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ACTIVE ELECTRICITY METERS ERROR ANALYSIS IN CASE OF HARMONICALLY DISTORTED VOLTAGES AND CURRENTS

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A b s t r a c t: High order harmonic components in voltage and current signals are nowadays more prevalent in power grids at any voltage level, therefore demands for accurate measurements of the system's parameters go beyond the performance of instruments under pure sine wave conditions. This topic is highly challenging, especially in domain of electricity meters intended for legal metrology purposes, i.e. for billing in the regulated trade of electrical energy. Test procedures for examination of electricity meters' output in case of harmonically distorted signals are proposed in several international standards and recommendations. The drawbacks of the signals presented in these documents are the lack of complexity and random behavior of single harmonic component's amplitude and phase shift. Because many types of electricity meters are used worldwide, different output is expected for instruments based on different measurement principles. For faithful presentation of meters' errors in case of harmonics, several devices are about to be tested with random distorted signals, by using different currents and phase shifts.

Key words: high order harmonics; distorted waveforms; electricity meter; phase shift

АНАЛИЗА НА ГРЕШКИ КАЈ БРОИЛА НА АКТИВНА ЕНЕРГИЈА ПРИ ХАРМОНИСКИ ИЗОБЛИЧЕНИ НАПОНИ И СТРУИ

А п с т р а к т: Вишите хармоници во напонските и струјните сигнали се сѐ поприсутен феномен во електричните мрежи на кое било напонско ниво. Согласно оваа констатација, потребата од точно мерење на параметрите во системот ги надминува границите на грешка декларирани во спецификациите на инструментите, кои се однесуваат на чисти синусоидални влезни сигнали. Одредувањето на влијанието на вишите хармоници врз точноста на мерењата е важно и претставува посебен предизвик во доменот на мерење електрична енергија, т.е. кај електричните броила како уреди кои подлежат на законска регулатива и кои учествуваат во обезбедувањето наплата во трговијата со електрична енергија. Во светот постојат повеќе меѓународни стандарди и препораки кои опфаќаат тест-процедури за испитување на одзивот на броилата за активна енергија при хармониски изобличени напони и струи. Основниот недостаток на тест-сигналите, пропишани во овие документи, е нивната едноставност, која не секогаш кореспондира со приликите во пракса, какви што се случајните промени на амплитудите и фазните поместувања на поединечни виши хармоници. Бидејќи денес во светот во употреба се различни типови броила, очекуван е поинаков одзив кај инструменти кои функционираат според различен мерен принцип. За веродостојно претставување на грешките кај различни типови броила, во овој труд се применети напони и струи со случајни хармониски изобличувања, а тест-процедурите опфаќат различен интензитет на влезните струјни сигнали и различни фазни поместувања помеѓу фундаменталните компоненти.

Клучни зборови: виши хармоници; хармониски изобличени сигнали; електрични броила; фазно поместување.

1. INTRODUCTION

The presence of high order harmonics in voltage and current waveforms is an undesirable occurrence in the network, which may cause incre-ased electrical and magnetic losses in the system, high current flow through the neutral conductor and inaccurate measurement of system's actual parameters [1]. Harmonics are most commonly result of non-linear loads [1–3], such as: arc furnaces and welding equipment, lighting installations with discharge lamps and LEDs, battery chargers, rectifiers, etc. Because their existence in the system is an actual problem and reality, a challenge arises for accurate measurement of the electrical energy with different types of instruments, in different situations [2, 4–6].

