A Flickermeter based on Voltage Peak Detection Method - Part II: Standardize Verification and Performance in Real Deployment

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Abstract

The paper deals with a standardized verification procedure applied on an alternative digital time domain based flickermeter type having response to high-frequency interharmonics and its performance testing in real deployment. The flickermeter utilizes a Voltage Peak Detection (VPD) method and the signal processing is realized using virtual instrumentation in LabView together with a NI cDAQ platform.

Standardize verification is performed by means of tests and requirements defined in the standard IEC 61000-4-15. The performance in the real deployment was tested by a set of tests focused mainly on cumulative disturbances including interharmonic distortion and by a long time measurement in the supply network with the simultaneous deployment of other types of flickermeters. The results of all measurements are compared and discussed.

Keywords: Flicker, Flickermeter, IEC 61000-4-15 Ed.2, Verification, Calibration system, LabView

1 Introduction

It has been demonstrated in the past, that the standard flickermeter [1] is not able to provide response to the high frequency interharmonics at frequencies over double of the system fundamental frequency in fundamental supply voltage [5]. Even if it is known that such disturbance is capable to cause flickering of some types of lamps, especially of fluorescent lamps [7][11][12] .

For fix this discrepancy in the time domain flickermeter design there is possible solution based on replacement of the quadratic demodulator by another demodulator type with fixation of a voltage envelope or magnitude fluctuation in the flicker signal as well as for high frequency interharmonics in supply voltage.

The voltage-peak-detection design and the main idea were presented in [5] and developed in [6]. The LabView implementation of VPD flickermeter was presented in [8].

2 Test system

For the purpose of verification there was built a test system shown at the Fig. 1. Its hardware consists of a linear power amplifier 108-AMX from Pacific and a PXI instrumentation system which is shared with the light-flickermeter [3][4]. Both the standard IEC and VPD flickermeters are based on the LabView implementation and utilize the DAQ card NI 9225 inserted in cDAQ chassis. The controller PXI-8106 drives the arbitrary waveform generator PXI-5421 to generate among others the test signals defined in [1] and [2]. The output analog signal is amplified by the power source 108-AMX and feeds a lamp and the IEC and VPD flickermeters. 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 [3], 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.

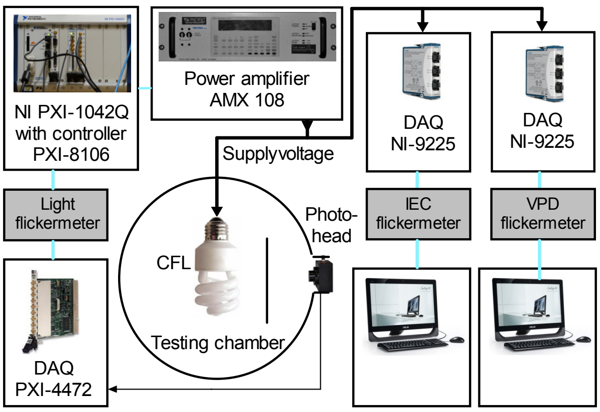

Fig. 1. Test system diagram

2.1 The standard tests

The standard [1] describes test signals with sinusoidal and rectangular amplitude modulation, frequency and phase changes and steps and harmonic and interharmonics interferences and their combinations thereof. Short time flicker level and instantaneous flicker level outputs are tested. The response to all tests must meet all requirements with the required accuracy. Selected tests were performed to show capabilities and weaknesses of VPD flickermeter.

3 Test results

Test 1: Rectangular and sinusoidal voltage changes

Flickermeter response characteristics on P_{inst} output for rectangular and sinusoidal voltage Amplitude Modulation (AM) have to be checked according to the standard [1]. The

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$P_{inst,max}$ values for specified test points have to be 1.00 with tolerance of ±8%. The results are shown on Fig. 2 and Fig. 3.

As it can be seen on the Fig. 2, VPD flickermeter satisfies this requirement. However as for Fig. 3, the flickermeter meets the requirement only in the limited range, up to 15 Hz. On other hand, this is an expected property of the instrument. It can be explain by a summation effect of all frequency components in the rectangular modulation waveform [8].

