

A Light-flickermeter – Part II: Realization and Verification

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ABSTRACT

The paper is focused on realization and verification of a light-flickermeter simulating response of the average observer on disturbing light flicker under specific conditions. The design of the light-flickermeter is based on digitized the standard UIE/IEC flickermeter measuring scheme where the measuring chain does not include model of the reference incandescent bulb. It means that this type of flickermeter output is expected to be independent on a light source type producing light flicker. The developed instrument evaluates measured luminous flux fluctuation utilizing appropriate hardware and signal processing. The light is sensed by a photodiode with build-in transimpedance amplifier and photopic correction light-filter. The amplifier RC feedback allows control of its transfer function gain and bandwidth. Then the subsequent signal processing is based on NI PXI (cDAQ or cRIO) platform and virtual instrumentation in LabView. For purpose of various type flickermeters verification and calibration, a test system composed of a SW designed in LabView, NI PXI arbitrary waveform generation board, a power amplifier and a lamp placed in a test chamber, allowing generation of testing signals, has been developed. And finally, results of the light-flickermeter advanced performance analysis are shown and discussed.

Keywords: Voltage fluctuation, Interharmonics, Light flicker, Light-flickermeter, Test system, LabView

1 INTRODUCTION

Lamp flickering due to supply voltage variation is one of the main problems of power quality affecting comfort of human's visual perception. A factor having substantial effect on level of light flicker generation by lamps is the lamp technology [3][12][14], of course in view of applied voltage disturbance type [12][13]. With reference to necessity of EMC coordination in this field aimed to prevent from rise of disturbing flicker there is need to know what the lamps immunity is. The flicker severity produced by different lamp types could be determined with help of a light-flickermeter.

The paper continues with a previous work published in [4] where such type of light-flickermeter is proposed and discussed. Similar flickermeter design with differences in light measurement and in subsequent signal processing is also presented in [9]. However it has to be taken into account that applicability of this type of light-flickermeter is limited to comparative measurements only from many reasons summarized in [4].

2 LIGHT-FLICKERMETER REALIZATION

The proposed and developed instrument contains following basic blocks: measurement of the instantaneous luminous flux using a photo-detector, signal conditioning, emulation of the average observer eye-brain chain response and finally statistical analysis. In order to measure flickering light, a PIN-555AP filter-photodiode-amplifier hybrid from OSI optoelectronic [15] satisfying the requirements given in [4] was chosen for the photo-head realization. The photo-head output signal is led to input of the accurate PXI-4472 Data Acquisition (DAQ) board where it's conditioning and digitization is performed. And finally, obtained digital signal is processed by digital implementation of the flicker signal processing proposed in [4] on the basis of virtual instrumentation in LabView. Block diagram of the realized light-flickermeter is at Fig. 2.

2.1 Photo-head

The PIN-555AP photo-detector is of following parameters [15][16]: filter-photodiode combination responsivity $\rho=400 \mu\text{A/lm}$; filter-photodiode combination $V(\lambda)$ match error up to 4%; active area $S_D=100 \text{ mm}^2$; photodiode junction capacitance in PV mode $C_{J,PV}=1.5 \text{ nF}$, and in PC mode $C_{J,PV}=0.3 \text{ nF}$, amplifier input capacitance $C_A=7 \text{ pF}$; and amplifier gain bandwidth product $GBP=3.5 \text{ MHz}$. The typical spectral response of the PIN-555AP photo-detector is depicted in comparison with $V(\lambda)$ curve at Fig. 1.