There are several international standards [7–8], a recommendation [9] and many scientific works [4, 6, 10–12] which comply with the research topic of electrical power and energy instruments' output and errors, in case of high order harmonics. In the international standard EN 50470-3 [7], several distorted signals and procedures intended for testing of electricity meters for active energy in non-sinusoidal conditions are presented. An example of such a procedure is the test that implies examination of an instrument with waveforms, which beside the components at fundamental frequency possess the 5th order voltage and current harmonic. The 5th order harmonic components are limited to 10 %, i.e. 40 % of the fundamental voltage, i.e. current value. Another example of a document which encompasses test signals with high order harmonics is OIML R 46-1/-2 Recommendation [9]. Two test signals are presented in this document, named Quadriform and Peaked waveform. The harmonic distortion in both waveforms is limited to 5 % and 40 % for the voltage and current signals, respectively. These characteristic waveforms possess odd high order harmonics, up to the 13th order, which are either in phase, or 180° shifted in correspondence with fundamental voltages and currents. Other research documents [10–13], deal with the problem of active power or energy measurement in case of harmonically distorted waveforms. Different waveforms are regarded, those taken from the standards [7, 9] and random signals as well. However, no effect of single harmonic distortion parameter, such as amplitude, or phase shift, on the tested meter's output is provided. In the following work, the effects of harmonically distorted voltages and currents on instruments for active energy, based on different measuring principles, will be discussed. Their output will be regarded in correspondence with the intensity of the test current, the phase shift between the fundamental components, the Total Harmonic Distortion (*THD*) of the proposed signals, as well as a phase shift existence between the high order harmonic components and fundamental voltages and currents.

2. THEORETICAL BACKGROUND

Voltage or current signals which, beside the component at fundamental frequency, possess high order harmonics up to the n^{th} order, can be expressed, in time domain, by using Fourier series [1, 3]:

$$x(t) = \sqrt{2}\sum_{h=1}^{n} X_h \sin(h\omega t + \alpha_{xh}), \qquad (1)$$

where X_h is the RMS of the h^{th} order voltage or current harmonic and α_{xh} is its initial phase shift. The single harmonic component RMS value, is usually expressed as a percentage of voltage or current at fundamental frequency [7, 9]:

$$x_h[\%] = \frac{X_h}{X_1}\cdot 100, \qquad (2)$$

while the phase shift is usually presented as an angle between the fundamental's and the high order harmonic's vectors:

$$\theta_{xh} = \angle(\alpha_{xh}, \alpha_{x1}). \qquad (3)$$

The RMS of the voltage or current signal, expressed in time domain via (1), equals [14]:

$$X_{RMS} = \sqrt{\sum_{h=1}^{n} X_h^2}, \qquad (4)$$

while for distortion quantification, usually, the parameter **Total Harmonic Distortion** *(THD)* is used [1, 3]:

$$THD = \sqrt{\frac{\sum_{h=2}^{n} X_h^2}{X_1^2}}\cdot 100. \qquad (5)$$

Because in the work, examination of electricity meters for active energy is about to be performed, the quantity of particular interest is active power. Measurement error of different type electricity meters, will be regarded as error in power measurement, taking into account that the time factor is not affected by harmonic distortion. That being said, active power in case of harmonically distorted voltages and currents can be expressed as [1, 3, 14]:

$$P = \frac{1}{T}\int_0^T u(t)i(t)\partial t = \sum_{h=1}^{n} U_h I_h \cos\varphi_h, \qquad (6)$$

where U_h and I_h are RMS values of the voltage and current harmonic of order h and φ_h is the phase shift between them. The phase shift is calculated, as [15]:

$$\varphi_h = h\varphi_1 + \theta_{ih} - \theta_{uh}, \qquad (7)$$

φ_1 being the phase shift between current and voltage at fundamental frequency, while θ_{ih} and θ_{uh} are the phase shifts of the h^{th} order harmonic of current and voltage in relation to components at fundamental frequency.

3. EQUIPMENT AND MEASUREMENT PRINCIPLES

The experimental part of the work is performed in Laboratory of Electrical Measurements (LEM), which is part of the Faculty of Electrical Engineering and Information Technology (FEEIT), Ss. Cyril and Methodius University in Skopje (UKIM). It is an accredited laboratory for calibration of instruments and reference standards for variety of electrical quantities [16–17], according to international standard ISO EN МКС 17025:2018 [18]. The role of a harmonic source is played by LEM's secondary (working) standard in domain of electrical power and energy, CALMET C300 [15]. CALMET C300 is software controlled three phase AC voltage and current source, which can be used for automated electricity meters calibration and error testing. The tests can be performed with sine wave signals, as well as with random, manually set, distorted waveforms. The scheme, regarding testing of a three phase electricity meter is illustrated on Figure 1.

