplishment of this standard predecessor (IEC 61000-4-15 Ed.1.0 2003-08), was not sufficient to guarantee identical results between different instruments when submitted to the stimulus actually present in electrical networks. This was not in accordance with the main objective of the IEC 61000-4-30 [2] which invokes IEC61000-4-15 for flicker measurement. To reinforce this weakness the Cigrè C.4.1 protocol [1] was created. It stated a series of 11 tests to evaluate digital flicker meters. In the present, the design normative IEC 61000-4-15 Ed. 2.0 2010-08 adopts some of the Cigrè protocol tests. The tests applied and its results on the PQ1000 data logger [5] are presented:

7. TEST PERFORMANCE - IEC 61000-4-15

7.1. Test N°1 – PST 1 with square modulation

PST of 1 ±5% should be given when stimulus established in table 5 of [3] are applied. See the PQ1000 results in Fig. 9.

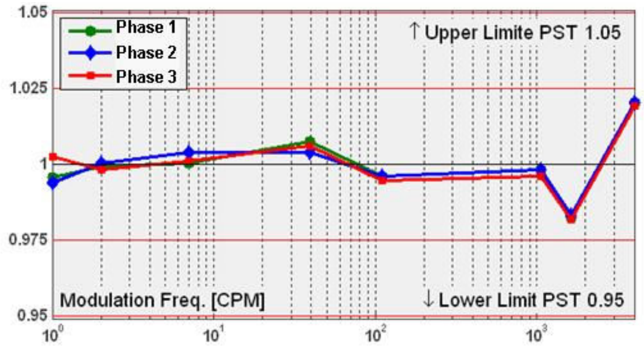

Figure 9. PST vs. Rectangular changes per minute

7.2. Test N°2 – Instant Flicker with square modulation

Unit perceptibility for instant flicker ±8% should be given when stimulus established in table 2 of [3] are applied. See the PQ1000 results in Fig. 10.

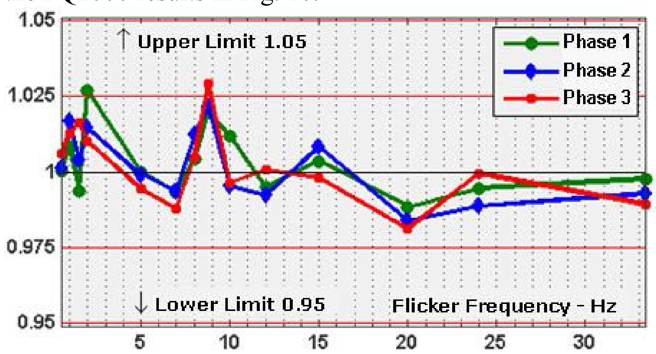

Fig. 10. Unit perceptibility ±8%

7.3. Test N°3 – Instant Flicker with sin modulation

Unit perceptibility for instant flicker ±8% should be given when stimulus established in table 2 of [3] are applied. See the PQ1000 results in Fig. 11.

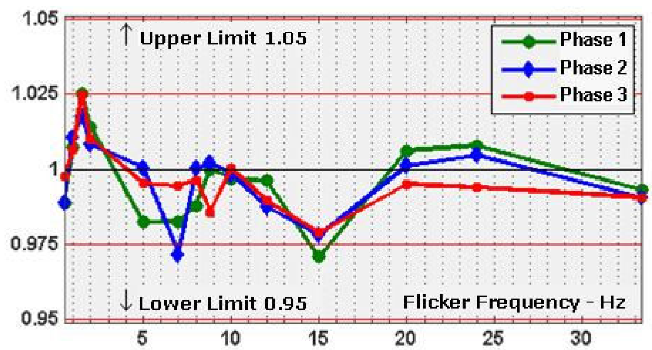

Fig. 11. Unit perceptibility ±8% with sinusoidal modulation

8. IMMUNITY TESTS – CIGRÈ PROTOCOL

Two tests of immunity from Cigrè protocol [1] that are not included in IEC 61000-4-15 [3] are shown, to demonstrate that when applied to PQ1000 do not give false flicker response. Additionally a linearity test is applied (this one included in [1] and [3]).

8.1. Test N°4 – Mains Frequency variations

Mains frequency magnitude fluctuation in stability conditions of 5mHz/s should not give (false) flicker response. This test is verified with an 8.8Hz modulation with unit PST, verifying that the measurements given are within ±5%. See results in Fig. 12.