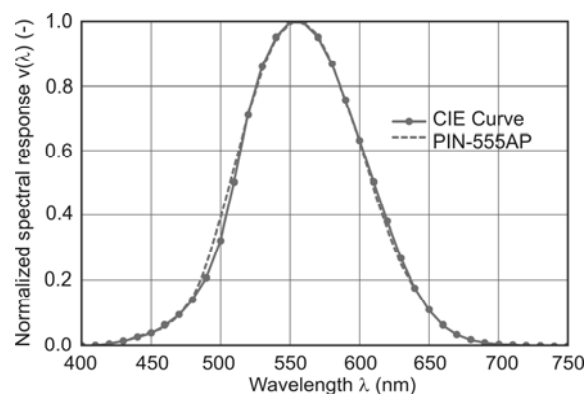


Fig. 1. Typical spectral response of a PIN-555AP photo-detector [15]

The photo-head is expected to be used in various applications with its illumination in range from 1 lx to 100 klx, while the output voltage U_A range should be up to 10 V regarding

the amplifier power supply level and NI PXI-4472 DAQ board input voltage limits.

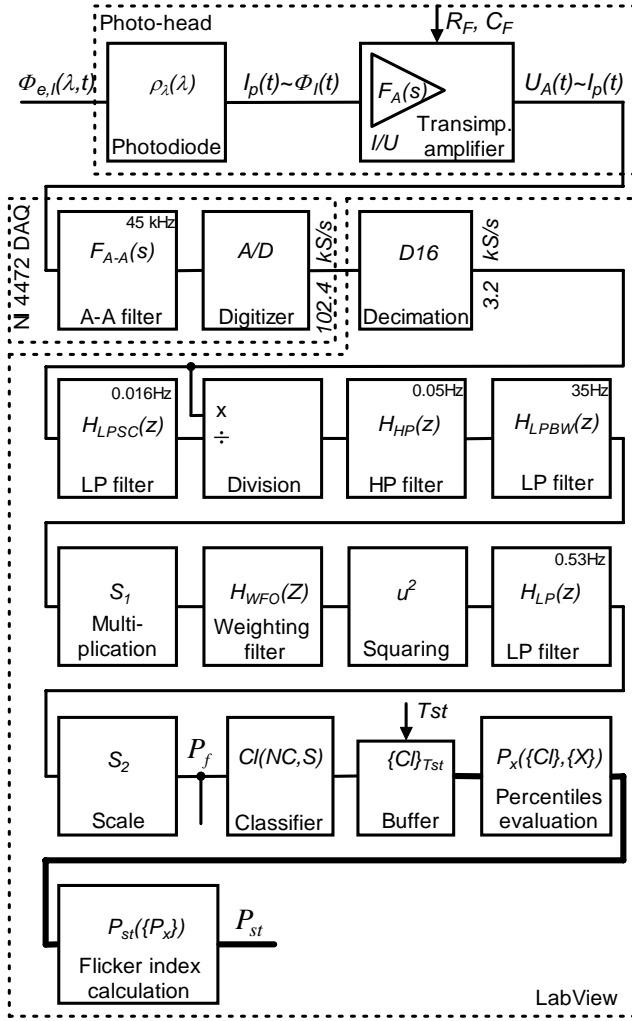


Fig. 2. Block diagram of the light-flickermeter

For achieving sufficient level of output voltage and measurement accuracy, five measuring ranges of illuminance as 10, 100, 1000, 10000 and 100000 lx were proposed. The gain is directly set by the amplifier feedback resistor R_F and the wanted values can be calculated using form [4]:

$$R_F = \frac{U_A}{E \cdot S_D \cdot \rho} \quad (1)$$

where U_A is the maximum output voltage of 10 V, E are the illuminance measuring ranges (substituted subsequently), S_D and ρ are the photodiode parameters pointed above. The calculation was used as starting for search of available values. Then the chosen values of R_F and reversely calculated parameters are for each measuring range in Tab. 1.