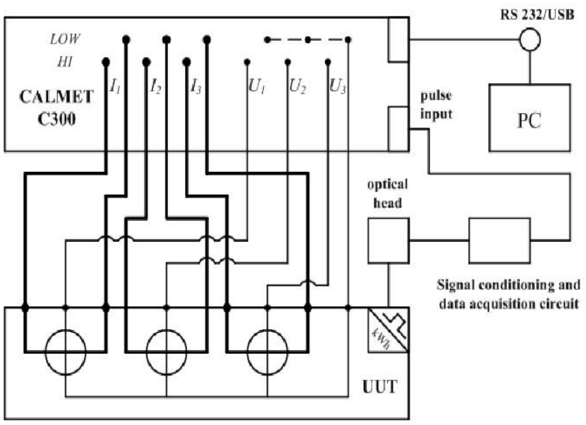

Fig. 1. Three phase electricity meter connection to CALMET C300 reference standard

For the purpose of this paper, three electricity meters are used as Unit Under Test (UUT):

- ISKRA E3, single phase induction meter for active energy of accuracy class 2, 220 V/(10–30) A,
- SIEMENS 7EC49 52-2CM41, three phase electronic meter of accuracy class 2, 3*220 V/10 A, and
- Landys+Gyr, ZMD405CT44.2407, digital three phase electricity meter of accuracy class 0.5, 3*58 V/5 A.

The first UUT, ISKRA E3, is an induction electricity meter, which is still used in some rural parts of the Republic of North Macedonia. It consists of 2 electromagnets, namely a voltage and a current coil, in which currents proportional to the measured voltage, i.e. current flow. The current in the voltage coil is approximately 90˚ phase shifted in accordance to the measured voltage, because of the predominantly inductive character of the coil itself. The current flow through the coils results in magnetic fluxes, Φ_U and Φ_I, which contribute to electromagnetic momentum existence, resulting in aluminum disk rotation. This momentum is proportional to the fluxes [4]:

$$M = K\Phi_U \Phi_I \sin\left(90^\circ + \varphi\right) = K'UI\cos\varphi, \quad (8)$$

i.e. it is proportional to the system's active power. In (8), K and K' are proportionality coefficients, correlated to the constructional characteristics of the electricity meter, while U and I are the measured voltage and current.

The second electricity meter, SIEMENS 7EC49 52-2CM41, is an electronic active energy meter and its working principle is based on pulse – width modulation [19–20]. Namely, the product of the measured voltage and current is transformed into pulses procession. The pulses' duration, T_P, is proportional to the measured current, I, while the pulses' amplitude, U_P, is proportional to the measured voltage, U. The pulses mean value, $U_{P,M}$, during the period T, equals:

$$U_{P,M} = \frac{1}{T}\int_0^{k_I I} k_U U \partial t = \frac{k_I k_U IU}{T} = KP, \quad (9)$$

and it is proportional to the measured power. In (9), k_I, k_U and K are proportionality coefficients.

The last UUT, Landys+Gyr ZMD405CT44.24 07, is a digital electricity meter, intended for instrument transformers connection. Its working principle is based on digital signal processing (DSP), i.e. on averaging the instantaneous power obtained by multiplication of momentum current and voltage sample values, over a certain period of time. The measured power can be calculated as follows:

$$P = \frac{1}{N}\sum_{i=1}^{N} u_i i_i, \quad (10)$$

where u_i and i_i are voltage and current samples respectively, and N is the number of samples during the averaging time.

Electricity meters, based on different working principles are selected, in order to monitor the influence of high order harmonics on different active power and energy measurement techniques. Before harmonic tests are conducted, sine wave signals calibration is about to take place, in order to establish reference margins for instruments' output deviation.