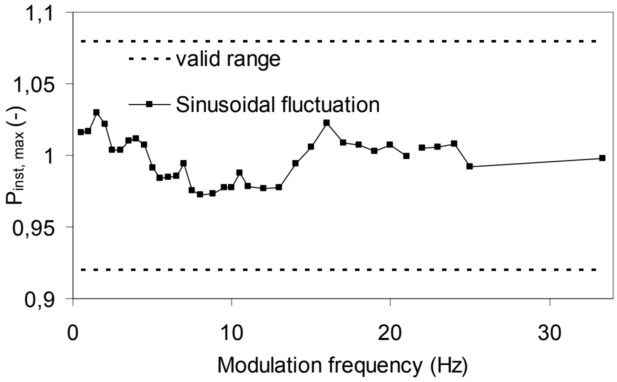

Fig. 2. Response characteristic to sinusoidal voltage changes

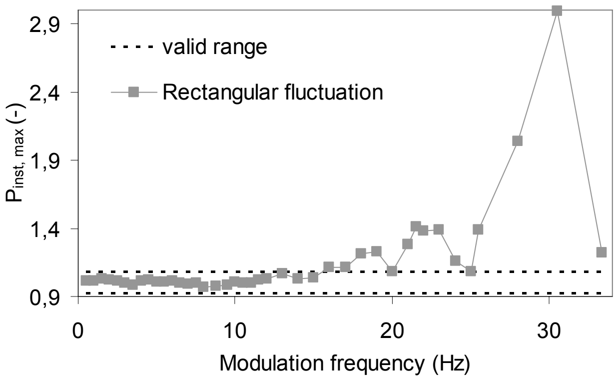

Fig. 3. Response characteristic to rectangular voltage changes

Test 2: Rectangular voltage changes and performance test

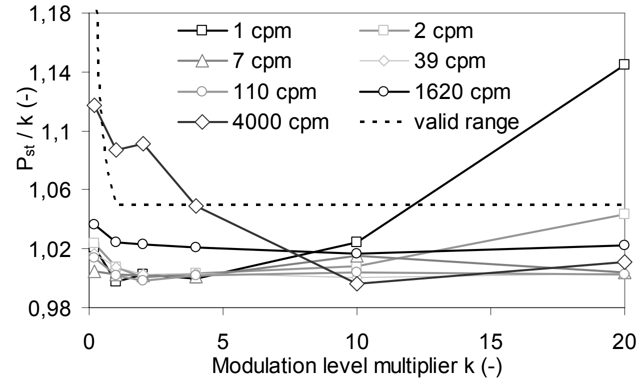

Fig. 4. Response characteristic to rectangular voltage changes and performance test and linearity test

This part consists of two tests. Aim of the first test is to verify overall accuracy of the flickermeter and the second is focused on linearity, more precisely, on determination of the flickermeter working range. The testing signal is composed of mains frequency voltage signal modulated by periodical rectangular changes of specified modulation depth and frequency combinations and P_{st} output values are evaluated. As for the accuracy testing, expected P_{st} for test points is of 1.00 with a tolerance of ±5% and the results can be seen on Fig. 4.

Test the functionality shows that the VPD flickermeter does not show the correct response for rectangular variations with higher number of changes than 1620 cpm. It is caused by flickermeter response to higher frequency components.

Test 3: Combined frequency and voltage changes

Within the test 3 the flickermeters are at once subject to periodical amplitude and frequency modulation to verify the measuring circuit characteristics. In this case the P_{inst} output is observed, thus $P_{inst,max}$ has to be 1.00 with a tolerance of ±8%. The results are shown in Tab. 1. In this test, flickermeter shows the correct response.

Tab. 1. Results for combined frequency and voltage changes

$P_{inst, max}$ (-)	δ (%)
1.00751	0.751

Test 4: Distorted voltage with multiple zero crossing

The voltage for Test 4 is composed of the fundamental voltage waveform distorted by specified set of harmonic components causing multiple zero crossing and amplitude modulated by defined sine wave. However in the standard there are some gaps concerning magnitude of the components. For the performed test, the fundamental voltage magnitude was set to 230 V. Then the harmonic components were superimposed on and the modulation depth was taken to be related to the fundamental voltage magnitude. For this test, the P_{inst} output is observed again and $P_{inst,max}$ has to be 1.00 with a tolerance of ±8%. The results are shown in Tab. 2. In this test, the flickermeter shows the correct response.

