Electrical Power Quality and Utilisation
Vol. IX No 1 2003

IEC FLICKERMETER USED IN POWER SYSTEM MONITORING
Part 1: Comparative Tests

Miernik wahań napięcia IEC do pomiarów w systemie elektroenergetycznym
Część 1: Testy porównawcze

Marcin SZLOSEK[1] Zbigniew HANZELKA[1] Andrzej BIEŃ[1]
Marek HARTMAN[2] Marek ROGOŻ[3],
[1] University of Science and Technology, Cracow, POLAND; [2] Gdynia Martime University, Gdynia, POLAND
[3] Power Distribution Company – Cracow, POLAND

***Summary*: The test has been carried out for the flickermeters being designed according to the requirements and provisions of IEC 61000-4-15 standard. Objective of the test is the assessment of flickermeters suitability for measuring voltage fluctuations of various waveforms, occurring in power supply systems. The paper presents results of the measurements carried out at one of Polish steelworks, at the electric steelworks supply bus-bars. Duration of the measurement was seven days. Ten various flickermeters, their conformity to IEC 61000-4-15 standard requirements declared in specifications, have been used for these measurements.**
The second part of this paper presents results of laboratory tests performed for five selected flickermeters. The investigation has been carried out according to UIE WG 2 "Power Quality" specified tests for calibration and verification of a flickermeter [11]. Because of the limitations of instruments used during the investigation not every test has been performed in accordance with the original proposition. The other tests, as being unrealizable, were performed for the flickermeter model developed in MATLAB – SIMULINK environment 10].

***Streszczenie*: Testy przeprowadzone zostały dla mierników migotania światła skonstruowanych w oparciu o przepisy normy IEC 61000-4-15. Ich celem było sprawdzenie przydatności przyrządów do pomiarów różnorodnych przypadków wahań napięcia występujących w systemach zasilania. W artykule przedstawiono wyniki tygodniowych pomiarów wykonanych na szynach elektrostalowni w jednej z polskich hut, za pomocą dziesięcu mierników migotania, które zgodnie z specyfikacja techniczną ich producentów spełniaja wymagania normy IEC 61000-4-15.**
W części drugiej niniejszego artykułu przedstawiono wyniki testów laboratoryjnych pięciu wybranych mierników migotania przeprowadzonych zgodnie z procedurą zaproponowaną przez UIE WG 2 "Power Quality" [11]. Nie wszystkie testy zostały przeprowadzone zgodnie z oryginalną propozycją, ze względu na techniczne ograniczenia aparatury stosowanej podczas badań. Pozostałe testy, niemożliwe do realizacji przeprowadzono dla modelu miernika migotania opracowanego w środowisku MATLAB – SIMULINK [10].

Key words: electrical power quality, voltage fluctuations, flicker, flickermeter, test
Słowa kluczowe: jakość energii elektrycznej, wahania napięcia, migotanie światła, miernik migotania światła, test

1. INTRODUCTION

It can be shown that different digital flickermeters implementations, that meet the performance tests defined in IEC 61000-4-15 can still disagree significantly in some actual measurements [1, 11]. The IEC standard explicitly states the functional design criteria for flickermeters. Therefore, all flickermeters built according to the IEC standard should in principle give the same P_{ST} and P_{LT} readings for the same input voltage. However, the IEC specification for flickermeter processing blocks 1–4 (see IEC 61000-4-15) is specified for an analogue design. Additionally, a certain amount of design freedom is allowed. Most flickermeters in use today are digital, having attributes such as sampling rate, digital resolution, and windowing that are not specified in the IEC standard.

The UIE WG 2 "Power Quality" specified tests for calibration and verification of a flickermeter such as are performed in type testing [11]. In order to understand how a given flickermeter responds to voltage fluctuations, each test is performed to assess a particular aspect of the flickermeter.

The main objectives of presented research work are: (i) test how well flickermeters comply with IEC standards, (ii) provide a reproducible method of testing so that tests can be repeated another time with any flickermeter designed to IEC 61000-4-15, (iii) prepare test data and test programs for distribution to potential flickermeter manufacturers, (iv) gain knowledge about additional functionality or limitations provided by the tested flickermeters.

2. SITE TESTS

2.1. Points of measurement

The measurements have been carried out at the Zawiercie Steelworks S.A., in the south of Poland. Diagram of the substation, indicating points of instruments connection is shown in Figure 1. The measurement points were located on the secondary side of a supply transformer, at the phase-to-phase voltage level U_{RMS} = 30 kV. Measuring instruments, listed in Table 1, were connected via voltage transformers with secondary voltage 100 [V]. For the purpose of further analysis the instruments are divided into two groups (Table 1).

The measurement have been carried out for seven days from 12:40hr 30-01-2002 until 12:40hr 06-02-2002. Synchronization of measurements of particular instruments consisted in synchronization of the instruments' internal clocks and synchronization of the clocks in computers used in the measurements with respect to GPS.

Apart of measuring the flicker severity P_{st}, the instruments used in the experiment performed also measurements of:

— rms values of voltage,
— rms values of currents,
— active and reactive power for the fundamental harmonic,
— harmonic content and harmonic distortion THD.

Table 1. List of tested instruments

Instrument No.	Instrument type	
1	Arbiter Systems 1133A	
2	ION 7600	First
3	Memobox 800Q	group of
4	Power Recorder 1650	instruments
5	Topas 1000	
6	Mavowatt 45	
7	MEF – Panensa	Second
8	Electrotechnical Institute, Gdansk Division - own design	group of
9	Oscillostore P513	instruments
10	Qwave	

2.2. Voltage rms value

The rms voltage values, obtained at the outputs of the instruments used in the measurement, differ between themselves. Figure 2 shows changes in the phase L_1 rms voltage value versus time over example 12 hours of the measurement. When analysing the plot in Figure 2 two groups of instruments can be distinguished, for which the voltage waveforms are close to each other.

The values indicated by instruments (1), (2), (3) and (5) (Table 1) agree over the entire measuring period presented, while instruments (4), (9) and (10) give lower readings. Moreover, there are differences between these readings. Instruments 6, 7 and 8 did not measure rms voltage value.

Figure 3 shows waveforms of the maximum and minimum rms value of the L_1 phase voltage, obtained at outputs of all tested instruments. The least and the greatest differences in the instruments' readings in all phases are tabulated in table 2.

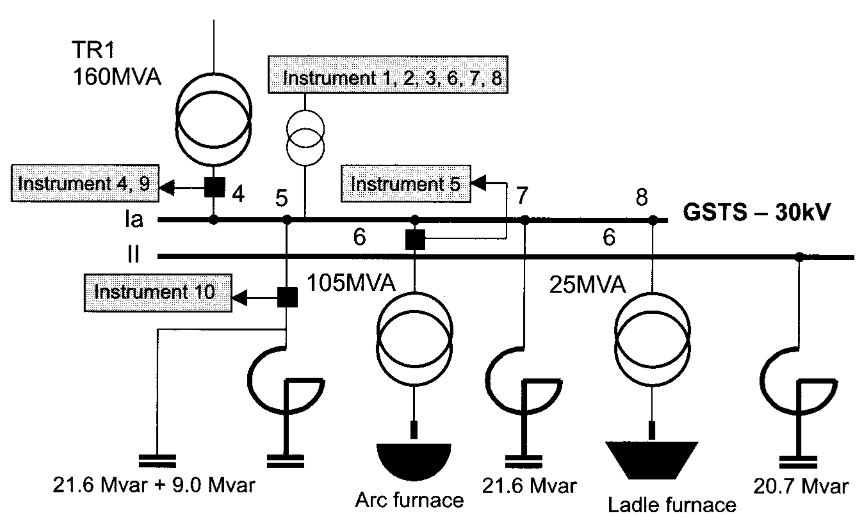


Fig. 1. Schematic diagram of the measurement site—the electric steelworks power supply system

Table 2. Extreme values of the voltage measurement differences for all instruments employed in the experiment

	Phase L_1		Phase L_2		Phase L_3	
	Value [kV]	Time of occurrence	Value [kV]	Time of occurrence	Value [kV]	Time of occurrence
Min	0.06	12:20 02-02	0.09	6:10 31-01	0.07	3:30 05-02
Max	1.2	23:10 04-02	1.24	23:10 04-02	1.25	23:10 04-02

2.3. Voltage fluctuations

Short term flicker severity P_{st}

Changes in the short term flicker severity P_{st} during the measurement are shown in Figure 4. In order to illustrate the results a time interval of 16h during charge melting in the furnace has been selected.

As seen in Figure 4, results of the P_{st} measurements on instruments (2), (3), (5), (7), (8), (9), (10) are similar. The P_{st} values obtained with the instrument (6) are about two times larger than at most of other instruments outputs. Certain differences in the short term flicker severity P_{st} have been obtained from instruments (1) and (4). The P_{st} values at the output of instrument (1) are approximately half of the results obtained from other instruments (excluding instrument (6)). Readings of the instrument (4) are ca. 30% less as compared to the above group of instruments. In case of the instrument (6) the recording was finished at 9:10 hour, 04–02. The number of the short term flicker severity P_{st} measurements performed is 699, which is 69.35% of the assumed number 1008 results. Recording the P_{st} values every 10 minutes gives after 7 days 1008 results.

Time interval, from 15:50 01–31 to 9:50 02–01, is presented in Figure 6 in a way, which enables to notice certain trends in flicker severity relations at the instruments' outputs.

The vertical line, added in the plot enables checking the accuracy of instruments' synchronization. When analysing the presented plot it could be found that instruments in the first group (Table 1) show conformity in readings of the short term flicker severity P_{st} changes, whereas the readings of instrument (8) in the second group proceed the results of other instruments. Reason for the discrepancy could be a software error, which causes the instrument holds the 10-minute P_{st} measuring period with insufficient accuracy. During the measurement this period has varied from 9 to 11 minutes. Loss of synchronization was visible after 24 hours.

Differences between the least and the greatest P_{st} value, measured at the same time with instruments used in the experiment, are listed in Table 3 in order to compare readings of all instruments.