4. SINE WAVE CALIBRATION AND PROPOSED TEST SIGNALS

A first step of the practical part of the analysis is electricity meters' error recording in case of voltages and currents with pure sinusoidal waveform. Instruments are calibrated in total of 6 measurement points. The RMS of the test voltage equals the meter's nominal value in every test point. One half of the calibration procedure is conducted with current RMS equal to the rated current of the electricity meter, while the other 3 measuring points correspond to current RMS equal to 50 % of the rated current. Tests are performed for 3 phase shift values between 50 Hz voltages and currents: 0˚, 60˚ and –36.87˚. These values are chosen because of international metrological traceability existence [16–17] and because of standard's [7] correspondence. The results are illustrated in Table 1.

As it can be seen from Table 1, both electronic and digital electricity meters provide excellent measurement results when tested with pure sinewave signals. The recorded errors are small, comparable to the error margins dictated by their accuracy class, 2 % and 0.5 %, respectively. That is not the case with ISKRA E3, induction based meter, where higher errors than the accuracy limits are recorded. However, because this device is rather old, and has many years of service behind, in different conditions and for different applications, these errors are regarded as satisfactory for the purposes of this work.

The error testing of the electricity meters with distorted waveforms, is going to encompass 3 test procedures. In every test procedure, voltages and currents with different harmonic distortion are used. Single harmonic components share is presented in Table 2, as proposed by (2) and (3), and the test signals are named as Signal Set 1, 2 and 3.

T a b l e 1

Test results using sine wave signals

Measurement point	ISKRA	SIEMENS	LANDYS+GYR
		ε (%)	
$U = U_n$,, $I = 0.5\, I_n$, $\varphi_1 = 0˚$	–3.64	–0.66	0.14
$U = U_n$,, $I = 0.5 I_n$, $\varphi_1 = 60˚$	–3.21	–0.92	0.067
$U = U_n$,,, $I = 0.5 I_n$, $\varphi_1 = –36.87˚$	–4.01	–-0.57	0.13
$U = U_n$, $I = I_n$, $\varphi_1=0˚$	–2.77	–0.63	0.16
$U = U_n$, $I = I_n$, $\varphi_1=60˚$	–2.67	–0.83	0.04
$U = U_n$, $I = I_n$, $\varphi_1 = -36.87˚$	–2.97	–0.52	0.18

T a b l e 2

Harmonic components in test waveforms

Harmonic order, *h*	**Signal set 1**				**Signal set 2**				**Signal set 3**			
	u_h (%)	θ_{uh} (˚)	i_h (%)	θ_{ih} (˚)	u_h (%)	θ_{uh} (˚)	i_h (%)	θ_{ih} (˚)	u_h (%)	θ_{uh} (˚)	i_h (%)	θ_{ih} (˚)
3	2.45	0	7.25	0	0	0	0	0	8.26	114	26.3	223
5	1.16	0	6.32	0	6.2	356	18.3	278	5.36	223	15	146
7	0.76	0	4.20	0	2.5	215	8.64	114	1.11	96	7.63	98
9	0.24	0	2.26	0	0	0	0	0	0.62	179	11	342
11	0.13	0	1.19	0	1.32	324	4.23	69	1.14	332	5.32	46
13	0.05	0	0.42	0	0.17	248	1.78	95	0	0	0	0
15	0	0	0.63	0	0	0	0	0	0	0	0	0
17	0	0	0	0	1.6	18	0.56	13	0	0	0	0
19	0	0	0	0	0.08	125	1.3	17	0	0	0	0
THD (%)	2.83		10.83		7		20.82		9.99		33.53	

Signal set 1 corresponds to waveforms with low *THD*, which equals 2.83 % for the voltage signals and 10.83 % for the current signals. These distortions are rather smaller than the prescribed limits for electricity meters testing, highlighted in [7–8]. Harmonics up to 15th order are taken into account, with no phase shift in relation to voltages and currents at fundamental frequency.

