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DESIGN AND VALIDATION TESTING OF VIRTUAL FLICKER METERS

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Abstract: *The paper explains directions for design of virtual flicker meters and their validation testing according IEC 61000-4-15 Standard. One possible solution of virtual flicker meter and virtual instrument for validation testing is proposed. The metrological support block is realized in LabVIEW environment which uses advanced methods for measurement and recording of the power quality parameters in accordance with the European quality standards.*

Keywords: ***Virtual flicker meter, Validation testing IEC 61000-4-15***

1. INTRODUCTION

The use of industrial and consumer equipment with nonlinear characteristics, loads that need reactive power and other causes, generate repetitive or random variations of the magnitude of the power supply. These magnitude changes occurring at frequencies up to 35 Hz can give rise to an effect called lamp flicker [1]. Flicker is an impression of unsteadiness of visual sensation induced by a light source whose luminance or spectral distribution fluctuates with time.

The flicker phenomenon has being known since the introduction of power supply networks, and it grows rapidly along with the increase in the number of loads and the increase in the power consumed. Before few decades the flicker problems arise not very often and in that time engineers develop empirical guidelines for determination of the flicker level that can be tolerated. These guidelines were based on a number of voltage fluctuations in minute and the percentage of the voltage fluctuation. This concept has several imperfections because it is based on approximations which simplify the complex events with one magnitude and repetition rate. Hereafter by their design, the first generation instruments were of relatively low accuracy.

In the last decade the development in the area of power-quality monitoring have been subject to large improvements, mainly caused by development in microprocessors, data storage, communication, and by the customer demands for information on power quality levels. The adoption of personal computers in the field of the power quality measurement offer great progress and flexibility. Step ahead for development of modern measurement systems is achieved by adopting the concept of virtual instrumentation. It is a methodology for realization of measurement instruments by using standard PC's, hardware data acquisition boards for signal conversions and specialized program platforms for processing and recording of the measurement results. The adoption of these tools for flicker measurements is very popular and many solutions have been reported in literature [2], [3]. The new generations of flicker instruments are more accurate and require calibration procedures with lower uncertainty.

2. FLICKER MEASUREMENT

The measurement of the light flicker is one of the most challenging tasks in the field of power quality measurements. The first instruments for registration of the flicker effect were based on simple observation of the luminous flux. These methods were of relatively low accuracy. Later a model of human reaction of the fluctuation of luminous flux has being developed. The model was based on 60W, 230V tungsten bulb (most commonly used in that time), a luminous flux sensor and analog model to simulate the human reaction. Further research resulted in development of completely electronic instrument which measures the voltage fluctuation and simulates the response of the light source and the human reaction. Two measurement results are obtained, Pst (short term flicker) for observation interval of 10 minutes and Plt (long term flicker) which is a Pst mean for interval of two hours. Later flicker monitoring has been standardized using a meter that is completely described in IEC 61000-4-15 Standard. The system can be divided in two main parts: simulation of the lamp-eye-brain response and statistical evaluation and results. The block diagram of the digital flicker meter according to this standard is shown on Fig.1.

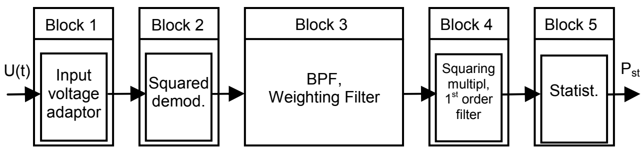

Fig. 1. *Block diagram of digital flicker meter*

The block 1 represents the signal conditioning circuit for filtering and attenuation of the input signal down to an appropriate reference level. The block 2 represents a squaring demodulator for reconstruction of the envelope of the voltage fluctuations, and simulation of the lamp behavior. The block 3 is a cascade of two filters. The first filter can be further divided on two filters forming a band pass filter:

- 3rd order high pass filter for DC removal with cut-off frequency of 0.05Hz,
- 6th order low pass filter with cut-off frequency of 42Hz