The waveforms of P_{st}, reactive power — $Q_{L1,L2,L3}$, active power — $P_{L1,L2,L3}$, current — I_{L1} and THD_{UL1} measured during the same period of time as in Figure 4, are presented in Figure 5. Time interval, over which the P_{st} values have been compared, has been selected taking into account the limited measurement range of the instrument (6). A difference gre-

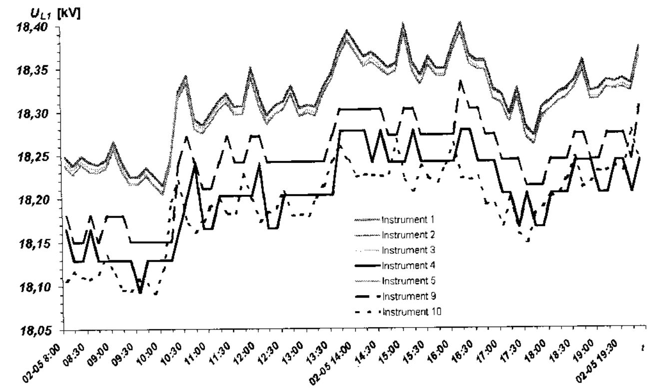


Fig. 2. Changes in the rms voltage value over selected 12h

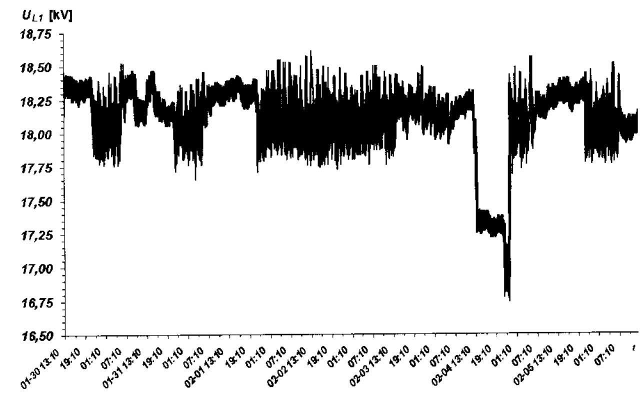


Fig. 3. Range of changes in the voltage value in phase L_1

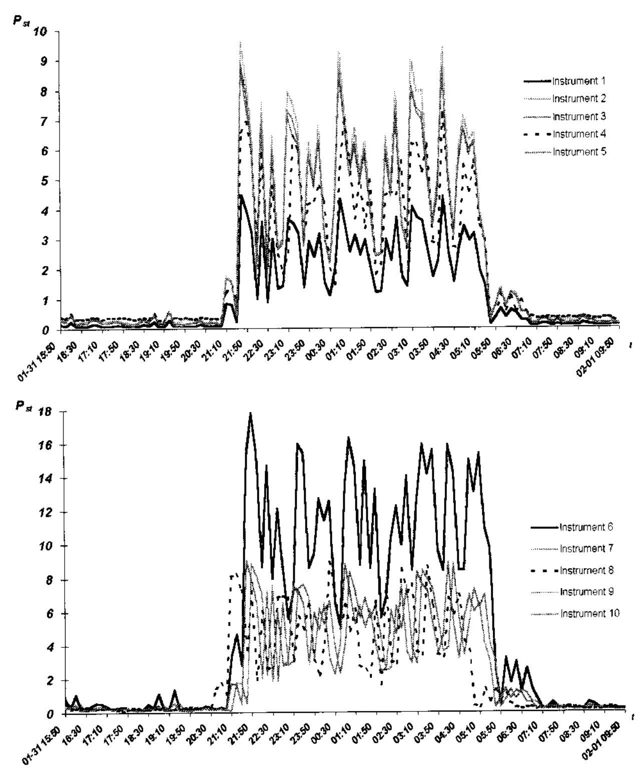


Fig. 4. Changes in the short term flicker severity P_{st} for the first and second group of instruments (Table 1)

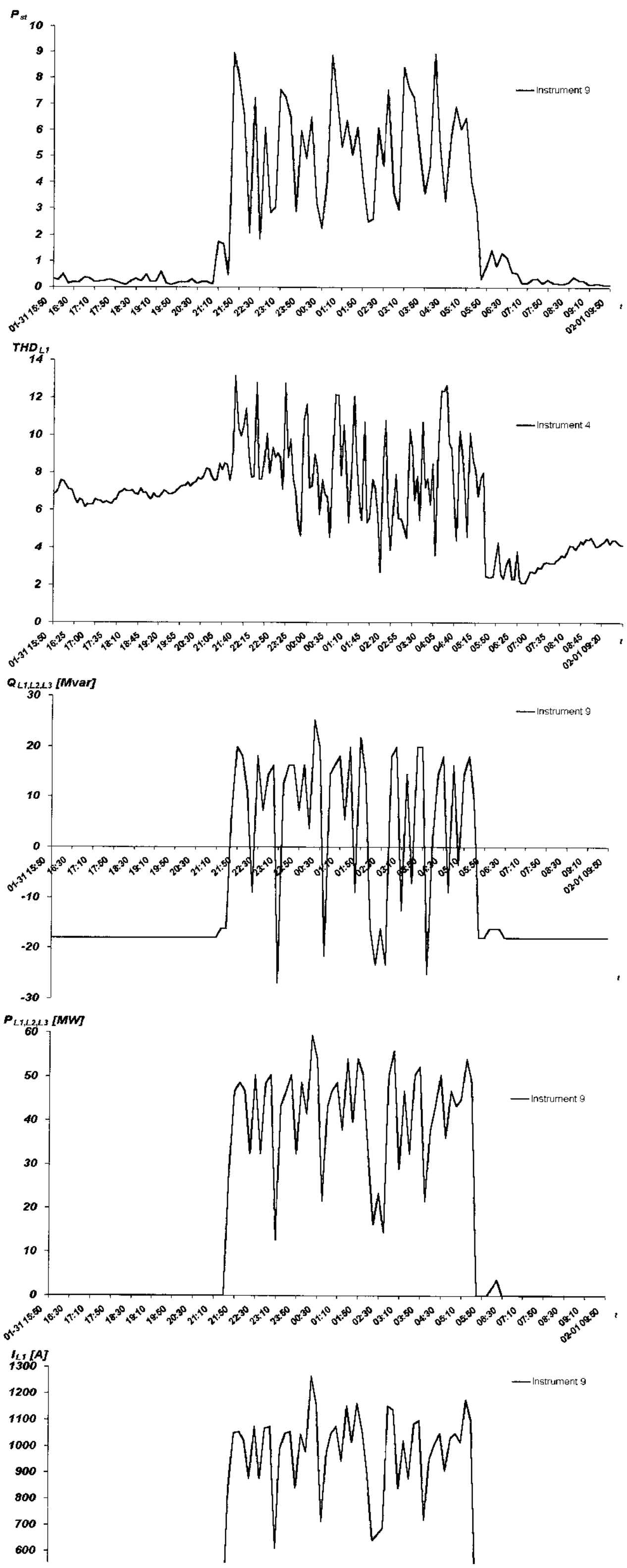


Fig. 5. P_{st}, $Q_{L1,L2,L3}$, $P_{L1,L2,L3}$, I_{L1} (instrument 9), THD_{UL1} (instrument 4)

Table 3. Comparison of the P_{st} indications

		L_1	L_2	L_3
All instruments	$\Delta P_{st\,max}$	14.52	13.24	13.81
	$\Delta P_{st\,min}$	0.12	0.11	0.12
Instruments (2), (3), (5), (7), (8), (9), (10)	$\Delta P_{st\,max}$	1.02	1.36	2.50
	$\Delta P_{st\,min}$	0.05	0.03	0.03

ater than 13 in the instruments' indications results from discrepancy of results between instruments (1) and (6). Also extreme differences in the indications obtained at the same time only with instruments (2), (3), (5), (7), (8), (9) and (10) are listed in Table 3. Differences between the instruments' indications are now much smaller.

Figure 7 shows the range of changes in short term flicker severity P_{st} obtained at outputs of all instruments tested presented against the changes of the P_{st} value at outputs of instruments 1 and 6.

Long term flicker severity P_{lt}

Changes in the long term flicker severity P_{lt} versus time are plotted in Figure 8, with selected portion expanded in Figure 9.

From the analysis of the plots, it can be found that tendencies of the P_{lt} changes are similar to those of the short term flicker severity P_{st}. The effect discussed in case of the short term flicker severity P_{st} changes, i.e. time-shift of results obtained at the instrument (8) output with respect to the other instruments' results, is clearly visible. The indications of instrument (6) are about 70% (58 results) of the assumed 84 two-hour measuring periods, because of the smaller memory capacity.

The P_{lt} values for instruments (2), (3), (5), (7), (8), (9) and (10) are similar. The P_{lt} values obtained at the instrument (6) are sometimes two times greater than indicated by other instruments. Differences in the P_{lt} values also occur in case of instruments (1) and (4). The P_{lt} values obtained at the instrument (1) output are half of the values obtained from other instruments. In case of the instrument (4) its results are 30% smaller when compared to the predominant group of instruments.

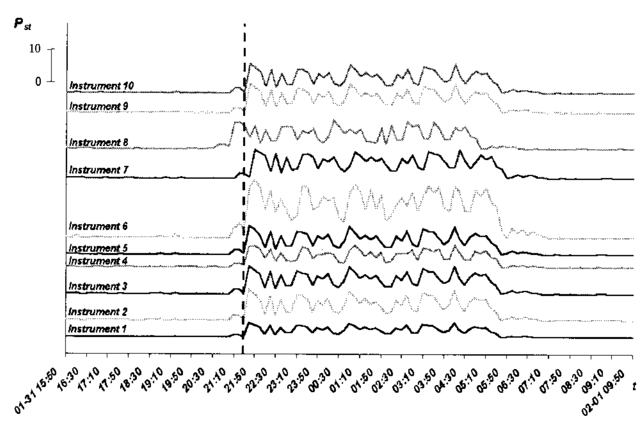


Fig. 6. Comparison of the P_{st} changes for all instruments (time interval as in Figures 4 and 5)

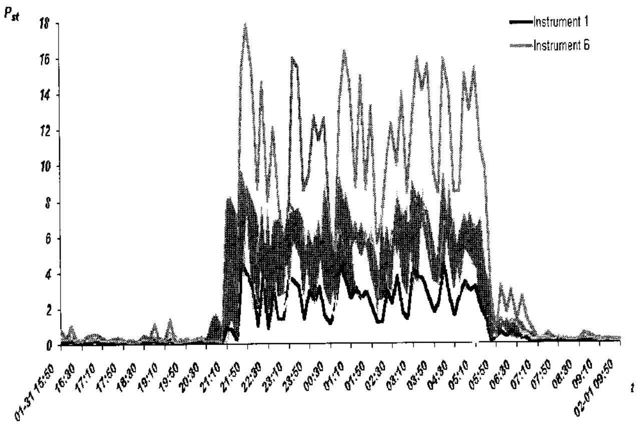


Fig. 7. Range of changes in P_{st} compared to results obtained from instruments 1 and 6

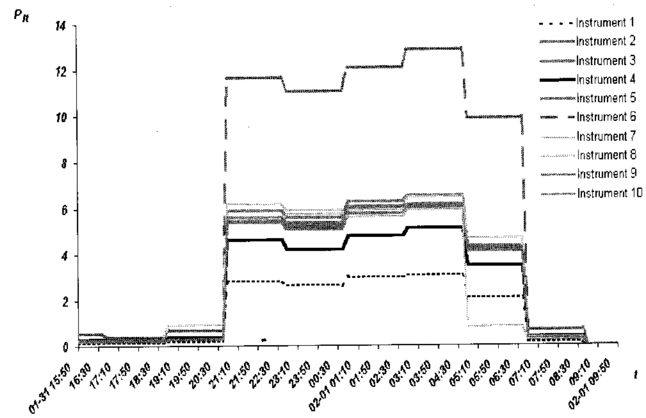


Fig. 9. Changes in the long term flicker severity P_{LT} in the selected time-window (Fig. 8)