The second signal set corresponds to a medium harmonic distortion, with random magnitude of single harmonic components, as well as random phase shift in accordance to 50 Hz voltages and currents. The most noticeable characteristics of this signal set is the absence of triplen harmonics, which is reality in low voltage networks, because of the triangular configuration of distribution transformer’s primary winding [3].

Signal set 3 corresponds to high harmonic distortion, which is comparable to the limits proposed in [7], for both test voltages and currents. Harmonics up to 11th order are taken into account, with random magnitude and phase shift in relation to 50 Hz signals.

5. TESTING WITH DISTORTED WAVEFORMS

In this chapter of the paper, results for the 3 electricity meters, which are tested with distorted voltages and currents presented in Table 2, are discussed. For every measurement point, 5 single measurements were conducted and the presented error is *de facto* an average value from the 5 recordings. A single measurement is performed by recording a predefined number of pulses (or rotations in case of the induction meter) made by the UUT, proportional to the active energy. 5 pulses, i.e. disk rotations were recorded, for every measurement, with electronic and induction meter, while 100 pulses were the threshold for a single measurement with the digital meter. The difference in number of pulses is due to the meter’s pulse constant variations and test duration. The experiment was performed in a laboratory controlled environment, the temperature was held constant at 23±1 ˚C, while the relative humidity was below 55 % for the whole measurement duration.

Measurement results, for the 3 UUTs, concerning Signal set 1 waveforms, are presented in Table 3. As can be seen from the table, errors in case of a low harmonic distortion are small and comparable to the errors when the electricity meter is tested with pure sine wave signals, for both digital and electronic electricity meters.

Table 3

Test results using Signal set 1 waveforms

Measurement point	ISKRA	SIEMENS	LANDYS+GYR
	ε (%)		
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = 0^\circ$	–3.67	–0.64	0.11
$U = U_n$, $I = 0.5I_n$, $\varphi_1=60^\circ$	0.4	–0.85	0.032
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = -36.87^\circ$	–5.19	–0.56	0.14
$U = U_n$, $I = I_n$, $\varphi_1 = 0^\circ$	–2.89	–0.56	0.14
$U = U_n$, $I = I_n$, $\varphi_1 = 60^\circ$	1.01	–0.96	–0.026
$U = U_n$, $I = I_n$, $\varphi_1 = -36.87^\circ$	–4.28	–0.44	0.21

For these 2 instruments, the output is within the declared accuracy limits, for all 6 measurement points. That is not the case, however, for induction based meter. Errors made by this UUT are comparable to errors in case of sinusoidal signals, but only for the measurement points which correspond to a 0˚ phase shift between voltages and currents at fundamental frequency. Errors in case of an inductive load, move into the positive direction, and for these particular measurement points the electricity meters lies within the accuracy limits. As being said earlier in this work, for the concrete UUT, the accuracy class is not relevant, because of the obvious measurement drift illustrated in Table 1. The situation is the opposite in case of capacitive phase shift, the errors move in opposite, negative direction, and are higher compared to the errors obtained during the sine wave test.

Test results from the second signal set procedure are illustrated in Table 4. The first thing which can be emphasized from these results, concerning all 3 instruments, is the fact that measurement errors do not vary significantly with the current’s RMS change. A general conclusion which can be derived from the test, for all 3 instruments, concerning the phase shifts, is that when $\varphi_1 = 0^\circ$, there is no significant error existence, compared to the situation when test signals are sinusoidal. However, that is not the case when a phase shift exists between U_1 and I_1. When the phase shift between the fundamental components of voltage and current equals 60˚, errors are bigger than the ones declared by the meter’s specification. That is especially noticeable in the procedure encompassing the digital meter, taking for comparison the low errors obtained during the sine wave test. Similar conclusions can be derived for the electronic and induction meters, although the deviation is not that significant. On the other hand, when $\varphi_1 = -36.87^\circ$, errors shift into negative direction, being significantly higher than in case of pure sine wave signals. Once again, that stands for all the 3 UUTs.