Tab. 2. Results for distorted voltage with multiple zero crossing

$P_{inst, max}$(-)	δ (%)
1,02481	2,481

Test 5: Bandwidth test using harmonics and inter-harmonics side band fluctuation

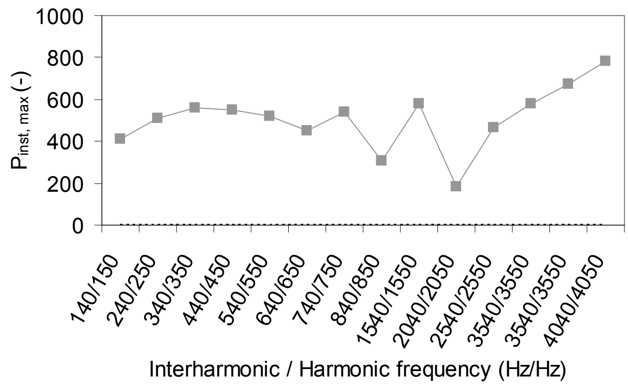

Fig. 5. Response characteristic to bandwidth test using harmonics and inter-harmonics side band fluctuation

This test is dedicated to verify the flickermeter bandwidth using a test voltage consisting of fundamental waveform with superimposed pair of harmonic and interharmonic components which are shifted for 10 Hz. Increasing the harmonic and of course interharmonic component frequency, starting from 150 Hz, the bandwidth is identified as maximal frequency of the harmonic component for which the $P_{inst,max}$ value is in tolerance of ±8% from $P_{inst,max}$ = 1.00. Then such harmonic frequency shall be at least 450 Hz.

The measurement results are on Fig. 5 and it is evident that the response of the VPD flickermeter is absolutely out of valid range. It is related to the fact that standard IEC flickermeter has very small response for the frequency components above 100 Hz. Because this test is test is designed for IEC flickermeter, the response of VPD flickermeter is huge and with respect to the expected behaviour it is correct.

Test 6: Phase jumps

The test voltage is composed of the fundamental nominal voltage affected by a train of five phase jumps of the same angle uniformly distributed in 10-minutes observation period. The phase jumps $\Delta\beta$ from set of +30°, -30°, +45°and -45° shall occur at the positive zero crossing in specified five moments of the observation period.

Used demodulation (VPD) method is not able to detect disturbances causing flicker, like phase jumps. It is also evident from the used signal processing [8]. The results of this test are in the Tab. 3.

Tab. 3 Results for the phase jumps test

$\Delta\beta$	P_{st} (-)	$P_{st,\ expected}$ (-)	δ (%)
-30°	0.0426	0.913	95.33
+30°	0.0572	0.913	93.73
-45°	0.05	1.060	95.28
+45°	0.283	1.060	73.3

Test 7: Rectangular voltage changes with 20% duty cycle

The voltage is rectangulary modulated at rate 28 Hz and a duty cycle of 12/60. P_{st} shall be 1.00 with tolerance of ± 5%.

The result in the Tab. 4 shows that VPD flickermeter response is slightly incorrect, although the error is relatively small.

Tab. 4 Rectangular voltage changes with 20% duty cycle

P_{st}	δ (%)
1.4842	6.62

3.2 Test for single interharmonics disturbance

The Interharmonic-Flicker Curve (IFC) [9] determines for each interharmonic frequency the maximal acceptable level of interharmonic voltage which no disturbing light flicker can be perceived by the "average observer" if the composed voltage is applied on a lamp. That means the interharmonic voltage relative amplitude vs. interharmonic frequency curve for achieving the P_{st}=1 which is unique for each lamp type [9]. Since the flickermeters simulate response of a lamp-eye-brain system they are having also their own IFC (Fig. 6).

One can conclude that the IFC of the fictive lamp included in the VPD flickermeter in frequency bands of 100-200 Hz, 200-300 Hz, etc. is the same as in the range of 0-100 Hz, which is valid for the reference 60W bulb. Nevertheless it was the object of the flickermeter design and the "like" mirroring has been expected [8].