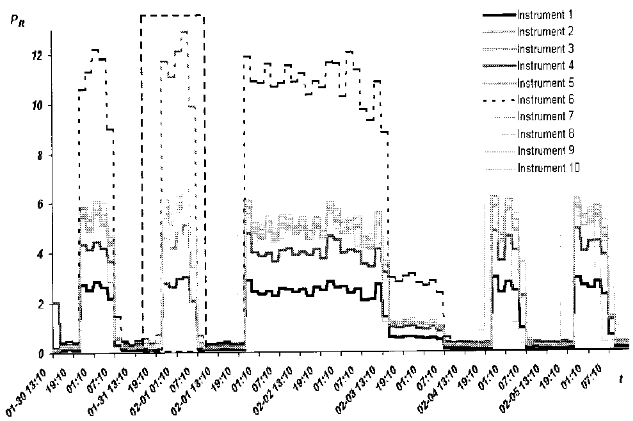


Fig. 8. Changes in the long term flicker severity P_{lt} versus time

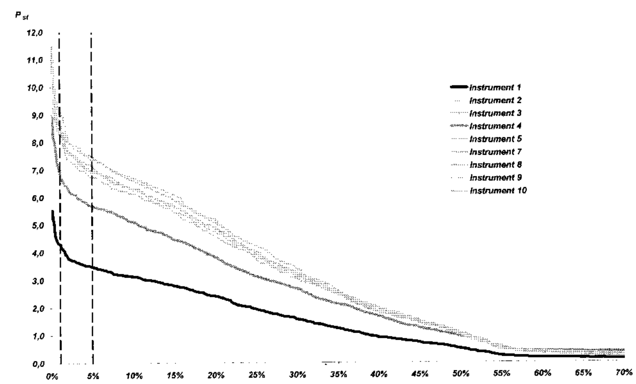


Fig. 10. Cumulative probability curves P_{st}

2.4. Cumulative probability curves

Cumulative probability curves determined from the results obtained during the measurement are shown in Figure 10. Hence the short term flicker severity value not exceeded during 95% (CP95) and 99% (CP99) of the measurement time can be determined.

The plot in Figure 10 shows the P_{st} results obtained in phase L1. CP95 and CP99 values for the other phases are shown in figures 11 and 12. Table 4 contains numerical values of percentiles.

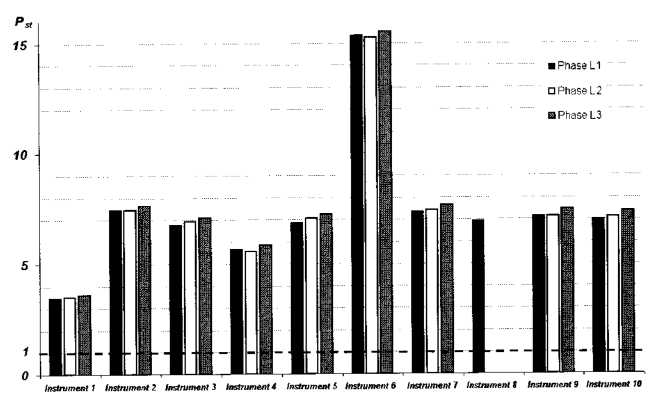


Fig. 11. P_{st} CP95

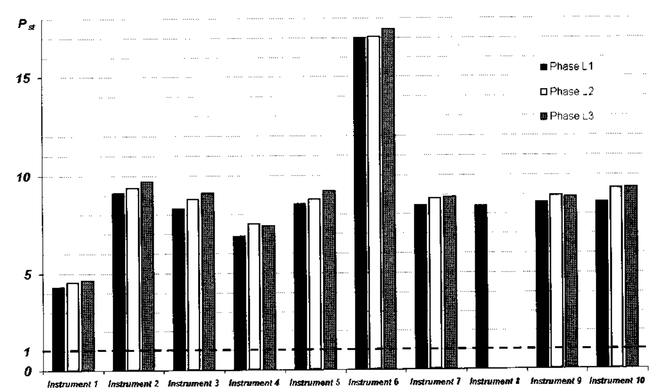


Fig. 12. P_{st} CP99

3. LABORATORY AND SIMULATION TESTS

The UIE/CIGRE WG 2 „Power Quality" is working on the tests for calibration and verification of a flickermeter such as are done in type testing [11]. In order to understand how a given flickermeter responds to voltage fluctuations, each test is conducted to assess a particular aspect of the flickermeter. The full suite of tests may be required when a new product is placed on the market and in case of a dispute between two parties on a measurement result.

This part of the paper is intended to apply a set of tests, proposed by UIE WG 2 to ensure that implementation is cor-

Table 4. Short term flicker severity value not exceeded during 95% (CP95) and 99% (CP99) of the measurement time

Instrument No	Phase L_1		Phase L_2		Phase L_3	
	CP95	CP99	CP95	CP99	CP95	CP99
1	3.48	4.31	3.52	4.52	3.61	4.63
2	7.47	9.12	7.46	9.36	7.64	9.70
3	6.75	8.31	6.91	8.79	7.08	9.08
4	5.70	6.91	5.58	7.50	5.83	7.42
5	6.87	8.55	7.06	8.76	7.23	9.20
6[1]	15.38	16.99	15.25	17.02	15.51	17.44
7	7.37	8.46	7.42	8.79	7.62	8.86
8[2]	6.92	8.42	—	—	—	—
9	7.15	8.62	7.11	8.90	7.44	8.86
10	7.00	8.63	7.09	9.27	7.36	9.32

1 Instrument (6) has been measuring for 69.35% of the measurement time of other instruments, hence the value 699 has been taken as 100% of the measurement duration (for other instruments1008)

2 Instrument (8) has been measuring P_{st} only in phase L_1

rect and different meters will agree with all types of actual measurements. Measurement performance is assessed by the flickermeter P_{st} output.

Because of the limitations of instruments used during the investigation not every test has been performed in accordance with the original UIE/CIGRE proposition. The other tests, as being unrealizable, were performed for the flickermeter model developed in MATLAB – SIMULINK environment [10]. The results obtained from simulation are denoted with the abbreviation MOD.

Tests have been performed using ten instruments listed in Table 1 – from 1 to 10. During the tests the instruments readings have been taken in the second subsequent measuring intervals.

3.1. Preliminary test

A fundamental issue concerning laboratory tests of the flickermeter is the method of modulation of the input voltages are used for calibration of the instrument. In the authors opinion the description given in the standard IEC 61000-4-15: 1997 is ambiguous and instances of its erroneous interpretation have occurred.

Instrument testing has been performed applying a series of square-wave (or sinusoidal) voltage changes. The modulated voltage was of rms value U_{RMS}=230[V] and frequency f=50[Hz], it could be described by the relationship: $u(t) = U_{RMS} \sqrt{2} \sin(\omega t)$.

Voltage changes are defined in the standard by means of two parameters: *the number of changes per minute,* further denoted as l_z, and *the voltage change* $\frac{\Delta V}{V}$ (%). The voltage changes defined this way have not described uniquely the modulating signal. Different interpretations of the standard text are resulting from two reasons.

Firstly it is not uniquely defined that *the number of changes per minute* shall be interpreted as the number of all changes of the voltage, or as the number of cycles of the modulating signal during one minute.

Secondly it is not uniquely defined which way the voltage changes have to oscillate around the nominal rms value (50 [Hz]) of the carrier signal.

The test had to demonstrate the way the standard requirement have been interpreted by the manufacturers of the instruments used in the test.

Test have been carried out for the measuring point, specified in Table 5 of the standard, and defined by the coordinates: $L_z = 10$ and $\frac{\Delta V}{V} = 0.725$ (%) (Table 5).

Technical specifications of generator used in the tests are comprised in the ANNEX. In measurements 1 and 3 the modulation depths have been defined identically. These measurements differ in the way the modulating signal frequency has been defined. In measurements 1 and 2 modulation frequency is twice the modulation frequency in the other measurements. Method of the input voltage modulation in measurements 1, 3 and 5 is defined in a manner different from that in measurements 2 and 4 (Table 5). The test has been performed for instruments 1 to 5 (Table 1).

Test results

Results obtained by measurements 1 to 5 are listed in Table 6.

Conclusions

From results of the measurements it could be established that manufactures of flickermeters have interpreted recommendations of IEC 61000-4-15 standard in various ways. As seen from Table 6 for each instrument employed in the experiment there could be found a method of modulation, which ensures meeting the $P_{st} = 1 \pm 5\%$ requirement. In result of the measurement 5 $P_{st} = 1 \pm 5\%$ has been obtained only for the instrument Arbiter 1133A. Other instruments readings were almost double that value. Considered that 3 of 5 instruments, used in the experiment show results very close to each other, in all further test has been applied the method of modulation as in the measurement 3.

If not otherwise indicated, in all test the modulated signal was the voltage of rms value U_{RMS} = 230 [V] and frequency f=50 [Hz].

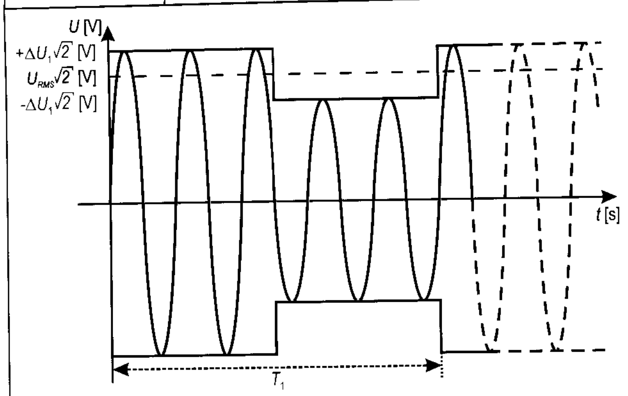
Test 1: According to standard IEC 61000-4-15, table V

The flickermeters were subject to 6-point tests, according to the recommendations of standard IEC 61000-4-15, Table V. A sinusoidal voltage, modulated with square-wave signal, has been applied to the instrument input, as shown in Figure 13. Points in Table 7 correspond to the values of modulation frequency and depth of modulation for the subsequent, ten-minutes measuring intervals.

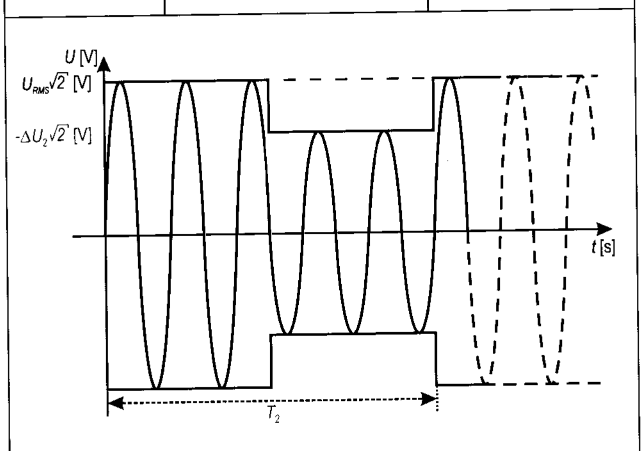
Test result is considered positive if values of short term flicker severity, obtained at the instrument output for the modulating signal parameters listed in Table 7, are contained in the interval $P_{st} = 1 \pm 5\%$.

