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ORIGINAL PAPER

An update on the performance of active energy meters under non-sinusoidal conditions

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Abstract

The performance of electrical energy meters in non-sinusoidal conditions has been discussed since the early twentieth century and as of yet has not reached a fully comprehensive standardization. Within this context, this paper aims to update the present understanding on the subject through a closer look at the power definitions established by the IEEE Std. 1459-2010. The paper concentrates its goals across two different approaches. The first deals with the analytical development in the time domain, aiming at the decomposition of the instantaneous power in its different elementary components. The second, in turn, deals with the development of several calibration tests in different active electrical energy meters considering different voltage and current waveforms. The results show that the measurement deviations in non-sinusoidal conditions may be greater than 30% in some practical cases, which reinforces the need for more specific standards concerning the subject.

Keywords Harmonics · Measurement errors · Power meters

1 Introduction

One of the first works to address the performance of active energy meters in non-sinusoidal conditions was that published by Hollister [1] in 1915. In noteworthy fashion, the analytical approach presented in [1] reflects the essence of the physical meaning of active power under non-sinusoidal conditions, as currently proposed by IEEE Std. 1459-2010 [2]. However, although the analytical developments indicate the contrary, the author emphasizes that the impact of the presence of harmonic components is practically unnoticeable in real metering systems. Most likely, this statement was associated with the fact that the amplitudes of the harmonic distortions were practically inexpressive at the time, compared to that seen nowadays. Other pioneering studies developed during the first half of the twentieth century contributed significantly to the measurement of active energy under non-sinusoidal conditions. The studies reported in [3] and [4], for example, presented some specific analyses considering the performance of energy meters when measuring individual loads represented by power rectifiers. The results obtained in these studies showed measurement deviations of less than 1% in the active energy values, compared to the results obtained considering only voltages and currents in the fundamental frequency.

The study presented in [5] addressed the growing concern related to the subject in the early 1940s and highlights the fact that the energy meters existing at the time were developed in such a way that their full performance was obtained only when considering voltages and currents in sinusoidal conditions. At the same time, the work showed that the measurement deviations verified in non-sinusoidal conditions, for usual levels of voltage distortion, remained within acceptable limits for current distortion amplitudes of less than 30%. Until the publication of [5], all papers published on the subject considered only the measuring technology available during that period, which was represented by electromechanical meters. However, electronic meters have gained ground since the late twentieth century and currently account for more than half of all active energy meters in operation world-

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wide, which includes new variables in the performance of such devices under non-sinusoidal conditions.

In this sense, several papers published in the 1990s [6–8] continued those studies related to the performance of active energy meters under non-sinusoidal conditions, and some of these started to perform tests considering electronic meters. The study presented in [8], for example, indicates that there is no other waveform suitable for the calibration of DSP (digital signal processor)-based meters. However, the same study concluded that there existed the need to consider distorted signals in the calibration processes of both meter technologies. In the following years, what occurred in relation to the studies on the same subject can be summarized, basically, as a little more of the same [9–15]. Only in 2016, with the publication of the paper indicated in [16], the subject was again in evidence with the international scientific community. In this specific study, the authors stated that in certain cases, such as electrical installations containing a mix of lighting technologies, the measurement deviations between different active energy meters, monitoring the same voltage and current signal, could be higher than 500%.

Based on this historical information, aimed at motivating interest in an update on a subject that has not been specifically defined for more than 100 years, this study proposes, among other things, an analytical review of the problem in the light of IEEE Std. 1459-2010 [2], besides the practical verification of deviations in active energy measurements for non-sinusoidal conditions, considering different electromechanical and electronic meters. Additionally, a critical analysis of the results indicated in [16] will be presented.