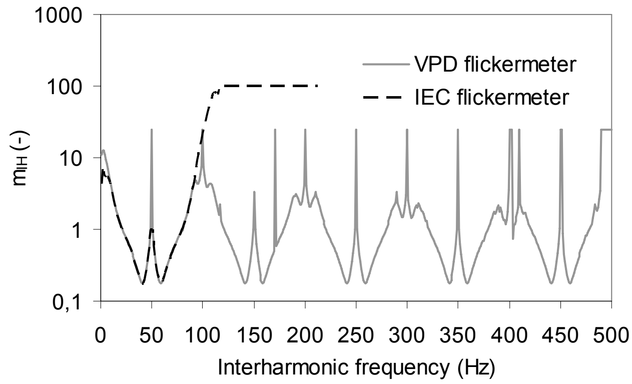

Fig. 6. Relative amplitude of the interharmonic voltage vs. interharmonic frequency for achieving the P_{st}=1

3.3 Response for variety of test signals

Measurements were performed with a set of nineteen test signals specified in Tab. 5 and response of the VPD flickermeter, IEC flickermeter and Light-flickermeter with incandescent lamp and two Compact Fluorescent Lamps (CFLs) was measured and recorded simultaneously with results shown at Fig. 7.

Test signal 1

If an interharmonic components at frequency below 100 Hz in injected to the amplitude-modulated supply voltage (test signal 1), the incandescent lamp produces a flicker, which is correctly detected by both the flickermeters (IEC and VPD). The compact fluorescent lamps in this case also visibly flicker, but with a lower level than the bulb. Because the sensitivity of the CFL is lower the of the reference 60W lamp which is simulated by both the flickermeters (IEC and VPD).

Test signals 2-7

In the cases of test signals 2-6, the supply voltage amplitude-modulated by sinusoidal signal with frequency of 8.8 Hz and modulation depth of 0.25 %, then is distorted by single interharmonic component with the amplitude 2 % of U_{fund} at following frequencies:

$$f_{IH} = k \cdot f_{fund} + 42\,, \tag{1}$$

where k = 2, 4, 6, 8, 10 and 12, consequently.

As it is explained in [7], the injected interharmonic component causes luminous flux fluctuation of the CFL with frequency of 8 Hz, i.e. in the range of maximum sensitivity of human eye. While the incandescent lamp does not react to the presence of interharmonics above 100 Hz and the indicated level of P_{st} corresponds only to voltage fluctuations due to its AM. The same value of P_{st} is naturally indicated by the IEC flickermeter. However, it is evident that both compact fluorescent lamps produce visible flicker. This is captured by VPD flickermeter, but its response is relatively high, because the CFLs sensitivity to high-frequency interharmonics is typically lower [9].

Test signals 8 -12

In the cases of test signals 8-10, the supply voltage is amplitude-modulated by sinusoidal signal of the same parameters (f_M=8.8 Hz, $\Delta U/U$=0.25 % of U_1) and than is distorted by a single interharmonic with amplitude of 2% and of different frequencies than before. The interharmonic component frequencies are as follows:

$$f_{IH} = k \cdot f_{fund} + 17 \,, \qquad (2)$$

where k = 2, 4, 6, 8, and 10, consequently, and such interharmonic components cause fluctuation of luminous flux of the CFL at frequency of 33 Hz. The incandescent lamp does not respond to those interharmonics again and the P_{st} output measured by the Light flickermeter corresponds only to variation in luminous flux due to voltage amplitude modulation as well as in the case of the IEC flickermeter. While the CFLs produce flicker, where the P_{st} measured by the Light flickermeter is lower than before, because the frequency of luminous flux fluctuation is in the range with lower sensitivity of the human eye-brain chain. Therefore the response of the VPD flickermeter is relatively low.

Test signal 13

In the case of the test signal 13, only interharmonic component with amplitude 2 % of U_{fund} and at frequency of 217 Hz is superimposed on the supply voltage. It makes sense that P_{st} output is non-zero only for the VPD flickermeter and for the CFLs with the Light flickermeter.