Tab. 1. Photo-head measuring ranges parameters

U_A (V)	R_F (W)	I_P (A)	Φ_l (lm)	E (lx)
10	27M	370n	926 m	9.26
10	2.7M	3.7m	9.26m	92.6
10	270k	37 m	92.6m	926
10	27k	370 m	926m	9.26k
10	2.7k	3.7m	9.26	92.6k

As it described in [4] a capacitor C_F has to be added to the amplifier feedback to reach stable output. For calculation of its value, following eq. can be derived [4]:

$$C_F \geq \frac{1 + \sqrt{1 + 8\pi \cdot R_F \cdot GBP \cdot (C_A + C_J)}}{4\pi \cdot R_F \cdot GBP} \quad (2)$$

where GBP , C_A and C_J are the amplifier/photodiode parameters pointed above. At the same time, the amplifier feedback limits the photo-head frequency response. Resulting cut-off frequencies f_A for chosen (allowable) R_F and C_F values are shown in Tab. 2. While the choice of R_F defines gain i.e. magnitude of measuring range, the connected C_F value sets "maximal" transmitted frequency. The circuitry of the photo-head shown at Fig. 3 is designed to allow manual connection of suitable RC combination. The amplifier RC feedback can be also adjusted by externally connected components, in a case of need.

Tab. 2. The amplifier feedback characteristics

R_F (Ω)	C_F (nF)				
	1.8	5.6	18	56	180
	f_A (Hz)				
27M	3275	1053	327	105	33
2.7M	F	10526	3275	1053	327
270k	F	F	32748	10526	3275
27k	F	F	F	105261	32748
2.7k	F	F	F	F	327479

F – forbidden combination

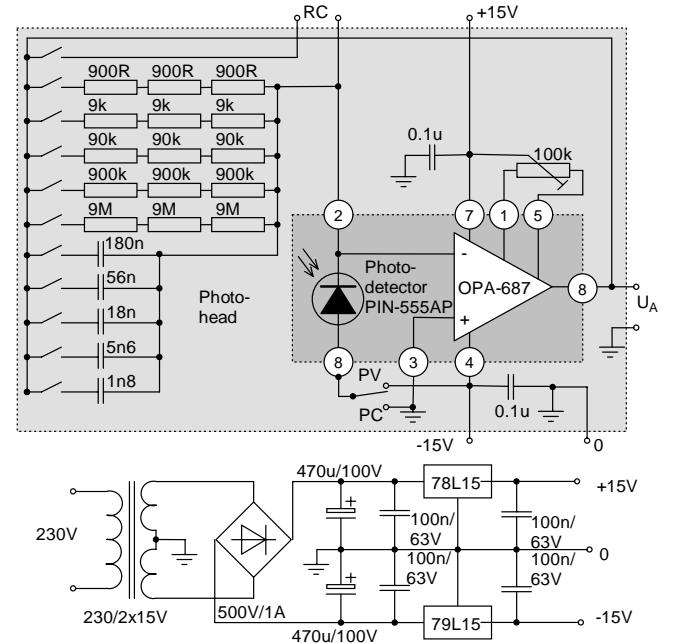


Fig. 3. The photo-head circuitry

The realized photo-head mechanics and final look is at Fig. 4. The reached constant of the realized photo-head, obtained by calibration, is de facto 10.07, 101.4, 1025, 10320 and 103900 lx per 10 V for 1st, 2nd, 3rd, 4th and 5th selectable range respectively.



Fig. 4. Photo-head prototype

2.2 Instrumentation in LabView

The photo-head output signal is digitized by PXI-4472 DAQ board with sampling rate of 3.2 kHz and 24-bits vertical resolution. Then the digital signal is taken from the board acquisition memory in frames of 3200 samples determining 1 second of the signal to be processed on the basis of virtual instrumentation in LabView in following blocks representing next part of the light-flickermeter (Fig. 2). In following, there is described digital implementation of the light-flickermeter analog model published in [4].