2 Theoretical background

The publication of IEEE Std. 1459-2010 [2], based on the study by Alexander E. Emanuel [17], which presents a physical and mathematical approach to the definitions of electrical power, allows for the completion of analytical studies in the time domain in order to increase understanding of the effects of harmonic distortions during the measuring of active energy. In this way, considering the instantaneous voltage and current indicated in (1) and (2), the total instantaneous power in an electric circuit can be obtained by (3).

$$v(t) = V_1 \sin(\omega_1 t + \phi_{v1}) + \sum_{h=2}^{\infty} V_h \sin(h\omega_1 t + \phi_{vh}) \tag{1}$$

$$i(t) = I_1 \sin(\omega_1 t + \phi_{i1}) + \sum_{h=2}^{\infty} I_h \sin(h\omega_1 t + \phi_{ih}) \tag{2}$$

$$p(t) = v(t) \times i(t) \tag{3}$$

where V_1 and I_1 are the magnitudes of the fundamental voltage and current, respectively. ϕv_I and ϕi_I are the phase angles of voltage and current at the fundamental frequency, respectively. V_h and I_h are the magnitudes of the h-order harmonic voltage and current, respectively. ϕv_h and ϕi_h are the phase angles of voltage and current at the h-order harmonic frequency, respectively. ω_1 is the fundamental frequency.

Substituting (1) and (2) in Eq. (3) results in:

$$\begin{aligned} p(t) = {} & V_1 \sin(\omega_1 t + \phi_{v1}) \times I_1 \sin(\omega_1 t + \phi_{i1}) \\ & + V_1 \sin(\omega_1 t + \phi_{v1}) \times \sum_{h=2}^{\infty} I_h \sin(h\omega_1 t + \phi_{ih}) \\ & + \sum_{h=2}^{\infty} V_h \sin(h\omega_1 t + \phi_{vh}) \times I_1 \sin(\omega_1 t + \phi_{i1}) \\ & + \sum_{h=2}^{\infty} V_h \sin(h\omega_1 t + \phi_{vh}) \times \sum_{h=2}^{\infty} I_h \sin(h\omega_1 t + \phi_{ih}) \end{aligned} \tag{4}$$

According to (4), the total instantaneous power can be represented by four elementary components, as follows:

$$p_1(t) = V_1 \sin(\omega_1 t + \phi_{v1}) \times I_1 \sin(\omega_1 t + \phi_{i1}) \tag{5}$$

$$p_{v_1 i_h}(t) = V_1 \sin(\omega_1 t + \phi_{v1}) \times \sum_{h=2}^{\infty} I_h \sin(h\omega_1 t + \phi_{ih}) \tag{6}$$

$$p_{v_h i_1}(t) = \sum_{h=2}^{\infty} V_h \sin(h\omega_1 t + \phi_{vh}) \times I_1 \sin(\omega_1 t + \phi_{i1}) \tag{7}$$

$$p_{v_h i_h}(t) = \sum_{h=2}^{\infty} V_h \sin(h\omega_1 t + \phi_{vh}) \times \sum_{h=2}^{\infty} I_h \sin(h\omega_1 t + \phi_{ih}) \tag{8}$$

thus resulting in

$$p(t) = p_1(t) + p_{v_1 i_h}(t) + p_{v_h i_1}(t) + p_h(t) \tag{9}$$

where $p_1(t)$ is the component related to the fundamental frequency, resulting from the multiplication of the fundamental voltage by the fundamental current instantaneous component. $p_{v1ih}(t)$ is the component resulting from the multiplication of the fundamental voltage by the harmonic current instantaneous component. $p_{vhi1}(t)$ is the component resulting from the multiplication of the harmonic voltage by the fundamental current instantaneous component. $p_h(t)$ is the component related to the harmonic frequencies, resulting from the multiplication of the harmonic voltage by the harmonic current instantaneous component, for a same frequency h.