Test signal 14

The test signal 14 is created as supply voltage with rectangular amplitude modulation with the frequency 8.8 Hz and depth of modulation of 0.196 % and than interharmonic component with amplitude 2 % of U_{fund} and frequency of 217 Hz is superimposed on the supply voltage. It is possible to see, that the interharmonic still cause flickering of the fluorescent lamp, while the flickering of the incandescent lamp is caused by rectangular modulation only.

Test signal 15 and 16

The test signals 15 and 16 check synergy effect of two independent interharmonic components injected to the supply voltage. The interharmonics are of the same amplitude of 2% and of the following frequency combinations: 42 Hz and 217 Hz as for the test signal 15 and 142 Hz and 217 Hz as for the test signal 16.

The response of the VPD flickermeter and IEC flickermeter to signal 15 is the same as flicker recorded by the Light flickermeter with the reference incandescent 60 W lamp. This is cased by interharmonic component at frequency of 42 Hz. This is de-facto the similar situation, as in the case of the test signal 1. But the test signal 16, where both of interharmonics are above 100 Hz, leads to zero at the output of the IEC flickermeter. Whereas the CFLs lamps still flicker and the VPD flickermeter do not change its response.

Test signals 17-19

In the case of the test signals 17-19, the flickermeters and lamps are subject to Ripple Control Signals (RCSs) of various parameters, which are superimposed on the supply voltage subsequently. The used RCS was of following properties: protocol: ZPA I-I (used in Czech Republic), command: (11111111111101010101010101010101010101010101), with carrier signal frequency of 183.33 Hz and amplitude of 2, 5 and 10 %. The telegram was repeated one times per 10 minutes [10].

It is clear that this type of disturbance can cause the flickering of the fluorescent lamps, while the incandescent lamp is almost immune. The response of the IEC flickermeter is the same as the sensitivity of the incandescent lamp. However, it is important that the VPD flickermeter measures the flicker severity index very accurate to the fluorescent lamp – the Light flickermeter response, because the ripple control signal is considered to be wanted signal in the supply voltage. It is one of the most common interharmonic interference in the power network.

Tab. 5 Test signal sequence

Test-signal	Disturbance	Supplement disturbance
1	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 42 Hz m_{IH} = 2 %
2	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 142 Hz m_{IH} = 2 %
3	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 242 Hz m_{IH} = 2 %
4	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 342 Hz m_{IH} = 2 %
5	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 442 Hz m_{IH} = 2 %
6	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 542 Hz m_{IH} = 2 %
7	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 642 Hz m_{IH} = 2 %
8	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 117 Hz m_{IH} = 2 %
9	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 217 Hz m_{IH} = 2 %
10	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 317 Hz m_{IH} = 2 %
11	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 417 Hz m_{IH} = 2 %
12	Sin. modulation f_M = 8.8 Hz $\Delta U/U$ = 0.25 %	Interharmonic f_{IH} = 517 Hz m_{IH} = 2 %
13	Superimposed interharmonic f_{IH} = 217 Hz m_{IH} = 2%	
14	Rectangular modulation f_M = 8.8 Hz $\Delta U/U$ = 0.196 %	Interharmonic f_{IH} = 217 Hz m_{IH} = 2 %
15	Interharmonic f_{IH} = 42 Hz m_{IH} = 2 %	Interharmonic f_{IH} = 217 Hz m_{IH} = 2 %
16	Interharmonic f_{IH} = 142 Hz m_{IH} = 2 %	Interharmonic f_{IH} = 217 Hz m_{IH} = 2 %
17	Ripple control signal, ZPA I-I 1/10 min f_C = 183 Hz m_C = 10 %	
18	Ripple control signal ZPA I-I 1/10 min f_C = 183 Hz m_C = 5 %	
19	Ripple control signal ZPA I-I 1/10 min f_C = 183 Hz m_C = 2 %	

3.4 Flickermeter response in the real deployment

Two time-independent socket voltage long time measurements were performed. The socket is accessible in a laboratory of Brno University of Technology and at the same time it was used for connection of a compact fluorescent lamp TUNGSRAM E6 / S 20W placed in the test chamber (Fig. 1). Both the measurements were taken for 12 hours period each. The Fig. 8 and Fig. 9 show a comparison of the recorded of short-term flicker severity values obtained by the IEC, VPD and Light (measuring on the lamp) flickermeters.