In first step the digital signal is normalized dividing the signal by its DC component which is acquired using the 1st order low pass filter transfer function. Resulting z-domain transfer function was obtained by bilinear z-transform of the original analog filter and is as follows:

$$H_{LPSC}(z) = \frac{n_0 + n_1 z^{-1}}{d_0 + d_1 z^{-1}} \quad (3)$$

where $n_0 = n_1 = 1.570772e^{-5}$, $d_0 = 1$, $d_1 = -0.9999685846$. As the high pass filter a 1st order digital filter eliminating the DC component in next step was chosen:

$$H_{HP}(z) = \frac{n_0 + n_1 z^{-1}}{d_0 + d_1 z^{-1}} \quad (4)$$

where $n_0 = -n_1 = 0.9999509150$, $d_0 = 1$, $d_1 = -0.9999018300$. For suppression of frequency components having no influence on flicker perception there have been used 6th order pre-warped Butterworth low pass digital filter with cut-off frequency of 35Hz in cascade form as:

$$H_{LPBW}(z) = \prod_{i=1}^3 \left[\frac{n_{0i} + n_{1i} z^{-1} + n_{2i} z^{-2}}{d_{0i} + d_{1i} z^{-1} + d_{2i} z^{-2}} \right] \quad (5)$$

where $n_{01} = n_{21} = 0.00110681$, $n_{11} = 0.00221362$, $d_{01} = 1$, $d_{11} = -1.87116747$, $d_{21} = 0.87559472$, $n_{02} = n_{22} = 0.00112557$, $n_{12} = 0.00225114$, $d_{02} = 1$, $d_{12} = -1.90288310$, $d_{22} = 0.90738539$, $n_{03} = n_{33} = 0.00115962$, $n_{13} = 0.00231923$, $d_{03} = 1$, $d_{13} = -1.96043693$, $d_{23} = 0.96507540$. In order to maintain the signal level within the processing in reasonable range, its multiplication is realized in current step. The light-flickermeter weighting filter z-transfer function modeling the eye-brain response was obtained by bilinear z-transform of the original analog filter [4] and is expressed in cascade form as follows:

$$H_{WFO}(z) = \prod_{i=1}^2 \left[\frac{n_{0i} + n_{1i} z^{-1} + n_{2i} z^{-2}}{d_{0i} + d_{1i} z^{-1} + d_{2i} z^{-2}} \right] \quad (6)$$

where $n_{01} = 0.04725783$, $n_{11} = -0.08162722$, $n_{21} = 0.03436940$, $d_{01} = 1$, $d_{11} = -1.95550141$, $d_{21} = 0.95560257$, $n_{02} = 1$,

$n_{12} = -1.98018993$, $n_{22} = 0.98025847$, $d_{02} = 1$, $d_{12} = -1.98386397$, $d_{22} = 0.98418451$. The weighted flicker signal is squared for simulation of the non-linear perception during flicker transfer from eye to brain and then is smoothed by a 1st order low pass digital filter, emulating memorization effect in the brain, with the following z-domain transfer function:

$$H_{LP}(z) = \frac{n_0 + n_1 z^{-1}}{d_0 + d_1 z^{-1}} \quad (7)$$

where $n_0 = n_1 = 5.520562e^{-4}$, $d_0 = 1$, $d_1 = -0.9989588756$.

In the next stage the signal is normalized using scaling factor S_2 to give together with scaling factor S_1 an optimal response in instantaneous flicker level $P_f = 1 \pm 0.05$, when a sine and square wave modulated input signals with fundamental frequency $f_f = 50$ Hz, and modulation frequencies and depths given in [7], was applied according to testing procedure introduced in chap. 3 (Fig. 8).

Then classification routine of the instantaneous flicker level with sampling rate of 3.2 kS/s to get short-time flicker severity index P_{st} (described in details in [4]) was adopted. The P_f signal is sorted into 100 000 logarithmically spaced classes Cl which are recorded for a short time period T_{st} into a buffer. The short time period can be chosen via user interface from preset times (1, 2, 5, 10, 20 minutes). At the end of each successive T_{st} period a Cumulative Probability Function (CPF) is calculated by means of the number of samples to fall into each class. Percentiles defined in [7] are searched consequently as flicker levels exceeded for various percentages of the test time and P_{st} index according to the [7] is calculated finally.