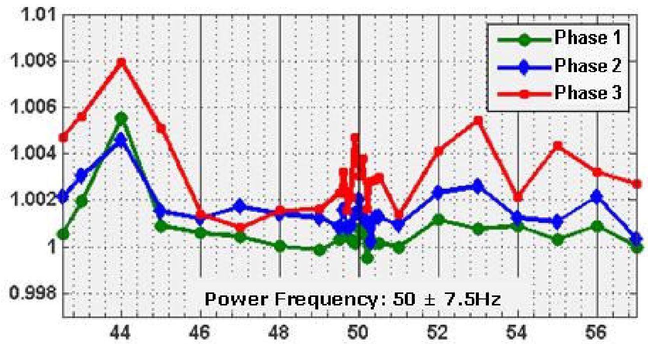

Fig. 12. PST performance with mains frequency variation

8.2. Test N°5 – Second order harmonic influence

The presence of components above twice mains frequency should not give (false) flicker measurements. These components could be cause of alias effect in the sampling stage. This test is verified with an 8.8Hz modulation with unit PST, verifying that the measurements given are within ±5%. It is important to observe that 2° harmonics can introduce false flicker readings when it is above 5% of the fundamental magnitude, for this reason it is eliminated using a stop-band filter.

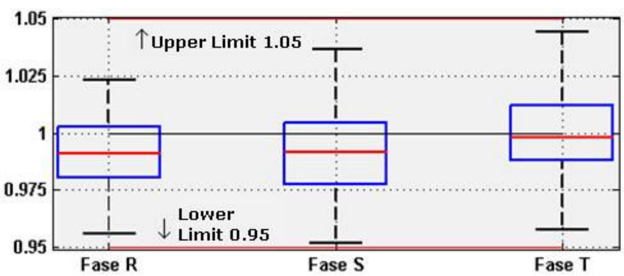

Fig. 13. Unit PST, square modulation with interharmonic sweep in the range 0.1 kHz to 2.4 kHz

8.3. Test N°6 - Linearity Evaluation

The performance of the instrument is also evaluated in accordance with the PST range it maintains uncertainty levels. The standard IEC 61000-4-30 [2] establishes a range of 0,2 to 10 for this parameter. The Cigrè protocol [1] Class 3 instrument defines a range from 0,2 to 20 for PST. The test verifies the linearity with respect to the amplitude of the voltage modulation. Linearity could be affected in the filter stages, and due to the resolution of the statistical classifier. (See Fig. 14).

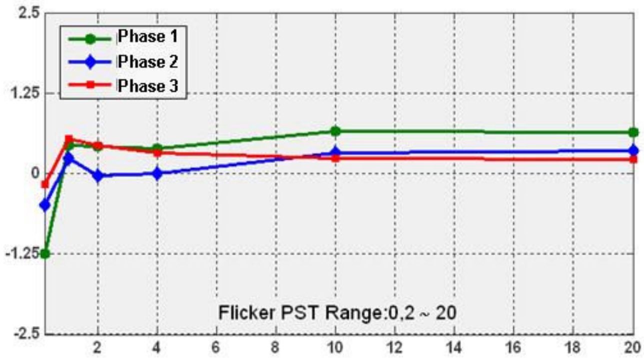

Fig. 14. Relative error % vs. PST

9. INFLUENCE TESTS – IEC 61000-4-15

9.1. Test N°7 – Interharmonics pair influence

The presence of two frequency components near each other can cause flicker modulation. This phenomenon occurs based in resonance loops with a frequency near a harmonic present in the voltage signal. For example, a 3° harmonic present in the network (150Hz or 180Hz) and an interharmonic of 157Hz or 187Hz also present. The verification of influence is to measure unit instantaneous flicker with a tolerance of ±8% without modulation in the fundamental frequency. The pair amplitude is 4.126% starting with (150Hz, 140Hz) pair, and it has to be tested at least to the 9° harmonic (450Hz). (See Fig. 15).

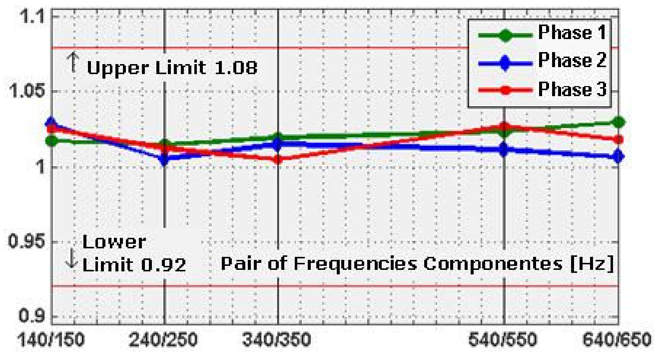

Fig. 15. Instant flicker response in presence of interhamonic pair

9.2. Test N°8 – Simultaneous periodical changes of voltage and frequency

Measurement of unit instant flicker with a tolerance of ±8% with simultaneous changes of voltage and frequency each four seconds in the zero crossing of the signal. In accordance to table 6 of [3], 49.75Hz @ 230.00V and 50.25Hz @ 228.812V where applied periodically. (See Table III).