It is obvious that the P_{st} values recorded by the Light flickermeter for the compact fluorescent lamps were partly in the observation periods higher than P_{st} values indicated by the IEC flickermeter. This variation can be explained by the presence of interharmonic components above 100 Hz in the supply voltage. The IEC flickermeter was not able to catch it, due to its principal function. VPD flickermeter detects even the interharmonic component and indicates a much higher level of P_{st}. It is because of its interharmonic-flicker response curve which makes the VPD flickermeter more sensitive to high-frequency interharmonics than there is the real sensitivity of CFLs. Nevertheless the P_{st} waveforms measured by the Light flickermeter and by the VPD-flickermeter are in the behaviour very similar.

The last measurement was taken from a socked directly connected to the building AC bus. The measurement set up was the same as in the case of the previous field measurements. The P_{st} level indicated by IEC flickermeter is generally higher. However the compact fluorescent lamp powered from this network flickers with lower levels of P_{st} than indicates the IEC flickermeter. The VPD flickermeter shows higher P_{st} values than the actual flickering lamp (compared by means of the Light flickermeter output), but displayed curves have very similar behavior again.

It means that in the given measurement point the voltage fluctuations resulting in almost constant level in P_{st} values is caused by other causes than the high-frequency interharmonic components, while the spikes in behaviors are probably their consequence.

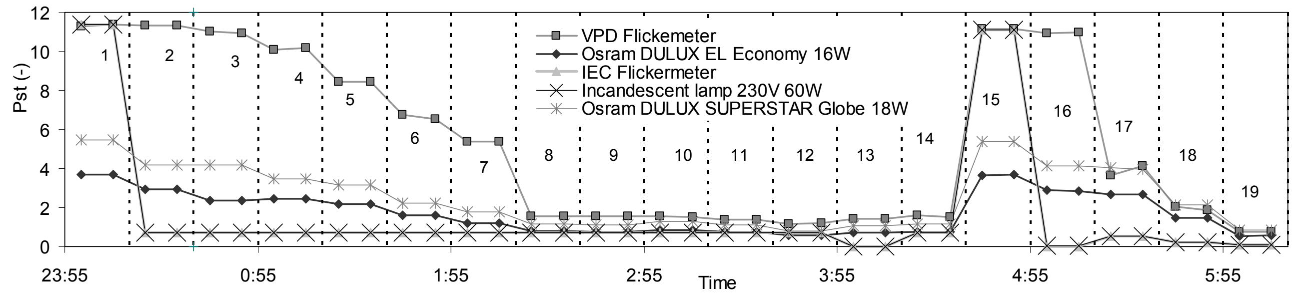

Fig. 7. Flickermeters and Light flickermeter - light sources combinations response to the sequence of test signals

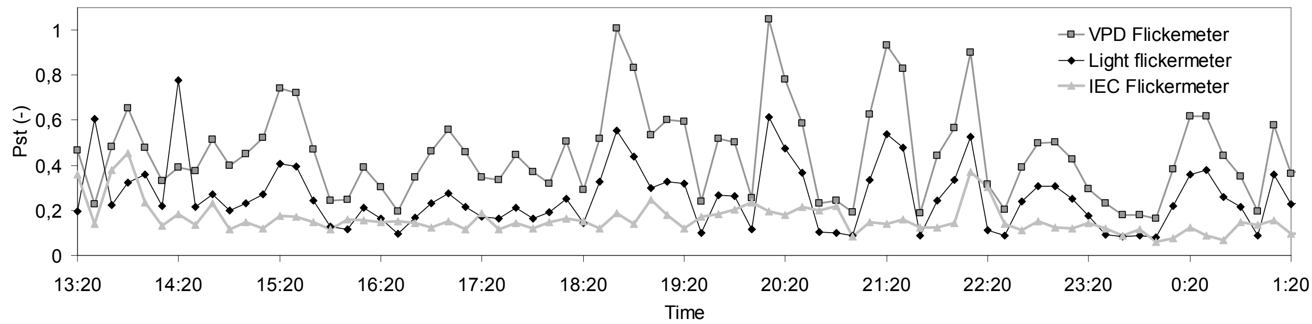

Fig. 8. The real deployment test No1; 12 hour record of the P_{st} in the socket voltage