The light-flickermeter front panel in LabView for instrument control and measurement results display is at Fig. 5.

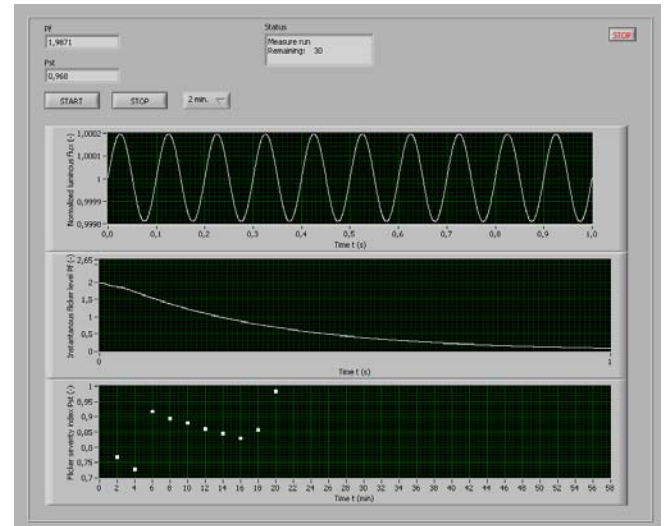


Fig. 5. The light-flickermeter front panel in LabView

3 LIGHT-FLICKERMETER VERIFICATION

Since there are not defined testing points for flickermeter based on the evaluation of luminous variation, the verification procedure for standard IEC flickermeter including advanced test protocol [11] has been adopted. It means that the test signals for light-flickermeter are generated by the reference 60W incandescent lamp which is subject to test voltages used for IEC flickermeter verification. It also implies that special tests system has to be developed.

3.1 Test procedure

The test protocol [11] introduces systematic verification of flickermeters in wide range of power systems disturbances. Summary of advanced test protocol in accordance to [11] is in Tab. 3. The test procedure applied for light-flickermeter verification is composed of selected particular tests which were updated by results from [1][10][5].

Tab. 3. Summary of advanced calibration protocol [11]

Category	Test No.	Exciting signal	Expected result
Existing EN 61000-4-15 [7]	1	Rectangular AM	$P_{sf}=1.00\pm0.05$
	2	Sinusoidal AM	$P_{f,max}=1.00\pm0.05$
	3	Rectangular AM	$P_{f,max}=1.00\pm0.05$
Having no influence on flicker level	4	Frequency variation	$P_{sf}=1.00\pm0.05$
	5	High frequency components	$P_{f,max}<0.2$ $P_{f,max}=1.00\pm0.05$
	6	Linearity	$P_{sf}=(1.00\pm0.05)*\gamma\pm0.1$
With influence on flicker level	7	Single interharmonic	$P_{f,max}=1.00\pm0.05$
	8	Harmonic/interharmonic pairs	$P_{f,max}=1.00\pm0.05$
	9	Phase jumps	$P_{st}=P_{st,expected}\pm0.05$
	10	Dips/Swells	$P_{st}=P_{st,expected}\pm0.05$
Complex systematic	11.1	Complex wave 1	$P_{st}=P_{st,expected}\pm0.05$
	11.2	Complex wave 2	$P_{st}=P_{st,expected}\pm0.05$
	11.3	Complex wave 3	$P_{st}=P_{st,expected}\pm0.05$