Table 5. Specification of input voltage modulations applied to the flickermeter

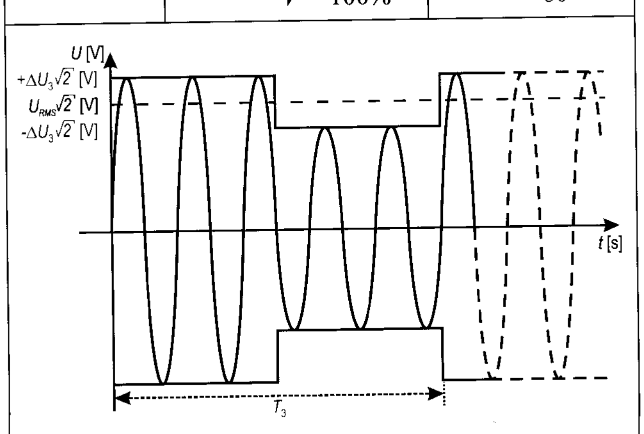
Test No.	Amplitude of the modulating signal	Frequency of the modulating signal
Measurement 1	$\Delta U_1 = \frac{\Delta V}{V} \cdot \frac{U_{RMS}}{100\%}$	$f_1 = \frac{l_z}{60}$



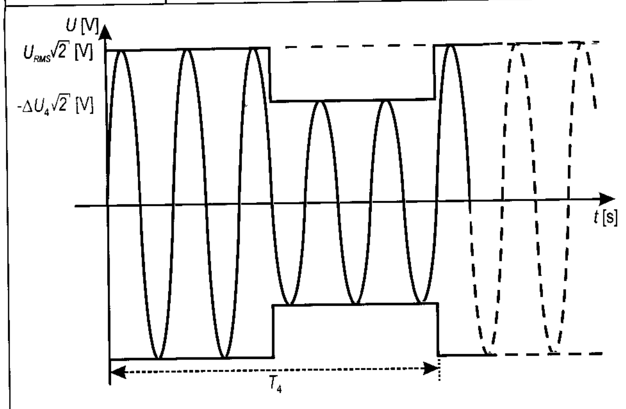
Test No.	Amplitude of the modulating signal	Frequency of the modulating signal
Measurement 2	$\Delta U_2 = \frac{\Delta V}{V} \cdot \frac{U_{RMS}}{100\%}$	$f_2 = \frac{l_z}{60}$



Test No.	Amplitude of the modulating signal	Frequency of the modulating signal
Measurement 3	$\Delta U_3 = \frac{\Delta V}{V} \cdot \frac{U_{RMS}}{100\%}$	$f_1 = \frac{l_z}{60}$



Test No.	Amplitude of the modulating signal	Frequency of the modulating signal
Measurement 4	$\Delta U_4 = \frac{\Delta V}{V} \cdot \frac{U_{RMS}}{100\%}$	$f_2 = \frac{l_z}{60}$



Test No.	Amplitude of the modulating signal	Frequency of the modulating signal
Measurement 5	$\Delta U_5 = \frac{\Delta V}{V} \cdot \frac{U_{RMS}}{100\%}$	$f_3 = \frac{1}{2} \cdot \frac{l_z}{60}$

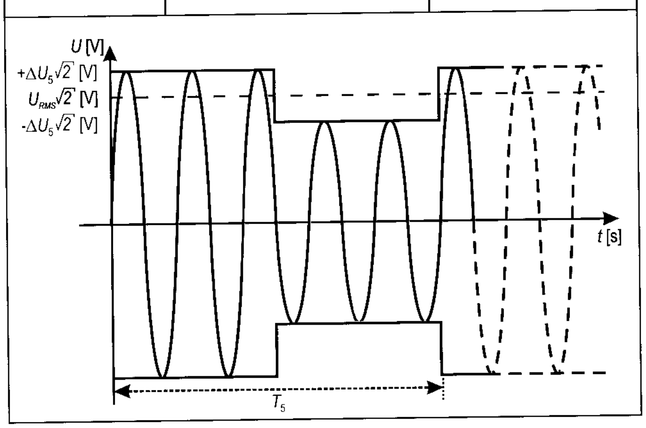


Table 6. Results of preliminary tests

No.	Arbiter 1133A	ION 7600	Memobox 800Q	Power Recorder	Topas 1000
Meas. 1.	0.63	1.25	1.23	1.0	1.23
Meas. 2.	0.62	1.26	1.24	1.0	1.24
Meas. 3.	0.51	1.02	1.02	0.85	1.02
Meas. 4.	0.52	1.02	1.02	0.85	1.02
Meas. 5.	1.0	1.98	1.99	1.64	1.98

Test results

Results of P_{st} obtained at the tested instruments output are shown in table 8.

Conclusions

It could be established from results obtained in test 1 that instruments (2), (3) and (5) comply with requirements of the standard, whereas the instruments (1), (4), (6) failed to meet the standard requirements.

Table 7. Parameters of modulating waveform (test 1)

No. (i)	Changes/ Minute IEC 61000-4-15	Modulation frequency f_{mi} [Hz]	$\Delta V/V$ [%] P_{st}=1 IEC 61000-4-15	Voltage changes ΔU_i [V]
1	1	0.0083	2.72	3.128
2	2	0.0167	2.21	2.542
3	7	0.0583	1.46	1.679
4	39	0.325	0.905	1.041
5	110	0.917	0.725	0.834
6	1620	13.5	0.402	0.462

Readings of instrument (l) are close to $P_{st} = 0.5$. This is in compliance with results in the measurement 5 of the preliminary test. It should also be noted that readings the instrumenent (6) exceeded the permissible range only in the last point of the test.

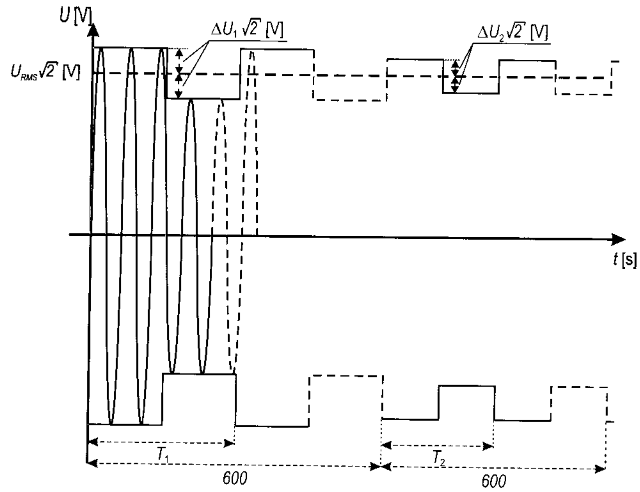


Fig. 13. Sinusoidal voltage modulated with square-wave signal (test 1)

Test 2: Voltage dips and swells in the measured signal

An unmodulated sinusoidal voltage has been applied to the instrument input. During a measuring interval of ten minutes voltage changes, described in Table 9, occurred after 1, 3, 5, 7 and 9 minutes (Fig. 14). The change in voltage rms value is not synchronized with respect to the zero crossing of the voltage waveform.

The aim of the test is a comparison of instruments readings in case of occurrence of the foregoing disturbances.

Test results

Values of a flicker severity P_{st} obtained at the tested instruments output are shown in Table 10.

The model has been assessed for 200 and 400 classes in Block 5 (Statistical analysis) to check the influence of number of classes on the obtained results. Increasing the number of classes, that is increasing the accuracy of P_{st} estimation, results in lower P_{st} value.

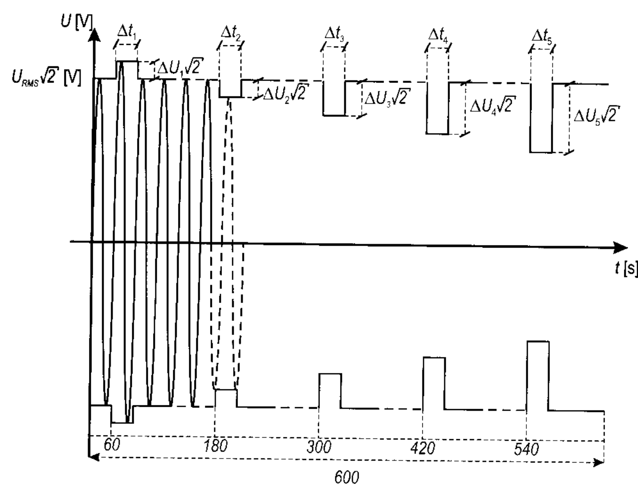


Fig. 14. Graphical representation of voltage changes shown in Table 10 (test 2)

Table 8. Results of P_{st} obtained at the instruments in test 1

	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6
Instrument 1	0.50	0.51	0.51	0.50	0.51	0,52
Instrument 2	**1.03**	**1.03**	**1.05**	**0.98**	**1.02**	**1.03**
Instrument 3	**1.03**	**1.04**	**1.03**	**0.98**	**1.02**	**1.05**
Instrument 4	0.83	0.86	0.85	0.78	0.85	0.72
Instrument 5	**1.01**	**1.02**	**1.03**	**0.99**	**1.02**	**1.03**
Instrument 6	**1.00**	**1.05**	**0.99**	**0.99**	**1.02**	1.06
Instrument 7	**1.01**	**1.02**	**1.04**	**1.01**	**1.04**	**1.04**
Instrument 8	**1.02**	**1.03**	**1.02**	**1.00**	**1.02**	**1.03**
Instrument 9	**1.03**	**1.03**	**1.05**	**1.03**	**1.05**	**1.03**
Instrument 10	**0.95**	**0.95**	**0.98**	**1.01**	**0.99**	**1.05**
MOD	**1.0112**	**1.0067**	**1.0096**	**1.0107**	**1.0017**	**0.9845**

Table 9. Parameters of modulating Waveform (test 2)

No. (i)	Time of occurrence from the start of the interval [s]	Voltage magnitude $U_{RMS} \pm \Delta U_i$ [V]	Duration of disturbance Δt_i [ms]
1	60	264.5	200
2	180	195.5	200
3	300	115.0	200
4	420	69.0	200
5	540	23.0	600

Table 10. Values of flicker severity P_{st} in test 2

	P_{st}
Instrument 1	7.58
Instrument 2	24.85
Instrument 3	3.78
Instrument 4	18.19
Instrument 5	15.19
Instrument 6	5.01
Instrument 7	3.06
Instrument 8	15.66
Instrument 9	15.22
Instrument 10	14.91
MOD – 200 classes	16.426
MOD – 400 classes	15.675

Conclusions

P_{st} values obtained after ten minutes significantly exceed the value P_{st} = 1 and show considerable discrepancy. It can be only concluded that results obtained from instruments (5), (8), (9) and (10) are close to each other and fluctuate around the value P_{st} = 15.