The second filter of block 3 is a weighting filter which simulates the frequency response of a lamp and human visual system caused by voltage fluctuations. The transfer function of this filter with maximum on 8.8Hz is defined by the Standard for 230V, 60W incandescent lamp. It is expressed with the equation:

$$F(s) = \frac{k\omega_1 s}{S^2 + 2\lambda s + \omega_1^{\,2}} \cdot \frac{1 + \dfrac{s}{\omega_2}}{(1 + \dfrac{s}{\omega_3}) \cdot (1 + \dfrac{s}{\omega_4})} \quad (1)$$

where: ω_1=2π9,2, ω_2=2π2,27, ω_3=2π1,22, ω_4=2π21,9 and k=1,74, λ=2π4,06.

The formula of Laplace-transformation refers to continuous time domain. However, during digital process only sampling signals can be taken into account. The other method of modeling the central filter cascade is the transformation of Laplace-transfer function. Consequently, the complex transfer function should be transformed into discrete transfer function in Z-domain. One of the applicable methods of transformation is the use of bilinear Z-transformation. Coefficients of weighting filter for 230V systems and sample rate of 200Hz are given in Table 1.

Table 1. *Coefficients of weighting filter for 230V systems*

Order	Numerator	Denominator
Z^0	+9.4872e-02	+1.0000
Z^{-1}	-1.5828e-01	-3.1671e+00
Z^{-2}	+4.023e-02	+3.7520e+00
Z^{-3}	+2.317e-02	-1.9582e+00
Z^{-4}		+3.747e-01

The block 4 contains squaring multiplier and a first order low pass filter with cut-off frequency of 0.54 Hz which simulates the eye-brain response. The output of this filter corresponds to an instantaneous flicker sensation.

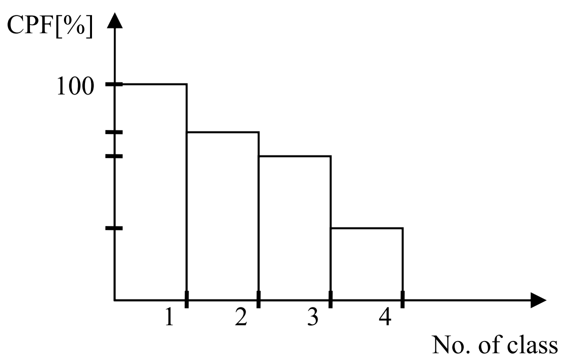

Fig. 2. *Evaluation of the cumulative probability function*

The last block 5 is used for statistical analyzes of the measurement results over short period (10 min.) where the amplitude of the instantaneous flicker is divided in 64 up to 1024 classes defined by IEC standard. The next step is calculation of the histogram, the relative frequencies, the cumulative probability function (Fig.2) and evaluation of the percentiles [1]. Percentiles are the levels of instantaneous flicker sensations which are exceeded for k% measurement time. Their evaluation is based on the cumulative probability function curve. The result of the statistical analyzes is a 10-minute short-term flicker severity Pst and two hours long-term flicker severity Plt. A unity value of the instantaneous flicker sensation corresponds to perceptibility threshold of 50% of the observers viewing 60W, 230V incandescent lamp, so when the instantaneous flicker sensation exceeds 1 more than half of the observers will notice a flickering of the light. The short-term flicker severity is calculated from the probability distribution function of the instantaneous flicker over a 10-min interval. The flickermeter standard prescribes that at least 50 samples per second shall be taken, resulting in at least 30.000 values over a 10-min interval. In the practice when implementing flicker meter in realistic conditions it is advised that the sampling frequency to be at least 200 samples per second, resulting in 180000 values in a 10-min interval. The flicker standard describes the short term severity from the instantaneous flicker sensation as follows:

$$P_{st} = \sqrt{0.031P_{99,9} + 0.052P_{99} + 0.065P_{97} + 0.28P_{90} + 0.08P_{50}}$$