9.3. Test N°9 – Fundamental modulation with odd harmonic distortion 3° ~ 31°

Measurement of unit instant flicker with a tolerance of ±8% with sinusoidal modulation of 0.25% at 8.8Hz, with simultaneous content of components from 3° to 31° in accordance with table 2, with a resultant THD equal to 11,06%. (See Table 3).

TABLE 2

Armónico	3	5	7	9	11	13
U%	5	6	5	1,5	3,5	3,0
Armónico	17	19	23	25	29	31
U%	2,0	1,76	1,41	1,27	1,06	0,97

9.4. Test N°10 – Flicker caused by phase jump in fundamental

Verification of PST in a 10 minutes interval according to reference values given in Table 3, with phase changes of ±30° and ±45° in the zero crossing in the minutes 1, 3, 5, 7 and 9 of the interval. See Table 3.

9.5. Test N°11 – Flicker present in modulation of 20% of duty cycle of the observation period

Verification of PST in a given time interval with 28Hz and 1.418% amplitude modulation according to table 11 in [3] for a nominal voltage of 230V. 20% of the measurement period is done with this stimulus and the 80% left without modulation. See Fig. 16 and the results in Table 3.

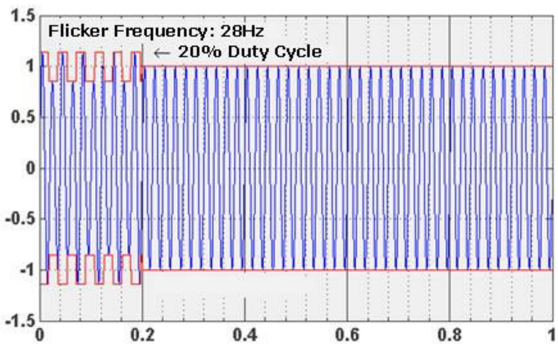

Fig. 16. Modulation shape for test N°11

TABLE 3

Test Nº8	Test Nº9	Test N°10		Test N°11
Δ Freq & voltage	Harmonics 3 ~ 31	Phase jump		Duty Cycle 20%
		±30º	±45º	
1.022	1.025	0.914	1.03	1.015
Reference values:				
iFLK 1 ±8%		PST 0.863 ~ 0.963	PST 1.007 ~ 1.113	PST 1 ±5%

10. CONCLUSION

The results of the evaluation of PQ1000 accomplished with the Fluke 6100A widely satisfies the requirements of the IEC 61000-4-30 [2], IEC 61000-4-15 [3] and the digital flicker meter evaluation protocol [1].

REFERENCES

[1] Joint Working Group on Power Quality Cigrè C4.1.01/CIRED 2 CCO2/ UIE WG2, Test Protocol for IEC Flickermeter used in Power System Voltage Monitoring, Draft 11. July, 2004.

[2] IEC61000-4-30 Edition 2.0 – 2008-10 - Electromagnetic compatibility (EMC) Part 4-30: Testing and measurement techniques – Power quality measurement methods

[3] IEC61000-4-15 -2010-08 - Electromagnetic compatibility (EMC) – Part 4-15: Testing and measurement techniques – Flickermeter – Functional and design specifications.

[4] IEC61000-4-7 Edition 2 – 2002-08. EMC – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto.

[5] Power Quality Registen: ECAMEC model PQ1000, that fulfills IEC 61000-4-30, Clase A requirement. http://www.ecamec.com.ar/productodetalle.php?id=56

[6] Fluke 61000A. Electrical Power Standard.

[7] E. A. Feilat, Senior Member IEEE, “Detection of voltage envelope using prony analisys – Hilbert transform method”, IEEE Transaction on power delivery, Vol. 21 Nº 4, Oct 2006.

[8] T. Abdel-Galil, E. El-Saadany, Member, IEEE, and M. Salama, Fellow, IEEE, ”Hilbert transform based control algorithm of the DG interface for voltage flicker mitigation”, IEEE Transaction on power delivery, Vol. 20, Nº. 2, April 2005.

[9] T. Abdel-Galil, Member, IEEE, E. El-Saadany, Member, IEEE, and M. Salama, Fellow, IEEE “Online tracking of voltage flicker utilizing energy operator and Hilbert transform”, IEEE Transaction on power delivery, Vol. 19, Nº. 2, April 2004.

[10] J. J. Gutierrez, J. Ruiz, L. A. Leturiondo, et. Al., “A simplified implementation of the test protocol for the IEC flickermeter”, 9th International Conf. Electrical Power Quality and Utilisation, Barcelona, October 2007.