Table 4

Test results using Signal set 2 waveforms

Measurement point	ISKRA	SIEMENS	LANDYS+GYR
	ε (%)		
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = 0^\circ$	–3.95	–0.49	0.29
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = 60^\circ$	–1.87	2.17	3.02
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = -36.87^\circ$	–4.33	–1.83	-0.87
$U = U_n$, $I = I_n$, $\varphi_1 = 0^\circ$	–2.65	–0.46	0.31
$U = U_n$, $I = I_n$, $\varphi_1 = 60^\circ$	–1.05	2.1	3.04
$U = U_n$, $I = I_n$, $\varphi_1 = -36.87^\circ$	–2.91	–1.45	–0.81

Similar conclusions can be derived if the results from the test, conducted with the third signal set, are observed. These results are illustrated in Table 5. When fundamental components of voltage and current are mutually in phase, the error in UUT's output is comparable to the error in case of sine wave test signals. This conclusion stands for the all three electricity meters. However, the errors are not negligible, when a phase shift exists between U_1 and I_1. Because of a higher *THD* in both current and voltage signals, compared to the previous 2 signal sets, in this test procedure the highest errors are recorded. In the case, when the electricity meter is subjected to an inductive load, its output is higher than the actual energy generated, i.e. the errors are positive. On the other hand, when the load is capacitive, the meters measure less energy, than the one actually present in the system. In case of electronic and digital instruments, errors are not dependent on the RMS of the current, while certain error change is observed when ISKRA E3 is subjected to a test.

Table 5

Test results using Signal set 3 waveforms

Measurement point	ISKRA	SIEMENS	LANDYS+GYR
	ε (%)		
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = 0^\circ$	–3.82	–0.74	0.086
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = 60^\circ$	–2.21	1.87	2.97
$U = U_n$, $I = 0.5I_n$, $\varphi_1 = -36.87^\circ$	–7.79	–5.52	–4.81
$U = U_n$, $I = I_n$, $\varphi_1 = 0^\circ$	–2.51	–0.67	0.085
$U = U_n$, $I = I_n$, $\varphi_1 = 60^\circ$	–0.7	3.17	2.9
$U = U_n$, $I = I_n$, $\varphi_1 = -36.87^\circ$	–6.36	–5.78	–4.77

In the figures that follow, measurement results from the instruments', rather than from the test signals', perspective are illustrated. On the figures, only measurement points which correspond to a current equal to 0.5 I_n are presented, as stated by the standard [7]. In Figure 2 errors made by ISKRA E3, induction meter are illustrated. Because of the obvious measurement drift existence, the measured value is approximately 3.5% – 4% lower than the electricity generated by the standard [15], even in case of a sine wave signal. When $\varphi_1 = 0^\circ$, measurement results does not recede from the instrument's performance in case of sinusoidal voltages and currents, no matter the harmonic distortion. When a phase shift exists between voltages and currents at fundamental frequency, a significant error appears in comparison to the results from the calibration with sine wave signals.

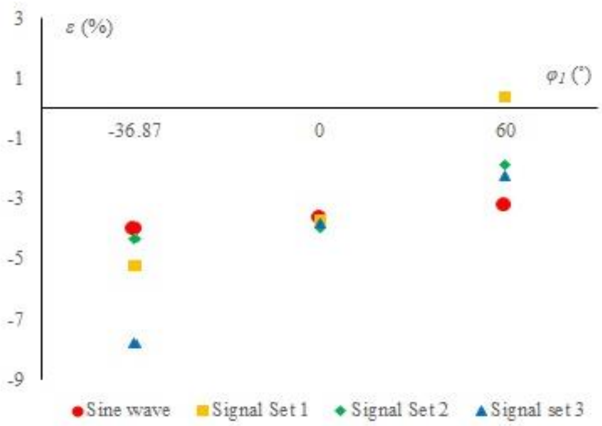

Fig. 2. Test results for ISKRA E3 induction meter

Errors for the 3 tests are positive in case of an inductive phase shift equal to 60˚, i.e. negative in case of a capacitive phase shift with $\varphi_1 = -36.87˚$. The highest deviation is recorded when there is a high harmonic distortion, in case of Signal set 3 waveforms, for capacitive load with phase shift of –36.87˚.