where: P99.9 is the value not exceeded by 99.9% of the samples, and so on. The 99 percentile is the value exceeded during 6s, the 97 percentile during 18s, and the 90 percentile during 1 min, considering that 0.1% of a 10-min interval corresponds to 600ms. In practical implementation the percentile values are obtained as an average of a number of neighboring percentiles:

$$\begin{aligned} P_{50} &= (P_{70} + P_{50} + P_{20})/3 \\ P_{90} &= (P_{94} + P_{92} + P_{90} + P_{87} + P_{83})/5 \\ P_{97} &= (P_{97,8} + P_{97} + P_{96})/3 \\ P_{99} &= (P_{99,3} + P_{99} + P_{98,5})/3 \end{aligned} \quad (2)$$

From the 12 consecutive values of the short-term flicker severity Pst, the long-term flicker severity Plt is calculated by using the following expression:

$$Plt = \sqrt[3]{\frac{1}{12}\sum_{i=1}^{12} Pst(i)^3} \quad (3)$$

However, the IEC flicker meter is built based on the coiled filament gas-filled 230V, 60W or 120 V, 60W incandescent lamp. Nowadays, energy saving lamps, fluorescent lamps and other lamp types become more and more popular. Previous measurements show that different types of lamps have different flicker responses to the same voltage modulation [4]. Since the lamp flicker responses strongly depend on the lamp type, the IEC flicker meter is not accurate to measure the flicker level for different types of lamps.

3. SIGNAL CONDITIONING CIRCUIT FOR POWER QUALITY MEASUREMENT

The signal conditioning circuits should provide few functions like: galvanic isolation from supply network, attenuation or amplification of the measured signals, protection of DAQ card and noise suppression. The main role of the signal conditioning circuit is to adjust the sensor's output signal span to match the analog-to-digital converter (ADC) input range.

The block diagram of the signal conditioning circuits is shown in Fig.3.

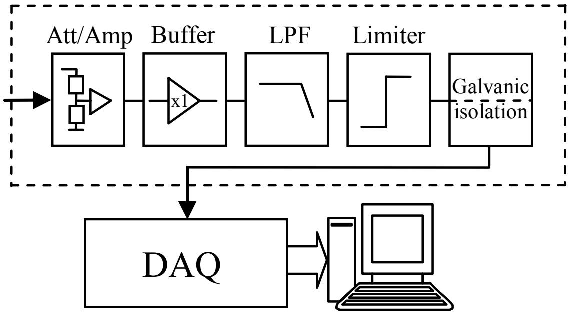

Fig. 3. *Signal conditioning circuits block diagram*

In the absence of proper signal conditioning the signal can exceed the ADC input range and cause saturation of its output.

The signal is first attenuated or amplified and DC level shifted with the input attenuator/amplifier. The next block is a unity gain buffer with very high input impedance which is used for adaptation of the impedances of the attenuator and the filter. Sixth order active anti-aliasing filter has been designed with cut-off frequency of 6 kHz and near flat amplitude-frequency and phase-frequency characteristics. The filter is used before a signal sampler to restrict the signal's bandwidth and to satisfy the sampling theorem. Fast circuits for limiting the input voltage to the ADC input range have been designed. These circuits allow signals below a specified input level to pass unaffected while attenuating the peaks of stronger signals that exceed this level. The used data acquisition card is with galvanic isolated inputs. The galvanic separation eliminates all forms of operating disturbances such as ground loop and potential separation.

4. IMPLEMENTATION OF VIRTUAL INSTRUMENT FOR FLICKER MEASUREMENT

In the process of virtual instrument design it is very important to determine the appropriate sampling frequency and observation interval. Lower sampling frequency decreases the quality of the modulation signal envelope and higher sampling frequency expands the calculation period. Having in mind these concepts and the experimental analyzes, 200 Hz sampling frequency and 2 sec averaging interval is chosen.