3.2 Test system

The test system has been developed to prove light-flickermeter appropriate accuracy requirements. Its hardware consists of a linear power amplifier 108-AMX from Pacific and the PXI instrumentation system which is shared with the light-flickermeter. The simplified diagram of the test system is at Fig. 6. The controller PXI-8106 drives the arbitrary waveform generator PXI-5421 to generate among others the test signals defined in [7] and [11]. The output analog signal is amplified by power source 108-AMX and feeds a lamp and reference flickermeters which are LMG 500 from ZES Zimmer and developed and calibrated standard IEC flickermeter which also utilizes DAQ board PXI-4472 and virtual instrumentation in LabView. In order to achieve test voltage accuracy, the voltage feedback from power amplifier output to waveform generator is adopted [8]. For controlling and coordinating the devices via PXI and GPIB buses as well as waveforms (test signals) creation according to the specifications there is used a SW developed in LabView. In consonance with conditions of light-flicker measurement using the realized type of light-flickermeter which are defined in [4], the lamp (reference and others) have to be placed in a testing chamber of specific properties allowing comparative measurements of luminous flux variations. As the testing chamber there have been used Ulbricht-type integrating sphere with diameter of 2.5 m.

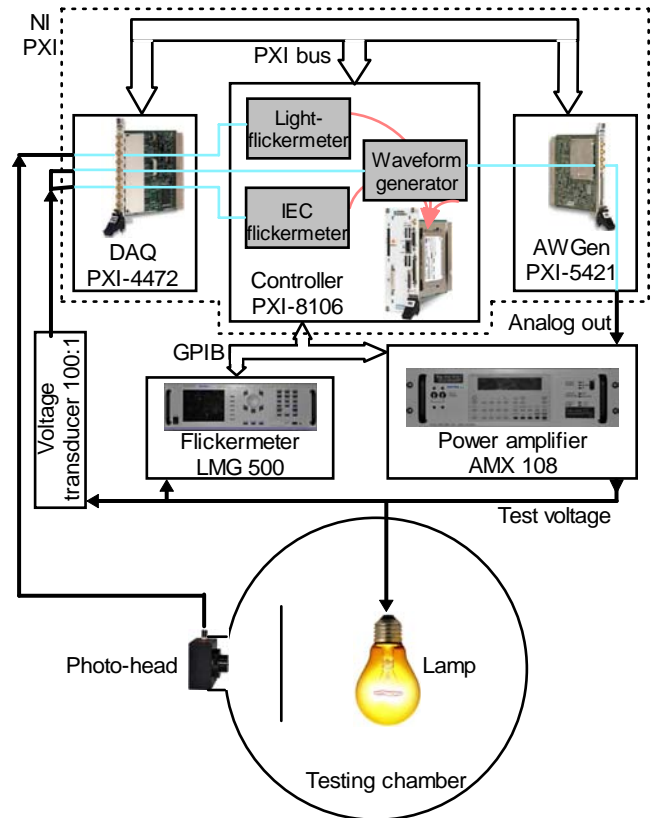


Fig. 6. Test System

3.3 Verification test results

Results of the light-flickermeter overall response test which is defined in [7] (table 5) with testing procedure specification in [11] (Test No.1) are shown at Fig. 7. The allowed deviation is $\pm 5\%$ from $P_{st}=1$.

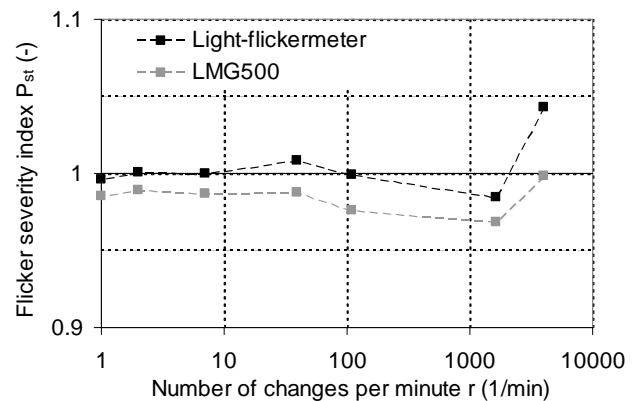


Fig. 7. Rectangular voltage AM performance test results, test No.1

Verification of the normalized light-flickermeter response has been performed, Test No.2 and 3 according to [11], using normalized sine and rectangular wave modulated signal over the range of modulation frequencies and depths specified by the standard [7] (table 1 and 2). Results are shown in Fig. 8. Required accuracy is $\pm 5\%$ of the reference value ($P=1$).