Figure 3 presents the testing errors of the electronic electricity meter, SIEMENS 7EC49 52-2CM41. It can be concluded that its performance, in case of a low harmonic distortion, with no phase shift existence between the high order harmonic components and fundamental voltages and currents is comparable to the performance in case of a sine wave test signals. On the other hand, when U_1 and I_1 are not mutually in phase, and there are random phase shifts θ_{uh} and θ_{ih}, a significant error exists, which for the proposed signal sets 2 and 3 can reach up to 6 %. Similarly, as mentioned in the discussion of test results when the induction meter played the role of a UUT, deviations between the measured and generated active energy are positive when the phase shift is inductive, while they are negative for a capacitive φ_1.

Fig. 3. Test results for SIEMENS 7EC49 52-2CM41 electronic meter

Similar conclusion can be derived from Figure 4, on which the results from testing of the digital meter Landys+Gyr are presented. If Figure 3 and Figure 4 are compared, similar intensity of errors, for the same measurement points can be spotted. Once again errors in case of a harmonic distortion, with random phase shift between the high order harmonics and fundamental components are higher than the deviations obtained in sinusoidal conditions. For this instrument, maximal error is recorded in results concerning Signal set 3 test, when $\varphi_1 = -36.87˚$. In such a scenario, the measured active energy by the meter is 5 % lower than the energy generated by the reference standard. On the other hand, when $\varphi_1 = 0˚$, errors are small, comparable to the deviations obtained during calibration with pure sine wave signals, and the meter's performance is within its declared accuracy class.

Fig. 4. Test results for Landys+Gyr ZMD405CT44.2407 digital meter

5. CONCLUSION

In the paper, performance analysis of 3 active energy meters, in presence of harmonically distorted voltages and currents was conducted. The main purpose of the work, was examination of the measurement error intensity in case of high order harmonics, present in the test signals, in correlation to the working principle of the measuring device itself. For that reason, different meters were chosen: induction based meter, meter based on electronic pulse modulation and digital signal processing meter.

Before the testing procedures were conducted, the 3 UUTs were calibrated with sine wave signals. The errors obtained from these calibrations, were used as a basis for further meter's performance evaluation in case of harmonics present in voltages and currents. Total of 3 harmonically distorted waveforms were introduced for performance evaluation, regarding different real case situations. The outputs of electronic and digital meters, do not differ significantly from one another in any situation observed. Namely, in case of both instruments, when $\varphi_1 = 0˚$, the recorded errors were insignificant and belonged within the meters' accuracy class for different current values. Further on, recorded deviation between the applied and measured energy is small, when the examination is performed with small harmonic distortion, without phase shift between the high order harmonic components and fundamental voltages and currents. This is not the case when phase shift exists, both between high order harmonics and fundamental component and between U_1 and I_1. The errors, in such a scenario, are dependent on the phase shift and that is a topic of particular interest for further analysis.

The induction meter provides slightly different performance. The errors are significant, when this instrument is subjected to a harmonically distorted waveforms test, even in case of a small harmonic distortion without phase shift between high order harmonics, if 50 Hz voltages and currents are not mutually in phase. Performance of this meter is dependent on the current magnitude as well, taking into account the existence of increased magnetic losses because of high frequency components.

Further research on this topic is supposed to provide deeper analysis on high order harmonic parameters influence on meter's performance. For that purpose tests with simple waveforms, consisting of only one high order harmonic component are about to take place. Because the induction meters are gradually being removed from service, any future work is going to be conducted on the more prevalent, digital signal processing based instrumentation.

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