Test 3: Instrument linearity for square-wave modulation

The aim of the test was to find a range of P_{st} changes within which a linear relationship between instrument readings and the depth of modulation, for square-wave voltage changes, holds true. The modulating waveform amplitude was contained within range 1% to 20% of the modulated waveform magnitude for two different frequencies. Test result is considered positive if the final results of measurement (converted by means of the instrument static gain factor) are contained within $P_{st} = 1 \pm 5\%$ range.

(A) Input signal is modulated by a square-wave signal (Fig. 15) of a frequency value f_m = 0.917 [Hz], constant in all time intervals, which corresponds to the number of changes per minute l_z = 110, according to the test 3 (Table 5). Percentage value of modulation amplitude corresponding to the number of modulating waveform changes per minute l_z = 110, for which the short term flicker severity should assume value $P_{st} = 1 \pm 5\%$, equals $\frac{\Delta V}{V} = 0.725$ [%]. Absolute value of the modulation amplitude with respect to the nominal voltage magnitude U_N = 230 [V] is ΔU = 0.834 [V]. Amplitude of the modulating waveform, for each subsequent ten-minute measurement is determined from relation (1):

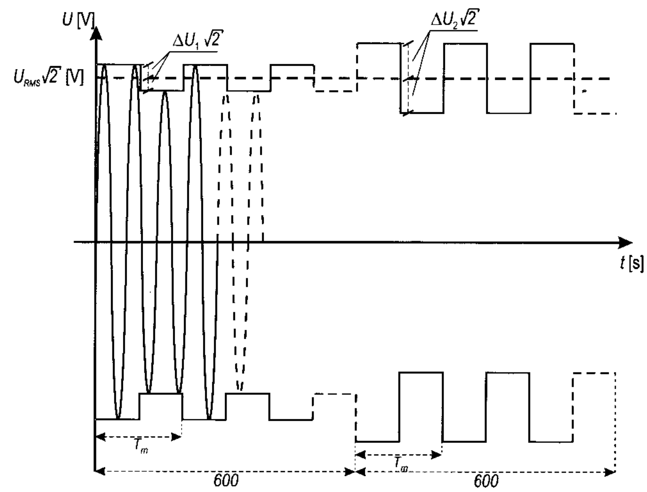


Fig. 15. Sinusoidal waveform modulated by a square-wave signal (test 3)

$$\Delta U_i = k_i \, \Delta U \text{ for } k_i \in [1; 10; 20], \; i = 1,2,3 \qquad (1)$$

Amplitude of the modulating waveform for each subsequent ten-minute measurement equals:

— first ten-minute measurement $\Delta U_1 = 0.834$ [V]
— second ten-minute measurement $\Delta U_2 = 8.338$ [V]
— third ten-minute measurement $\Delta U_3 = 16.675$ [V]

(B) Input signal is modulated by a square-wave signal (Fig. 15) of frequency equal f_m = 13.5 [Hz], constant in all time intervals, which corresponds to the number of changes per minute l_z = 1620, according to the test 3 (Table 5). Percentage value of modulation amplitude corresponding to the number of modulating waveform changes per minute l_z = 1620, for which the short term flicker severity should assume value $P_{st} = 1 \pm 5\%$, equals $\frac{\Delta V}{V} = 0.402$ [%].

Absolute value of the modulation amplitude with respect to the nominal voltage magnitude U_N = 230 [V] is ΔU = 0.462 [V]. Amplitude of the modulating waveform, for each subsequent ten-minute measurement is determined from relation (2).

$$\Delta U_i = k_i \, \Delta U \text{ for } k_i \in [0{,}2; 1; 2; 5; 10; 20], \; i = 1,2,3,4,5,6 \quad (2)$$

and equals:

— first ten-minute measurement $\Delta U_1 = 0.092$ [V]
— second ten-minute measurement $\Delta U_2 = 0.462$ [V]
— third ten-minute measurement $\Delta U_3 = 0.925$ [V]
— fourth ten-minute measurement $\Delta U_4 = 2.312$ [V]
— fifth ten-minute measurement $\Delta U_5 = 4.623$ [V]
— sixth ten-minute measurement $\Delta U_6 = 9.246$ [V]

Table 11. Values of flicker severity P_{st} obtained at the instrument output (Variant 3A)

	P_{st1}	P_{st10}	P_{st20}
Instrument 1	0.51	4,98	9,95
Instrument 2	1.02	10.47	19.78
Instrument 3	1.02	9.18	17.11
Instrument 4	0.85	8.20	16.45
Instrument 5	1.01	9.85	19.68
Instrument 6	1.02	7.66	7.67
Instrument 7	1.04	9.14	9.46
Instrument 8	1.02	9.93	19.97
Instrument 9	1.05	10.20	20.51
Instrument 10	0.99	8.57	18.69

Table 12. Values of flicker severity P_{st} with factors k_i taken into account (Variant 3A)

	$P_{st1}/1$	$P_{st10}/10$	$P_{st20}/20$
Instrument 1	0.51	0.50	0.50
Instrument 2	**1.02**	**1.05**	**0.99**
Instrument 3	**1.02**	0.92	0.86
Instrument 4	0.85	0.82	0.82
Instrument 5	**1.01**	**1.01**	**0.98**
Instrument 6	**1.02**	0.77	0.38
Instrument 7	**1.04**	0.91	0.47
Instrument 8	**1.02**	**0.99**	**1.00**
Instrument 9	**1.05**	**1.02**	**1.03**
Instrument 10	**0.99**	0.86	0.93

Table 13. Values of flicker severity P_{st} obtained at the instrument output (Variant 3B)

	$P_{st0.2}$	P_{st1}	P_{st2}	P_{st5}	P_{st10}	P_{st20}
Instrument 1	0.11	0.51	1.14	2.28	5.65	15.21
Instrument 2	0.24	1.03	2.28	5.52	12.06	22.32
Instrument 3	0.18	1.05	2.23	5.46	11.46	22.12
Instrument 4	0.15	0.72	1.62	3.67	7.58	15.21
Instrument 5	0.21	1.03	2.26	5.54	11.10	22.21
Instrument 6	0.11	1.06	2.38	5.81	7.67	7.67
Instrument 7	0.21	1.04	2.31	5.67	9.70	9.70
Instrument 8	0.23	1.03	2.26	5.53	11.08	22.19
Instrument 9	0.21	1.03	2.27	5.55	11.15	22.29
Instrument 10	0.21	1.05	2.28	5.49	10.62	22.02

Test results

Values of short term flicker severity in test 3A are included in Table 11.

In order to obtain data on linearity of the tested instruments characteristics, the results contained in Table 11 have been divided by relevant factors A; given by relation (1). Results of these calculations are contained in Table 12.

Values of short term flicker severity in test 3B are included in Table 13.

In order to obtain comparative data on linearity of the tested instruments characteristics, the results contained in Table 13 have been divided by relevant factors k_i given by relation (2). Results of these calculations are contained in Table 14.

Table 14. Values of flicker severity P_{st} with factors k_i taken into account (Variant 3B)

	$P_{st0,2}/0.2$	$P_{st1}/1$	$P_{st2}/2$	$P_{st5}/5$	$P_{st10}/10$	$P_{st20}/20$
Instrument 1	0.56	0.51	0.57	0.56	0.56	0.76
Instrument 2	1.18	**1.03**	1.14	1.10	1.21	1.12
Instrument 3	0.90	**1.05**	1.12	1.09	1.15	1.11
Instrument 4	0.75	0.72	0.81	0.73	0.76	0.76
Instrument 5	**1.05**	**1.03**	1.13	1.11	1.11	1.11
Instrument 6	0.55	1.06	1.19	1.16	0.77	0.38
Instrument 7	**1.05**	**1.04**	1.16	1.13	0.97	0.49
Instrument 8	1.15	**1.03**	1.13	1.11	1.11	1.11
Instrument 9	1.05	**1.03**	1.14	1.11	1.12	1.11
Instrument 10	**1.05**	**1.05**	1.14	1.10	1.06	1.10

Conclusions

Assuming the test being positive when the condition $P_{st} = 1 \pm 5\%$ (Table 12 i 14) is satisfied, then:

(A) Instruments (2), (5), (8) and (9) have passed the test. Instruments (1) and (4) show linearity, although at different levels than $P_{st} = 1$.

(B) In this part no instrument has passed the test.3

The model of flickermeter shows good linearity in the investigated range of frequency changes and modulation depth. The 5% permissible P_{st} deviation was not exceeded in any point.

Modulating voltage parameters and recorded P_{st} values for the test parts A and B are listed in Table 15. Short term flicker severity P_{st} has been estimated for 200 and 400 classes. The P_{st} values obtained for 400 classes are lower than those for 200 classes.

Test 4: Instrument linearity for sinusoidal waveform modulation

The aim of the test was to find a range of changes, within which the value of instrument linearity dependants on the depth of modulation for sinusoidal voltage changes. The modulating waveform amplitude was contained within range 1% to 20% of the modulated waveform magnitude.

Table 15. Changes of square-wave modulating voltage and measured P_{st} values (test 3) – MOD

Test	Value of k_i	Number of classes	P_{st}	P_{st}/k_i
3A	1	200	1.0031	1.0031
		400	1.0017	1.0017
3A	10	200	10.0146	1.0015
		400	10.0022	1.0002
3A	20	200	19.9544	0.9977
		400	19.9281	0.9964
3B	0.2	200	0.1974	0.9870
		400	0.1971	0.9855
3B	1	200	0.9859	0.9859
		400	0.9845	0.9845
3B	2	200	1.9706	0.9853
		400	1.9681	0.9811
3B	5	200	4.9272	0.9854
		400	4.9217	0.9843
3B	10	200	9.8512	0.9851
		400	9.8390	0.9839
3B	20	200	19.6842	0.9812
		400	19.6584	0.9829

Test result is considered positive if the final results are contained within $P_{st} = 1 \pm 5\%$ range.

(A) Input signal is modulated by a sinusoidal waveform (Fig. 16) of a frequency value f_m = 1 [Hz], constant in all time intervals. Percentage value of modulation amplitude corresponding to this frequency of the modulating waveform has been read from Table 1 in standard IEC 61000-4-15 and equals $\frac{\Delta V}{V}$ =1.432 [%]. Absolute value of the modulation amplitude with respect to the nominal voltage magnitude U_N = 230 [V] is ΔU=3.29[V].
Amplitude of the modulating waveform, for each subsequent ten-minute measurement is determined from relation (1) and equals:

— first ten-minute measurement $\Delta U_1 = 3.294$ [V]
— second ten-minute measurement $\Delta U_2 = 32.936$ [V]
— third ten-minute measurement $\Delta U_3 = 65.872$ [V]

(B) Input signal is modulated by a sinusoidal waveform (Fig. 16) of a frequency value f_m = 8.8 [Hz], constant in all time intervals. Percentage value of modulation amplitude corresponding to this frequency of the modulating waveform has been read from Table 1 in standard IEC 61000-4-15 and equals $\frac{\Delta V}{V}$ = 0.25 [%] . Absolute value of the modulation amplitude with respect to the nominal voltage magnitude U_N = 230 [V] is ΔU= 0.575[V].