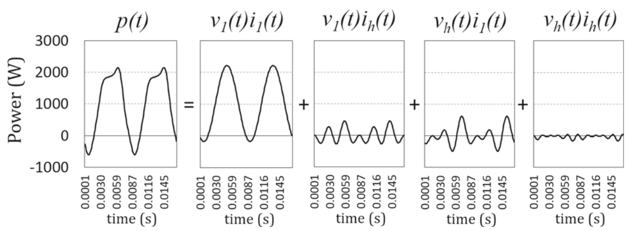

Fig. 1 Time-domain representation of the total instantaneous power decomposition

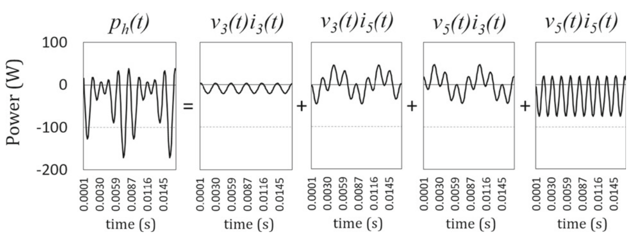

Fig. 2 Time-domain representation of the harmonic instantaneous power component decomposition

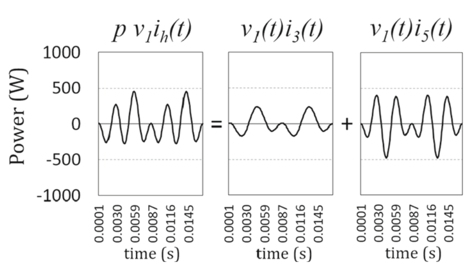

Fig. 3 Time-domain representation of the $p_{v1ih}(t)$ component decomposition

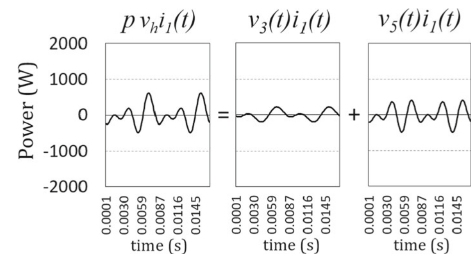

Fig. 4 Time-domain representation of the $p_{vhi1}(t)$ component decomposition

With the purpose of facilitating ones understanding into the four components constituting the total instantaneous power, Fig. 1 presents a numerical example considering:

$$\begin{aligned} V_1 &= 120V, \quad \phi v_1 = 0^{\circ}, \quad V_3 = 12\,\text{V}, \quad \phi v_3 \\ &= 10^{\circ}, \quad V_5 = 24\,\text{V}, \quad \phi v_5 = 45^{\circ} \\ I_1 &= 10A, \quad \phi i_1 = -32^{\circ}, \quad I_3 = 1\,\text{A}, \quad \phi i_3 \\ &= 145^{\circ}, \quad I_5 = 2\,\text{A}, \quad \phi i_5 = 170^{\circ} \end{aligned}$$

where the amplitudes of voltages and currents are indicated in rms values.

Note that Fig. 1 shows the time-domain representation of (9). Likewise, the instantaneous harmonic power component can be expressed as indicated in Fig. 2.

In the same way, considering the same numerical example, it is possible to segregate the instantaneous power components $p_{v1ih}(t)$ and $p_{vhi1}(t)$ as shown in Figs. 3 and 4, respectively.

Returning to the analytical expressions, the active power, considering the instantaneous power components indicated in (9), can be obtained by (10).

$$P = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} \frac{1}{T} \int_{0}^{T} v_m(t) i_n(t)\, \mathrm{d}t \tag{10}$$

It is important to highlight that the cross-multiplication of voltages and currents with different harmonic orders implies:

$$\frac{1}{T} \int_0^T v_m(t) i_n(t) \mathrm{d}t \begin{cases} = 0 \text{ for } m \neq n \\ \neq 0 \text{ for } m = n \end{cases} \tag{11}$$

The analytical proof of (11) is related to the fact that the integral of the product of two sine functions of different harmonic frequencies is zero, when the limits are taken for a complete period of the fundamental frequency. This way, Eq. (10) can be rewritten as:

$$P = \sum_{h=1}^{\infty} \frac{1}{T} \int_{0}^{T} v_h(t) i_h(t)\, \mathrm{d}t \tag{12}$$

In agreement with (11), one sees clearly in Fig. 1 that the components $p(t)$ and $p_1(t)$ possess an average value greater than zero. The same can be noted in Fig. 2 when considering of the instantaneous power component $p_h(t)$. However, in this case, fundamentally because of the components $v_3(t)i_3(t)$ and $v_5(t)i_5(t)$, the component $p_h(t)$ presents a negative average value, indicating that the related power flow moves in an opposite direction to $p(t)$ or $p_1(t)$. This is due to the fact that the considered numerical example represents a nonlinear load in such a way that part of the total power delivered to the load from the source is returned to the system in the form of harmonic power.