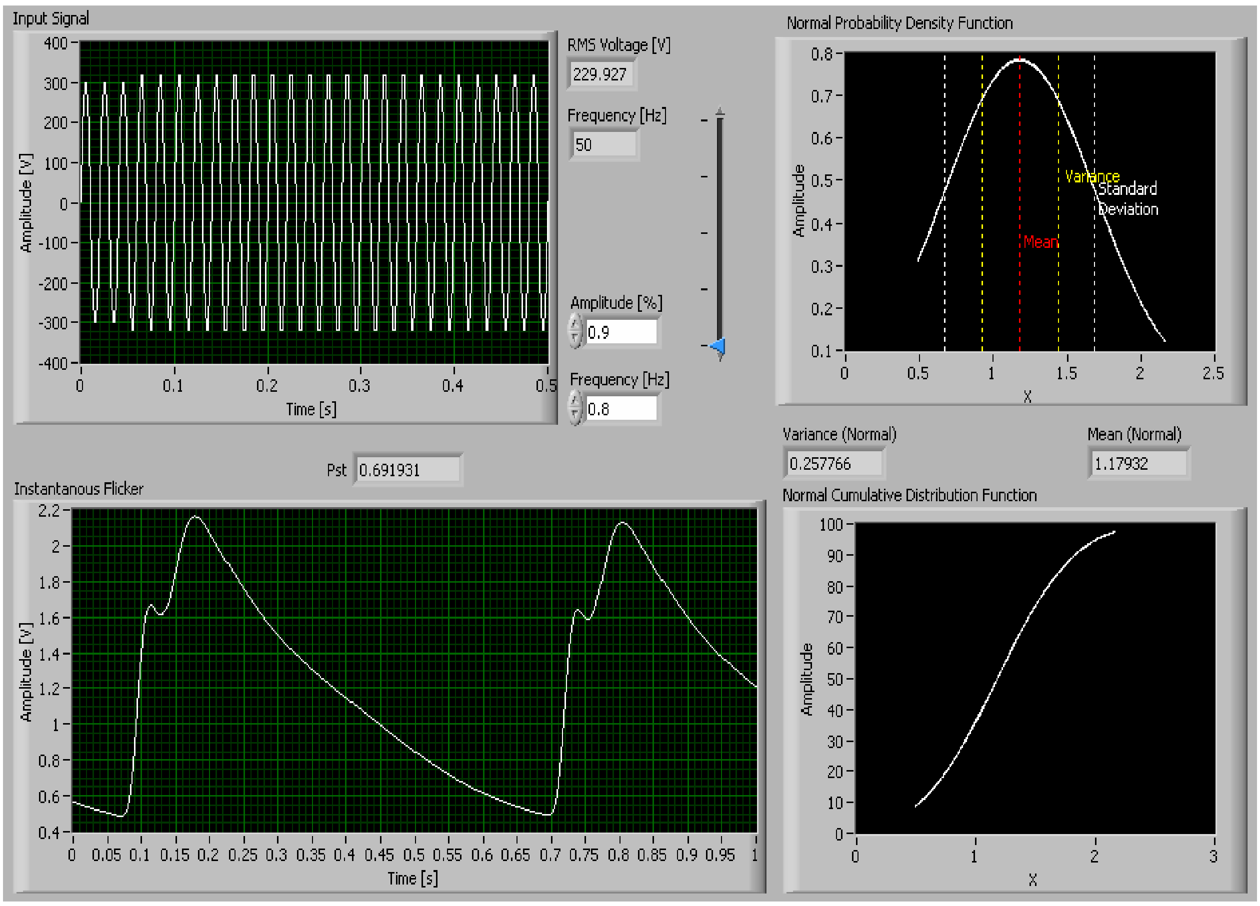

Fig. 4. *Front panel of the virtual instrument*

The process is simplified with reduction of the number of data records for statistical analyzes. The instantaneous flicker sensation signal is resample with sampling frequency of 100 Hz.

The values of the resample signal are used for statistical evaluation of the short term flicker value. The front panel of the virtual flicker meter is shown in Fig. 4.