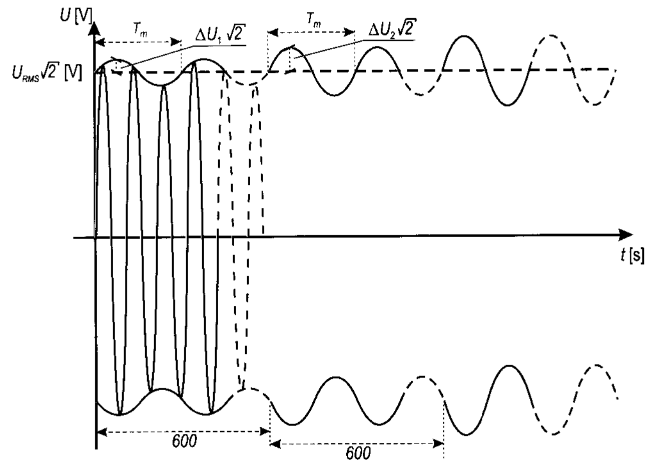


Fig. 16. Sinusoidal waveform modulated by sinusoidal signal (test 4)

Amplitude of the modulating waveform, for each subsequent ten-minute measurement is determined from relation (2) and equals:

— first ten-minute measurement $\Delta U_1 = 0.115$ [V]
— second ten-minute measurement $\Delta U_2 = 0.575$ [V]
— third ten-minute measurement $\Delta U_3 = 1.150$ [V]
— fourth ten-minute measurement $\Delta U_4 = 2.875$ [V]
— fifth ten-minute measurement $\Delta U_5 = 5.750$ [V]
— sixth ten-minute measurement $\Delta U_6 = 11.50$ [V]

Test results

Values of short term flicker severity obtained in test 4A are included in Table 16.

In order to obtain data on linearity of the tested instruments characteristics, the results contained in Table 16 have been divided by relevant factors k_i given by relation (1). Results of these calculations are contained in Table 17.

Results obtained at the output of tested instruments, during test 4B are contained in Table 18.

In order to obtain data on linearity of the tested instruments characteristics, the results contained in Table 18, have been divided by relevant factors k, given by relation (2). Results of these calculations are contained in Table 19.

Table 16. Values of flicker severity P_{st} obtained at the instrument output (Variant 4A)

	P_{st1}	P_{st10}	P_{st20}
Instrument 1	0.50	5.00	9.95
Instrument 2	1.08	11.54	21.73
Instrument 3	1.02	9.95	16.31
Instrument 4	0.87	8354	16.31
Instrument 5	1.00	9.95	19.83
Instrument 6	1.17	7.65	7.65
Instrument 7	1.01	9.70	9.70
Instrument 8	1.01	10.16	20.42
Instrument 9	1.04	10.39	20.87
Instrument 10	1.01	9.99	20.03

Table 17. Values of flicker severity P_{st} with factors k_i taken into account (Variant 4A)

	$P_{st1}/1$	$P_{st10}/10$	$P_{st20}/20$
Instrument 1	0.50	0.50	0.50
Instrument 2	1.08	1.15	1.09
Instrument 3	**1.02**	**0.96**	0.82
Instrument 4	0.87	0.85	0.88
Instrument 5	**1.00**	**0.99**	**0.99**
Instrument 6	1.17	0.77	0.38
Instrument 7	**1.01**	**0.97**	0.49
Instrument 8	**1.01**	**1.02**	**1.02**
Instrument 9	**1.04**	**1.04**	**1.04**
Instrument 10	**1.01**	**1.00**	**1.00**

Table 18. Values of flicker severity P_{st} obtained at the instrument output (Variant 4B)

	$P_{st0.2}$	P_{st1}	P_{st2}	P_{st5}	P_{st10}	P_{st20}
Instrument 1	0.11	0.51	1.00	2.53	5.04	10.11
Instrument 2	0.26	1.03	2.02	5.6	10.40	20.52
Instrument 3	0.19	1.05	2.04	5.03	10.46	20.37
Instrument 4	0.24	0.82	1.60	4.00	7.98	15.97
Instrument 5	0.23	1.01	1.98	5.00	9.98	20.00
Instrument 6	0.11	1.12	2.2	5.45	7.65	7.65
Instrument 7	0.23	1.04	2.04	5.15	9.7	9.7
Instrument 8	0.20	1.02	1.99	5.02	10.01	20.06
Instrument 9	0.24	1.02	2.01	5.08	10.29	20.29
Instrument 10	0.24	1.03	2.05	5.12	10.20	20.34

Table 19. Values of flicker severity P_{st} with factors k_i taken into account (Variant 4B)

	$P_{st0,2}$ /0.2	P_{st1} /1	P_{st2} /2	P_{st5} /5	P_{st10} /10	P_{st20} /20
Instrument 1	0.56	0.51	0.50	0.51	0.50	0.51
Instrument 2	1.28	**1.03**	**1.01**	**1.01**	**1.04**	**1.03**
Instrument 3	**0.95**	**1.05**	**1.02**	**1.01**	**1.05**	**1.02**
Instrument 4	1.20	0.82	0.80	0.80	0.80	0.80
Instrument 5	1.15	**1.01**	**0.99**	**1.00**	**1.00**	**1.00**
Instrument 6	0.55	1.12	1.10	1.09	0.77	0.38
Instrument 7	**1.05**	**1.04**	**1.02**	**1.03**	**0.97**	0.49
Instrument 8	**1.00**	**1.02**	**1.00**	**1.00**	**1.00**	**1.00**
Instrument 9	1.20	**1.02**	**1.01**	**1.02**	**1.03**	**1.01**
Instrument 10	1.20	**1.03**	**1.03**	**1.02**	**1.03**	**1.02**

Conclusions

Assuming the condition $P_{st} = 1 \pm 5\%$ (Tables 17 i 19) as a criterion of the instrument readings correctness:

1. Instrument (5), (8), (9) and (10) has passed the test. Instruments (1) and (4) show linearity, although at different levels than $P_{st} = 1$.
2. Only instrument (3) and (8) have passed the test. Instruments denoted with numbers (2), (5), (7), (9) and (10) yielded incorrect reading only in one point. The instrument (1) maintains its linearity, however at the level of $P_{st} = 0.5$.

The model of flickermeter shows good linearity in the investigated range of frequency changes and modulation depth. The 5% permissible P_{st} deviation was not exceeded at any point.

Modulating voltage parameters and recorded P_{st} values for the test parts A and B are listed in Table 20. Short term flicker severity P_{st} has been estimated for 200 and 400 classes. The P_{st} values obtained for 400 classes are lower than those for 200 classes.

Table 20. Changes of sinewave modulating voltage and measured P_{st} values (test 4) — MOD

Test	Value of k_i	Number of classes	P_{st}	P_{st}/k_i
4A	1	200	1.0126	1.0126
		400	1.0109	1.0109
4A	10	200	10.0996	1.0100
		400	10.0846	1.0085
4A	20	200	19.9931	0.9997
		400	19.9643	0.9982
4B	0.2	200	0.2013	1.0065
		400	0.2010	1.0050
4B	1	200	1.0051	1.0051
		400	1.0040	1.0040
4B	2	200	2.0100	1.0050
		400	2.0079	1.0039
4B	5	200	5.0247	1.0049
		400	5.0195	1.0039
4B	10	200	10.0483	1.0048
		400	10.0380	1.0038
4B	20	200	20.0883	1.0044
		400	20.0666	1.0033

Test 5: Phase jump test

Unmodulated signal is applied to instrument input. During a ten-minute measuring interval, after elapse of 1, 3, 5, 7 and 9 minutes a step change in phase took place, according to the data from Table 21.

The aim of the test is comparison of instruments readings under this type of disturbance.

Above values refer to the phase at the beginning of the measuring interval. Figure 17 shows an illustrative change of the voltage waveform. As seen from Figure 17, the instant of

Table 21. Specification of the input voltage phase changes (test 5)

Test variant	Time of the phase jump occurrence				
	1st minute	3rd minute	5th minute	7th minute	9th minute
5.1.	90[°]	0[°]	90[°]	0[°]	90[°]
5.2.	-35[°]	35[°]	-35[°]	35[°]	-35[°]
5.3.	5[°]	10[°]	15[°]	20[°]	25[°]
5.4.	20[°]	40[°]	60[°]	80[°]	100[°]

Table 22. Values of short term flicker severity P_{st} obtained in test 5

	5.1.	5.2.	5.3.	5.4.
Instrument 1	0.57	**0.97**	0.10	0.30
Instrument 2	3.37	2.76	0.21	**1.02**
Instrument 3	0.91	1.93	0.20	0.60
Instrument 4	0.44	1.71	0.26	0.73
Instrument 5	0.83	1.86	0.15	0.59
Instrument 6	0.58	1.71	0.16	0.47
Instrument 7	2.25	2.00	0.16	0.64
Instrument 8	1.18	2.02	0.16	0.47
Instrument 9	1.16	1.99	0.14	0.52
Instrument 10	0.77	1.90	0.17	0.63

Table 23. Phase jump tests and determined values of P_{st} (test 5) – MOD

Change in phase after 1; 3; 5; 7; 9 minute [°]	Number of classes	P_{st}
90; 0; 90; 0; 90	200	0.2956
	400	0.2845
-35; 35; -35; 35; -35	200	2.0433
	400	1.9583
5; 10; 15; 20; 25;	200	0.1788
	400	0.1705
20; 40; 60; 80; 100	200	0.6379
	400	0.6027

the voltage phase change does not agree with the waveform zero crossing.

Test results

Values of the flicker severity P_{st} are read out from Table 22 for each variant. Results obtained at the output of tested instru-ments are contained in Table 22 and 23 (MOD).

Conclusions

From results obtained m the test it could be established only that significant step changes in phase are resulting in large value of P_{st}. In addition, we can observe a significant discrepancy of measurements of all instruments for the same input signal.