Finally, as a consequence of (11) and (12), the average value of $p_1(t)$ represents the fundamental active power (P_1), expressed in watts (W). The average values of $p_{v1ih}(t)$ and $p_{vhi1}(t)$ are both equal to zero, and the average value of $p_h(t)$ represents the harmonic active power (P_h), also expressed in watts (W). Table 1 shows the theoretical results obtained from the considered numerical example.

Table 1 Theoretical results obtained from the numerical example

Instantaneous power component	Mean value
$v_1(t)xi_1(t)$	1017.66 W
$v_1(t)xi_3(t)$	0.0
$v_1(t)xi_5(t)$	0.0
$v_3(t)xi_1(t)$	0.0
$v_3(t)xi_3(t)$	− 8.49 W
$v_3(t)xi_5(t)$	0.0
$v_5(t)xi_1(t)$	0.0
$v_5(t)xi_3(t)$	0.0
$v_5(t)xi_5(t)$	− 27.53 W
$P = \sum_{m=1}^{5} \sum_{n=1}^{5} \frac{1}{T} \int_0^T v_m(t) i_n(t)\, dt$	981.64 W

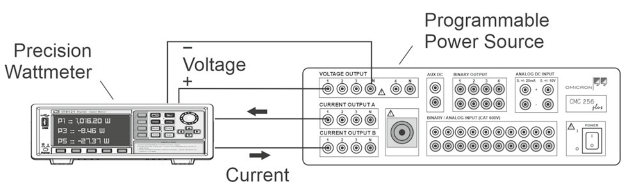

Fig. 5 Laboratory test setup

Table 2 Results obtained from the laboratory tests

Active power component	Theoretical value (W)	Wattmeter reading (W)	Deviation (%)
P_1	1017.66	1016.20	− 0.143
P_3	− 8.49	− 8.46	− 0.353
P_5	− 27.53	− 27.37	− 0.581
P	981.64	980.77	− 0.089

The theoretical results were compared with a laboratory test, where the same voltage and current signals were considered, which were generated by the programmable power source CMC 256 Plus, manufactured by Omicron Electronics Corp. and measured by the precision wattmeter IT9121, manufactured by ITECH Electronic Co. Both devices were previously calibrated by an accredited calibration laboratory.

Figure 5 shows the setup for the test carried out with the purpose of validating the theoretical results obtained from the numerical example. Table 2 presents a comparison between the theoretical values and the wattmeter readings.

The results presented on Table 2 show that for a precision wattmeter capable of measuring active power for different frequencies, the theoretical values and the wattmeter readings are very close, presenting a very low percentage deviation. These results validate the analytical approach presented in this section. However, the measurement of active power and energy, for billing purposes, is performed worldwide using meter devices with a very simple topology. It is common that traditional meter calibration laboratories do not consider harmonic distortions in the calibration procedures for meter certification. As such, the next section shows some laboratory test results considering different voltage and current signals applied to nine different single-phase energy meters.

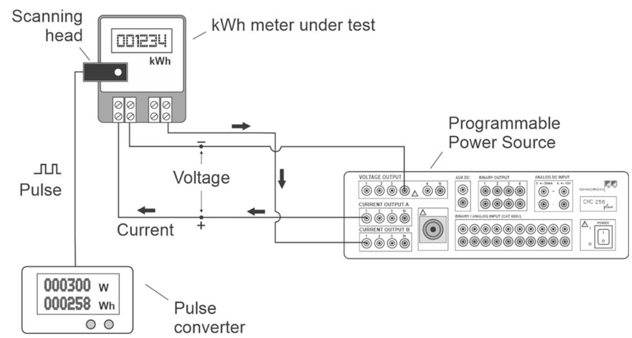

Fig. 6 Laboratory setup used to perform the meter calibration tests

3 Laboratory tests

The single-phase active energy meters considered in the laboratory tests are represented by letters and numbers, such that the letters indicate the manufacturer and the numbers indicate the model of the meter. The first two energy meters (A.1 and A.2) presented in the figures are electromechanical, and the others (A.3, B.1, B.2, B.3, C.1, D.1 and E.1) are electronic.