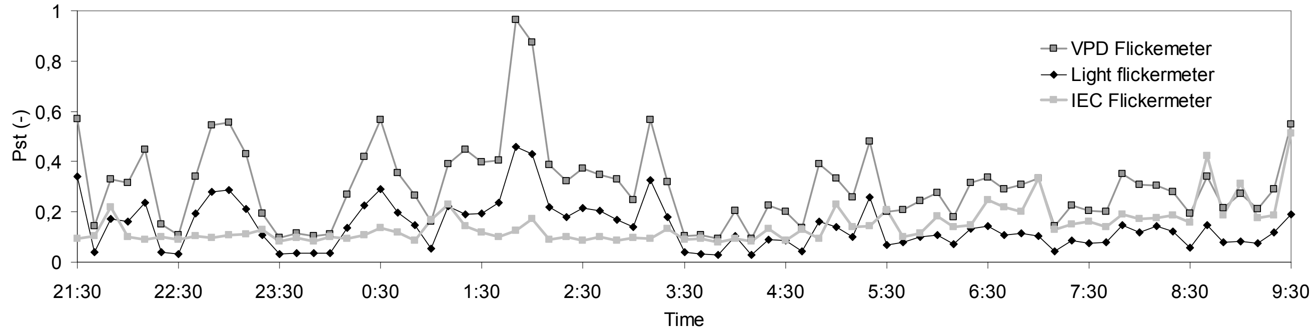

Fig. 9. The real deployment test No2; the 12 hour record of the P_{st} in the socket voltage

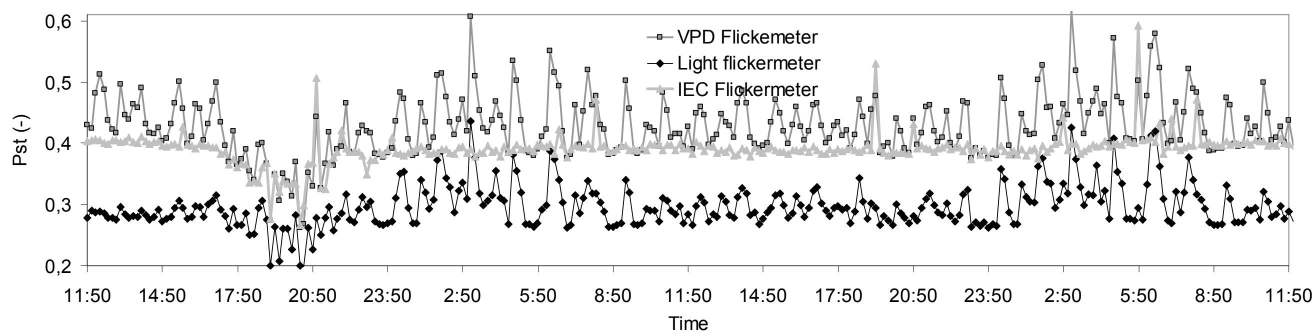

Fig. 10. The real deployment test No3; the 48 hour record of the P_{st} in the socket voltage

4 Conclusion

The perform tests have shown some shortcomings of the VPD flickermeter and also its ability to provide relevant output in the short time severity index in presence of high-frequency interharmonics. Some results showed the wrong response that disqualifies the VPD flickermeter for a full substitution for the standard flickermeter. However, all results presented in the paper proved, that the VPD flickermeter is able to be deployed as an adjunct to the standard flickermeter. It provides relatively high response to high-frequency interharmonic components and in conjunction with the standard flickermeter may be an appropriate tool to detect undesirable interference in supply.

The VPD flickermeter gain factor for the high-frequency interharmonics is always higher than is the response of any group of tested light sources. It can be assumed that the P_{st} value corresponding to the luminous flux fluctuation of a real lamp will never be worse than the value indicated by the VPD flickermeter.

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