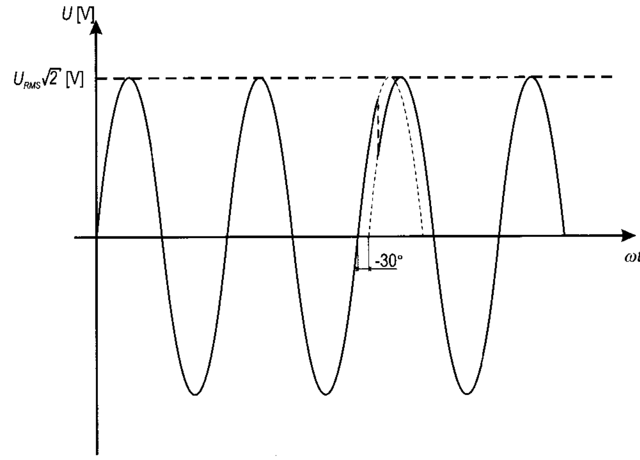


Fig. 17. Change of phase of the input voltage waveform (test 5)

Test 6: Flickermeter response to the change of input voltage frequency

In this test the response of instrument to changes in the input voltage frequency, contained in a given range of variation, is checked. Input voltage is modulated by a waveform, which under normal conditions (no changes in supply voltage frequency) gives result P_{st} = 1. The input voltage signal (50 Hz) is modulated by a square-wave signal of frequency f_m = 13.5 [Hz] and modulation depth ΔU = 0.4623 [V],

The test has been performed for five, ten-minute time-intervals. Frequency of the input voltage signal was constant during each measuring interval and equaled:

— first ten-minute measurement f_1 = 49 [Hz]
— second ten-minute measurement f_2 = 49.5 [Hz]
— third ten-minute measurement f_3 = 50 [Hz]
— fourth ten-minute measurement f_4 = 50.5 [Hz]
— fifth ten-minute measurement f_5 = 51 [Hz]

P_{st} values obtained at the instrument output have been read-out for each ten-minute measuring interval.

Test results

Results of flicker severity P_{st} measurements are contained in Table 24.

Table 24. Results of flicker severity P_{st} for different frequencies of the input voltage signal (test 6)

	f_1	f_2	f_3	f_4	f_5	f_1
Instrument 1	0.53	0.52	0.51	0.51	0.50	0.53
Instrument 2	**1.02**	1.06	**1.03**	**1.03**	**1.04**	**1.02**
Instrument 3	**1.05**	**1.05**	**1.05**	**1.04**	**1.01**	**1.05**
Instrument 4	0.87	0.86	0.72	0.65	0.65	0.87
Instrument 5	**1.01**	**1.02**	**1.03**	**1.03**	**1.02**	**1.01**
Instrument 6	1.15	1.07	1.06	1.06	1.06	1.15
Instrument 7	1.06	**1.05**	**1.04**	**1.02**	**1.02**	1.06
Instrument 8	**1.05**	1.10	**1.03**	**1.02**	**1.01**	**1.05**
Instrument 9	**1.03**	**1.03**	**1.03**	**1.03**	**1.04**	**1.03**
Instrument 10	1.07	**1.04**	**1.05**	**1.05**	1.07	1.07

Table 25. Frequency of modulated signal and measured P_{st} values; (test 6) – MOD

Frequency [Hz]	Number of classes	P_{st}
49	200	0.9859
	400	0.9845
49.5	200	0.9845
	400	0.9832
50	200	0.9859
	400	0.9845
50.5	200	0.9876
	400	0.9862
51	200	0.9889
	400	0.9877

Conclusions

Assuming the condition $P_{st} = 1 \pm 5\%$ as a criterion of the instrument adequate operation, instruments (3), (5) and (9) have passed the test. Instrument (2), (7) and (8) failed the test only in a single measuring point.

In the case of model simulation the input voltage was modulated by a square-wave signal with frequency $f_m = 13.5$Hz and relative modulation amplitude $\Delta U/U = 0.402$[%]. Recorded P_{st} values are listed in Table 25.

As follows from the test, the change in the modulated signal frequency does not decrease the accuracy beyond $P_{st}=1 \pm 5\%$.

Test 7: Flickermeter response to modulation by sinusoidal waveform

Input voltage signal (50 Hz) is modulated by a sinusoidal waveform. Frequency of the modulating signal is changed after each ten-minute measuring interval (Fig. 18).

Modulating signal frequency is changed in 0.5 [Hz] steps within the frequency change range from 0.5 to 25 [Hz] for each subsequent ten-minute interval. In this part of the test amplitude of the modulating signal equals 2.30 [V].

In frequency change range from 26 to 50 [Hz] the modulating signal frequency is changed in 1 [Hz] steps for each subsequent ten-minute interval. In this case amplitude of the modulating signal equals 2.30 [V].

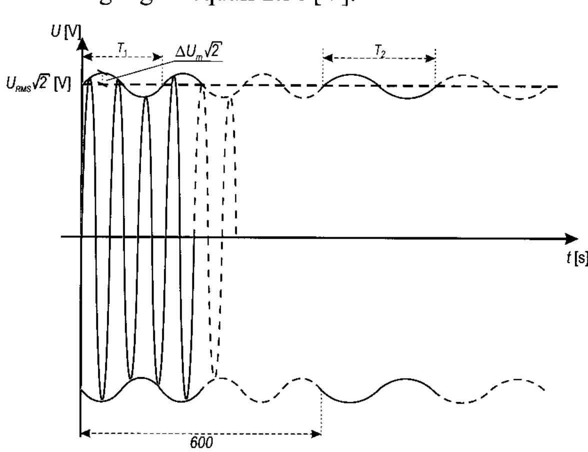


Fig. 18. Changes of the modulating signal frequency for ΔU = comst (test 7)

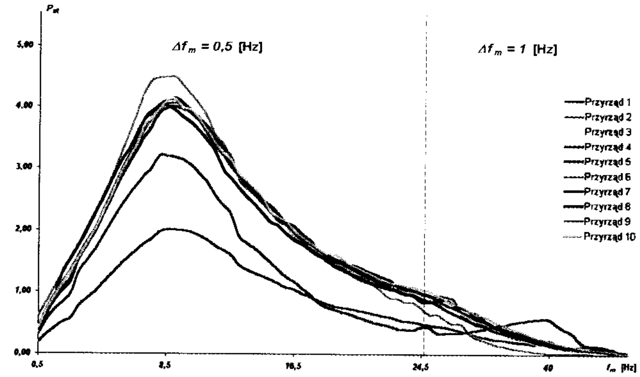


Fig. 19. Sinusoidal waveform modulated by sinusoidal signal (test 4)

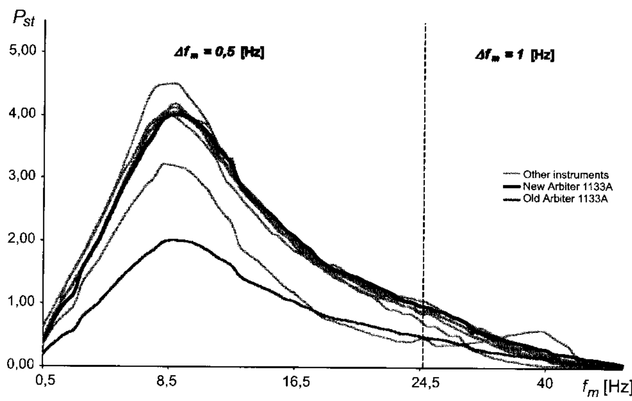


Fig. 20. The graph of P_{st} value as a function of the modulating sinusoidal signal frequency (test 7) for the new wersion of ARBITER

Test results

Results of P_{st} obtained at the tested instruments output, for each ten-minute measurement are shown in Figure 19.

Conclusions

As a result of the test 7 all tested instruments give maximal values of the short term flicker severity in the vicinity of the modulating signal frequency 8.8 [Hz]. This result is consistent with expectations. It can also be noted that characteristics of instruments (2), (3) and (5), (7) – (10) agree in the entire range of frequency changes, while characteristic of instrument (1) gives two times smaller values. An increase of the flicker severity value, recorded in case of instrument (4) for frequency about f_m = 40 [Hz] should be taken under consideration.

Figure 20 shows results of measurement of the frequency characteristic for a new version of the instrument ARBITER 1133A (serial No. 00040). The shape of the characteristic is correct, what proves an adequate operation of the instrument.

During the model simulation the relative modulation amplitude was $\Delta U/U$=1[%| over the whole range of frequency changes. Obtained P_{st} values are plotted versus frequency in Figure 21. The graph represents the amplitude-frequency characteristics of weighting filter. This fact confirms, that the instrument is "weighting" the signal in accordance with the filter characteristic.

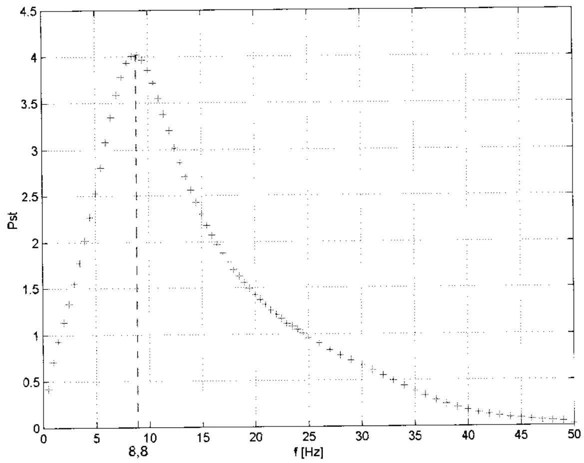


Fig. 21. The graph of P_{st} value as a function of the modulating sinusoidal signal frequency (test 7) – MOD

Test 8: The effect of a single interharmonic

Two signals have been applied to the model input for ten-minute period of time:

1. the first one is unmodulated sinusoidal signal with fundamental frequency 50 [Hz] – $u_{50}(t)$,
2. the second signal is the sinusoidal interharmonic waveform $u_{inth}(t)$ with frequency:
   (a) 20 [Hz] or,
   (b) 40 [Hz] or,
   (c) 60 [Hz] or,
   (d) 80 [Hz].

In result of summation the input signal is $u(t) = u_{50}(t) + u_{inth}(t)$. The interharmonic rms value U_{rmsh} was respectively: 1, 2.5 and 5 [%] of the 50 Hz rms voltage value (U_{rms}) for three subsequent, 10-minute measurement periods. Figure 22 presents an example the input signal; obtained results are given in Table 26.

Results of the test on the influence of a single interharmonic allow concluding that the instrument model exhibits symmetry with respect to 50 [Hz] frequency, and it remains linear, for a selected interharmonic frequency, with the increase of the interharmonic input signal rms value. It should also be noted that high P_{st} values was obtained for interharmonic frequencies 40 [Hz] and 60 [Hz], whereas for interharmonic frequencies 20 [Hz] and 80 [Hz] they were much lower.