5. TESTING DESCRIPTION

The actual IEC standard defines directions for implementation of digital flicker meters and measurement procedures for evaluation of the performance of the flicker meter in a case of sinusoidal and rectangular amplitude modulations. In real conditions, the flicker effect can be caused by other causes. This can result in design of digital flicker meter which satisfies the IEC performance tests, but occurrence of deviations of the flicker meter response in realistic conditions. Due to this, a new test protocol for the flicker meter validation is in preparation.

The testing of the flicker meter validation is made for two types of measurements, short-term flicker *Pst* and instantaneous flicker sensation *P*. The *Pst* response is tested with modulation signal with square wave shape, and *P* response is tested with both sinusoidal and square modulation signals. When these signals are the input data for the virtual flicker meter under test, the measured results for the maximum instantaneous flicker and the short-term perceptibility index should be equal to one. The maximum allowed error of the readings is ±5% according [5]. On Fig.5 a curve of equal severity (Pst=1) for rectangular voltage changes is given.

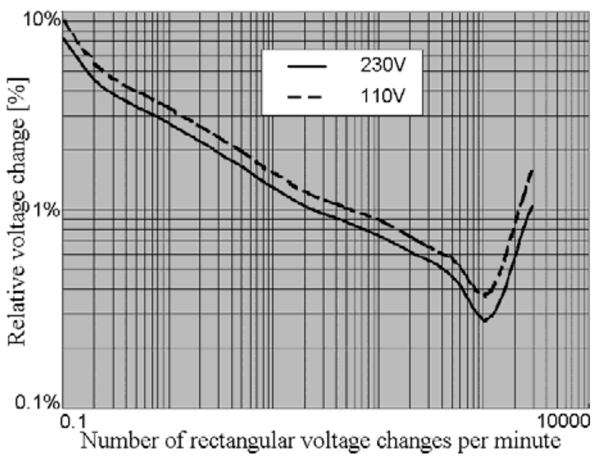

Fig.5 *Curve of equal severity for rectangular voltage change*

The testing system should be able to generate and measure three sets of wave shapes, one for the *Pst* response and two for the *P* response. This validation testing method requires measurement and setting of all combination of frequencies and voltage fluctuations for square or sinusoidal wave shapes.

One set of test points for sinusoidal and square modulation signals is given in Table 2 for *P=1* and Table 3 for *Pst=1*.

Table 2. *Test points for sinusoidal and square modulation (P=1)*

Squarewave modulation		Sinewave modulation	
f[Hz]	ΔV/V[%]	f[Hz]	ΔV/V[%]
0.5	2.290	0.5	0.501
1.0	1.375	1.0	0.463
2.0	0.865	2.0	0.391
3.0	0.635	3.0	0.345
4.0	0.489	4.0	0.326
5.0	0.390	5.0	0.286
6.0	0.320	6.0	0.243
7.0	0.275	7.0	0.213
7.5	0.261	7.5	0.202
8.8	0.247	8.8	0.192
9.5	0.251	9.5	0.196
10.0	0.258	10.0	0.203
13.0	0.351	13.0	0.271
16.0	0.489	16.0	0.378
20.0	0.717	20.0	0.557
24.0	0.997	24.0	0.768
25.0	1.076	25.0	/

Table 3. *Test points for square modulation (P_{st}=1)*

Changes/min.	f[Hz]	ΔV/V[%]
1	0.00833	2.724
2	0.01667	2.211
7	0.05833	1.459
39	0.32500	0.906
110	0.91667	0.725
1620	13.5000	0.402

Table 4. *Results for measurement of P_{st}*

Changes/min.	P_{st}	Error [%]
1	1.041	4.1
2	1.046	4.6
7	1.020	2.0
39	1.047	4.7
110	1.031	3.1
1620	0.964	-3.6