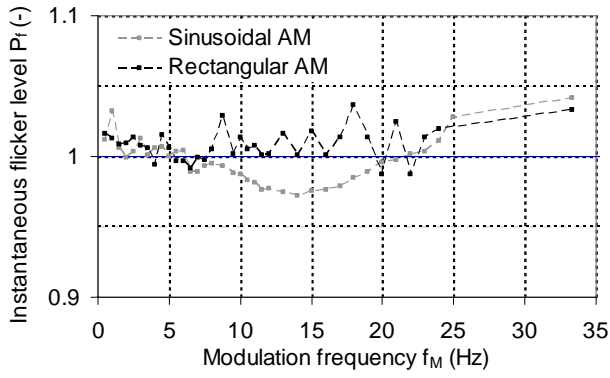


Fig. 8. Flickermeter compliance test results to normalized sinusoidal and rectangular voltage AM, test No.2, 3

Another requested and verified flickermeter characteristic is its response linearity (Test No. 6) in wide range of voltage magnitude fluctuation [7]. The linearity test results for light-flickermeter in accordance to specifications given in [11] are in Fig. 9 and as it can be seen the requirements are met again.

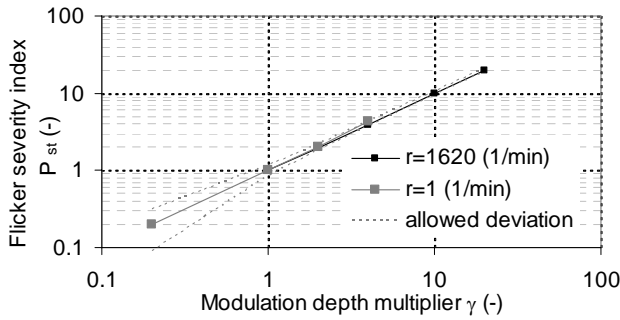


Fig. 9. Linearity test results, test No.6

Light-flickermeter compliance test results for single low-frequency interharmonic component superimposed on fundamental waveform specified in [11] (Test No. 7) are in Tab. 4.

Tab. 4. Test No.7 results

f_{IH} (Hz)	m_{IH} (% U_1)	$P_{f,max}$ (-) measured	$P_{f,max}$ (-) expected
20	0.765	1.0471	1.00±0.05
40	0.130	0.9868	
60	0.130	0.9846	
80	0.765	1.0444	

Test results for pair of harmonic and interharmonic injected to fundamental waveform with specification of test procedure in [11] (Test No. 8) are in Tab. 5 where the light-flickermeter response does not reach the required flicker level range for pair of components at frequencies of 105Hz-160Hz. (The reason is unknown).

Tab. 5. Test No.8 results

f_H-f_{IH} (Hz)	m_H, m_{IH} (% U_1)	$P_{f,max}$ (-) measured	$P_{f,max}$ (-) expected
150-160	3.612	0.8954	1.00±0.05
250-260		0.9959	
350-360		0.9827	
550-560		0.9876	
650-660		0.9954	

The last performed test checks the light-flickermeter response on light produced by the reference 60W lamp which is subject to series of voltage events defined in [11] (Test No. 10). The test results are in Tab. 6. As it can be seen the light-flickermeter output is for this test outside the allowed tolerances, while the reference IEC flickermeter gives the right output, even if the SW/HW platform is the same for both of them.

Tab. 6. Test No.10 results

Test signal for class	P_{st} (-) measured			P_{st} (-) Expected [5]
	Light-flickermeter	IEC flickermeter	LMG 500	
3	9.3624	15.5795	4.480	15.67*(1±0.05)

3.4 Other measurement results

In addition two other measurement types illustrating the differences between lamp types were realized. The first of them is measurement of the light-flicker produced by a Compact Fluorescent Lamp (CFL) which is subject to voltage AM with parameters for achieving $P_{st}=1$ in case of reference lamp. Measurement results are at Fig. 10.