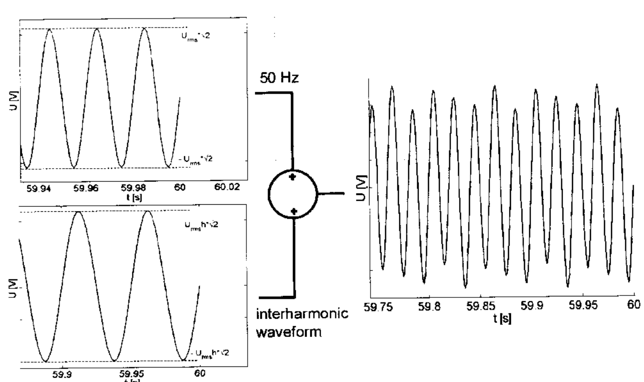


Fig. 22. The input signal for test 8 – MOD

Table 26. The P_{st} values for a single interharmonic input (test 8) – MOD

Interharmonic frequency [Hz]	Number of classes	P_{st} for 1 [%]	P_{st} for 2.5 [%]	P_{st} for 5 [%]
20	200	0.9248	2.3210	4.6136
	400	0.9240	2.3184	4.6689
40	200	5.4465	13.6063	27.1638
	400	5.4365	13.5819	27.1152
60	200	5.4465	13.6062	27.1639
	400	5.4365	13.5819	27.1153
80	200	0.9248	2.3214	4.6137
	400	0.9240	2.3183	4.6080

Test 9: The effect of two interharmonics

Three signals have been applied to the model input in a ten-minute period of time:

1. the first one is unmodulated sinusoidal signal with fundamental frequency 50 [Hz] – $u_{50}(t)$,
2. the next two signals are sinusoidal interharmonic waveforms $u_{inth1}(t)$ and $u_{inth2}(t)$ with respective frequencies:
   (a) 150 [Hz] and 160 [Hz] or,
   (b) 250 [Hz] and 260 [Hz] or,
   (c) 350 [Hz] and 360 [Hz] or,
   (d) 550 [Hz] and 560 [Hz] or,
   (e) 550 [Hz], and 660 [Hz].

In result of summation the input signal is $u(t) = u_{50}(t) + u_{inth1}(t) + u_{inth2}(t)$. The interharmonic waveforms rms values were respectively: 1, 2.5 and 5[%] of the 50 [Hz] rms voltage value (U_{rms}) for three subsequent 10-minute measurement periods. Figure 23 presents an example of input signal; obtained results are given in Table 27.

The P_{st} values obtained in this test are similar for three pairs of interharmonics, i.e. for 150 [Hz] and 160 [Hz], 250 [Hz] and 260 [Hz], 350 [Hz] and 360 [Hz]. For a chosen pair of

Table 27. The P_{st} values for the two interharmonics input

Interharmonic frequency [Hz]	Number of classes	P_{st} for 1 [%]	P_{st} for 2.5 [%]	P_{st} for 5 [%]
150 and 160	200	0.0554	0.3396	1.3556
	400	0.0553	0.3391	1.3531
250 and 260	200	0.0540	0.3364	1.3528
	400	0.0540	0.3359	1.3504
350 and 360	200	0.0471	0.3275	1.3418
	400	0.0471	0.3299	1.3399
550 and 560	200	0.2208	0.3903	1.5073
	400	0.2178	0.3900	1.5048
550 and 660	200	0.2739	0.3785	0.4150
	400	0.2714	0.3743	0.4077

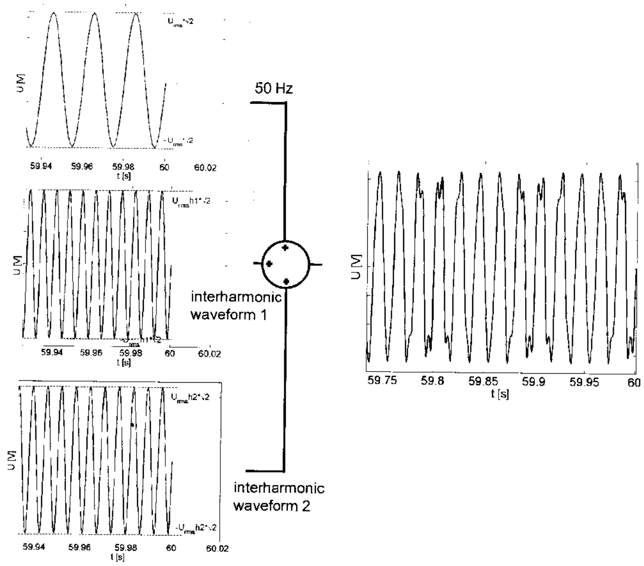


Fig. 23. The input signal for test 9 – MOD

interharmonic waveforms the model does not maintain linearity with the increase in rms value of the interharmonic input signal.

5. CONCLUSION

All instruments used in the experiment and tests comply with requirements of IEC 61000-4-15 standard [5], according to the designers' and manufactures' statements. Nevertheless, readings of the instruments, connected at the same measurement point, and measuring the same voltage signal, are significantly different. Taking into account the experience from laboratory tests it can be once again established, that the standard requirements are not enough precisely formulated, leaving designers too much freedom in the flickermeter design solutions.

A particular attention should be paid to operation of the instrument 6 (Table 1), which readings were two times greater tan results obtained with instruments 2, 3, 5, 7-10. The same instrument, when laboratory tested by means of the determined (not random) input signals, had results not significantly different from the results obtained from other instruments.

The laboratory test have demonstrated that:

— The requirements of standard IEC 61000-4-15 have been interpreted by manufacturers of flickermeters in different ways.

— Conformity with the requirements of the standard does not mean that flickermeters will respond the same way to the same input signal. The standard shall be amended with additional calibration and/or design requirements. Fulfilling these requirements shall ensure conformity (within assumed tolerance) of different flickermeters readings in response to the same input voltage signal with different levels of variability in time.

6. ACKNOWLEDGEMENT

The authors would like to thank Mr. Mirosław Semczuk of *Power Measurement,* Canada, for instrument ION 7600 and the *Arbiter Systems* Company, USA, manufacturer of instrument ARBITER 1133A, who are greatly acknowledged for making the instruments available free of charge for the purpose of this work.

Special thanks are to the *Elserw* Company, which made the site measurements at the *Zawiercie Steelworks S.A.* possible, and to our colleagues: Eugeniusz Gallus and Jerzy Wojciechowski for help in caring out the test at the steelworks.

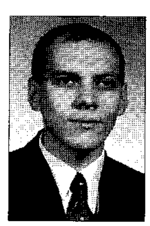
The work has been financed by the State Committee for Scientific Research within the research project No 8T10A05221.

7. REFERENCES

1. Bień A., Hanzelka Z., Hartman M. et al.: *Voltage fluctuations measurement – experiment in the industrial environment.* Electrical Power Quality and Utilisation, 7, 2, 2001.
3. Bień A., Hanzelka Z., Hartman M., Piekarz M., Szlosek M.: *Comparative test of flickermeters* X International Conference on Harmonic and Quality of Power. Rio de Janerio 2002.
4. *Guide to quality of electrical supply for industrial installations* Part 5: UIEPQ-9713, 1999.
5. Hashad M., Hartman M., Hanzelka Z., Bień A.: *The hypothesis for the wrong measurements results obtained during the flickermeter comparative test.* 6th International Conf. Electrical Power Quality and Utilisation, Sept. 19–21, 2001, Cracow.
6. IEC 61000-4-15: *Flickermeter – Functional and design specifications.* 2002.
7. Kowalski Z., Hanzelka Z.: *Limits of voltage fluctuations.* (in polish). EPQU 1, 3, 1997.
8. Matlab, Simulink, user guide.
9. Mombauer W.: *EMV – Messung von Spannungs-Schwankungen und Flickern mit dem IEC-Flickermeter.* VDE Verlag (109) 2000.
10. Rogoz M.: *The IEC flickermeter model.* Elektrotechnika i Elektronika. 2003 Zeszyt 1. T.22.
11. Szlosek M., Piekarz M., Hanzelka Z., Bień A. and others: *Comparative tests of flickermeters.* 17th CIRED - International Conference & Exhibition on Electricity Distribution 1, Barcelona, 12-15 May 2003.
12. *Test Protocol – IEC Flickermeter Used in Power System Monitoring.* Prepared by UIE WG2 "Power Quality" 2001.

8. ANNEX

Technical specification of the voltage generator (AC Power Solution Analyser). Manufacturer: Agilent Technologies. Model: 6812B. Certificate of calibration (standard calibration): No. 6812BUS38390646



Marcin Szlosek, MSc, eng
born 23-10-1976. He received MSc, eng in the faculty of Electrical Engineering, Automatics, Computer Science and Electronics, University of Science and Technology – AGH, Cracow. His choice is in power electronics, in particular its applications to the power quality improvement systems. Presently he continues his studies as a doctorate student at the faculty of Electrical Engineering, Automatics, Computer Science and Electronics at the AGH-UST.
e-mail: mszlosek@agh.edu.pl

Prof. Zbigniew Hanzelka
professor in the Institute of Electrical Drive and Industrial Equipment Control of University of Science and Technology – AGH. His area of interest includes electrical power quality, particularly methods of reducing the influence of power converters on supply network. He is the member of several national and international committees, among other IEC, UIE, CIGRE.
Mailing address: University of Science and Technology – AGH, 30-059 Cracow, Al. Mickiewicza 30, POLAND, phone: +4812 617 28 78, fax: +4812 633 22 84; e-mail: hanzel@uci.agh.edu.pl.

Andrzej Bień
born in 1954 in Warsaw, Poland. He received M.Sc. and Ph.D. degrees from the University of Science and Technology – AGH in Cracow. At present he is researcher in this university, Department of measurement and Instrumentation. His field of interest is digital instrumentation based on DSP for electricity property measurement (especially power quality).
Mailing address: University of Science and Technology – AGH, Department of Measurement and Instrumentation, Al. Mickiewicza 30., 30-059 Kraków, POLAND, phone:(+48 12) 6172873, fax:(+48 12) 6338565, e-mail: abien@uci.agh.edu.pl

Marek Rogóż, MSc, eng
Born 16 May 1976 in Olkusz, Poland. He completed his studies on electrical power engineering and graduated with distinction in 2001 at the faculty of Electrical Engineering, Automatics, Computer Science and Electronics, at the University of Science and Technology (AGH-UST) in Krakow. Presently employed in Power Distribution Company – Cracow. At the same time he continues his studies as a doctorate student at the faculty of Electrical Engineering, Automatics, Computer Science and Electronics at the AGH-UST. In his research work he focuses on the quality of electric power in power systems.
e-mail: marek@agh.edu.pl

Prof. Marek T. Hartman
received the M.Sc.Eng. and Ph.D. degrees in electronic engineering from The Technical University of Gdansk, Poland in 1970 and 1977, respectively. He received the habilitation degree from Warsaw University of Technology in 1988. In 1987/1988 he was on The British Council fellowship at Loughborough University of Technology, England. In the years 1989–2000 he worked at the Gdansk Branch of The Electrotechnical Institute as a Branch Director. Since 2000 he is a Professor at Maritime University at Gdynia and science consultant at the Electrotechnical Institute. Currently he is also the External Professor of Glamorgan University, Walsh. He is a Member of Power Electronics and Electric Drives Committee in the Polish Academy of Science and Corresponding Member and Fellow of IEE. He has published over 80 scientific papers in the field of power semiconductors, power converters, digital signal processing and electromagnetic compatibility. He is the Member of Scientific Committee of the Polish national technical magazine "Electrotechnical Review."