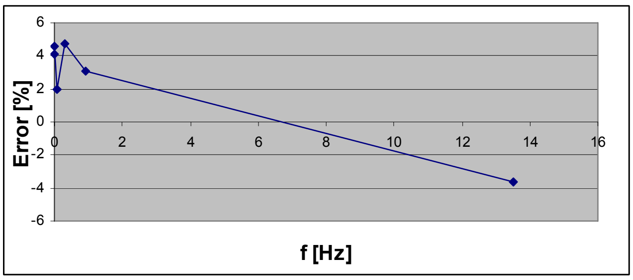

Fig. 6 *Error for P_{st} measurement*

Table 5. *Results for measurement of P (sinusoiudal)*

f[Hz]	P	Error [%]
1	0.96	-4
5	1.01	1
10	0.97	-3
15	0.99	-1
20	1.011	1.1
25	1.024	2.4

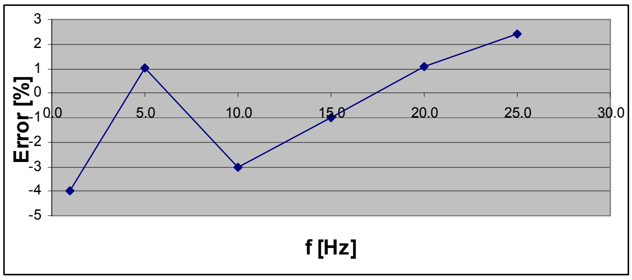

Fig. 7 *Error for P measurement (sinusoidal changes)*

Table 6. *Results for measurement of P (rectangular)*

f [Hz]	P	Error [%]
1	1.019	1.9
5	1.012	1.2
10	1.031	3.1
15	1.028	2.8
20	1.041	4.1
25	1.055	5.5

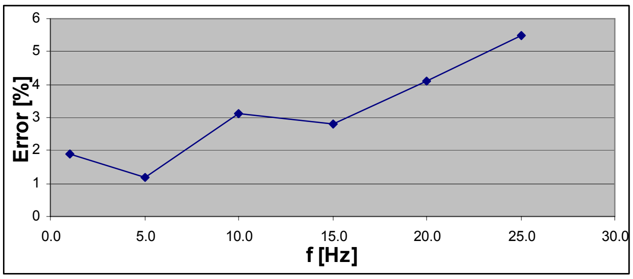

Fig. 8 *Error for P measurement (rectangular changes)*

Examples of typical results for measurement of Pst and P for one virtual flicker meter solution [6] are given in Tables 4, 5 and 6 and Figs. 6,7 and 8. Here, by using the curve of equal severity several test points are chosen which cover the region in which flicker phenomenon appears (Table 3). These values were used as an input data for the flicker meter under test for validation of the Pst measurement (Table 4). Second test was realized for validation of the instantaneous flicker sensation P measurements by using set of points extracted from the Table 2. The results for the instantaneous flicker sensation for sinusoidal and square input signals are shown in Table 5 and Table 6.

The errors of the measurements for validation of Pst and P response is further calculated by using the obtained measurement results and by using Pst=1 and P=1 as a true value in both cases. The errors for the measurements are shown in Fig.6 for Pst measurement and Fig.7 and Fig.8 for P measurements. From the error graphs can be seen that this flicker meter fulfills the maximum allowed errors of ±5% for P and Pst measurements, but having in mind the new test protocols that are in preparation the performance evaluation of IEC flicker meters in realistic conditions has to be done [7].

6. CONCLUSIONS

This paper describes a virtual instrument used for measurement of the light flicker and for testing of the flicker meter validation according to the standard IEC 61000-4-15. The standard defines procedure for determination of the flicker meter response which should be within the defined accuracy. The virtual instrument is used for generation of a set of amplitudes and frequencies for sinusoidal and rectangular modulation signals for 230V/50 Hz systems. These signals are the input data for the tested virtual flicker meter, where the measured results for the maximum instantaneous flicker and the short-term perceptibility index should be equal to 1 within ±5% accuracy.

A solution for virtual digital flicker meter based on data acquisition card and LabVIEW software is presented. The input conditioning module has been developed, which can be used for measurement of all power quality parameters.

Examples of typical results for measurement of Pst and P for this virtual flicker meter solution is given.

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