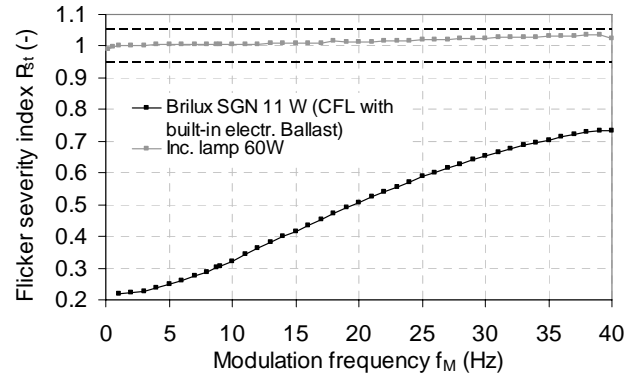


Fig. 10. Comparison of different lamp types under sinusoidal voltage AM for $P_{st}=1$ regarding to the ref. 60W/230V lamp

As the second experiment, Interharmonic-Flicker Curve (IFC) of the CFL utilizing the light-flickermeter was measured. IFC determines for each interharmonic frequency the maximal acceptable level of interharmonic voltage which no disturbing light flicker ($P_{st}=1$) can be perceived by the "average observer" if the composed voltage is applied on a lamp [6]. Measurement result is at Fig. 11. Discontinuity in the curve means that the interharmonic magnitude should be higher than 20% of U_1 to reach $P_{st}=1$ or it is not possible to get $P_{st}=1$ for any magnitude of injected interharmonic component at given frequency. For purpose of comparison, IFC of the reference 60W/230V incandescent lamp and of many other lamp types obtained by other developed methods can be found in [6].

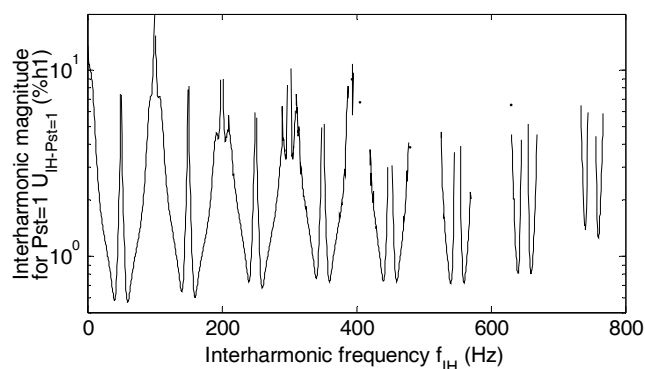


Fig. 11. Measured Interharmonic-Flicker curve of a Brilux SGN 11W compact fluorescent lamp

4 CONCLUSION

A light-flickermeter for comparative measurement of flickering lamps simulating response of the average observer on disturbing light flicker under specific conditions has been realized on the basis of previously proposed design and described in details. The developed instrument evaluates measured luminous flux fluctuation utilizing appropriate hardware and signal processing by means of virtual instrumentation in LabView.

The realized light-flickermeter has been calibrated and verified using developed test system employing reference 60W/230V incandescent lamp as a source of test signals for light-flickermeter and adopted test protocol introduced originally for advanced performance analysis of standard IEC flickermeters. The light-flickermeter passes all performed tests except one of them, de facto. Non-permissible deviation from expected value obtained for series of voltage events can be seen in different normalization process in input signal adaptor between standard IEC and light-flickermeter.

Applicability of the light-flickermeter concept for comparative measurements of flickering lamps has been proved on two experiments. Comparing results with previous work, using light-flickermeter for determination of different lamp type's immunity level relative to the reference observation conditions could lead to more accurate results than other methods.

ACKNOWLEDGEMENT

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