Figure 6 illustrates the laboratory arrangement used to perform the meter calibration tests under non-sinusoidal conditions. All equipment used in the tests was previously calibrated and certified by an accreditation and certification laboratory, in such a way that the complete set presents an accuracy range of ± 0.25% in the generation and measurement of active power.

The laboratory arrangement shown in Fig. 6 consists of a programmable power source (voltage and current), model CMC 256 Plus, manufactured by Omicron Electronics Corp, a scanning head and a pulse converter. The scanning head is suitable for scanning the marks of mechanical rotating disc meters or the detection of the pulses from the light-emitting diodes (LEDs) of electronic meters. The pulse converter was specifically developed for reading the pulses produced by the scanning head, allowing for the visualization of the active power and energy registered by the meter under test. The error verified in each test was calculated according to (13), considering two different references (P_{ref}): the fundamental active power (P_1) and the total active power (P), calculated according to (10) in terms of rms values.

$$\xi = \left(\frac{P_{\mathrm{meas}} - P_{\mathrm{ref}}}{P_{\mathrm{ref}}} \right) \times 100 \tag{13}$$

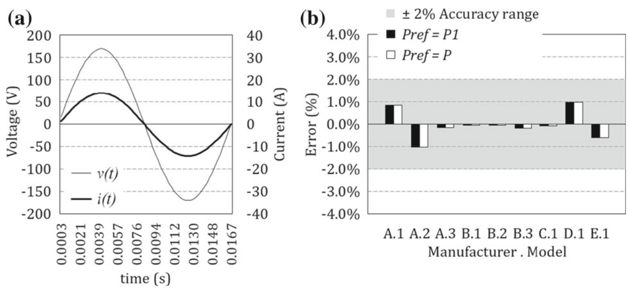

Fig. 7 *Test #1*—sinusoidal voltages and currents with unit power factor. **a** Waveforms of voltage and current, **b** resulting errors

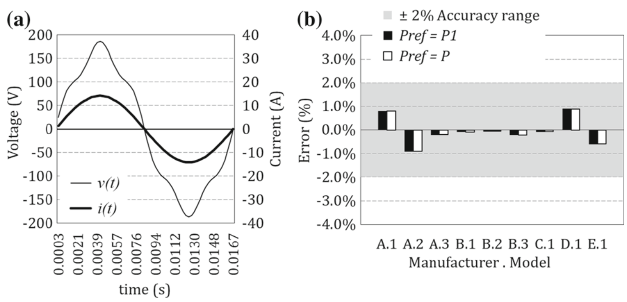

Fig. 8 *Test #2*—distorted voltage and sinusoidal current with unit power factor. **a** Waveforms of voltage and current, **b** resulting errors

where P_{meas} is the measured active power. P_{ref} is the reference active power.

The first test considers only sinusoidal voltages and currents with unit power factor. The results obtained are shown in Fig. 7.

As shown in Fig. 7, considering only voltages and currents at the fundamental frequency, all tested meters showed errors within their ranges of accuracy (± 2%).

In order to verify the compliance of equation (11) with the practical results verified in the calibration tests, the next three tests consider distorted voltages and currents with different harmonic orders and the same magnitudes for the fundamental voltage and current. The test indicated in Fig. 8a considers a distorted voltage, with 10% of fifth harmonic, and a sinusoidal current. Appendix A provides all the data associated with the tests performed.

In the same way, the test presented in Fig. 9 considers a sinusoidal voltage and a distorted current with 50% of fifth harmonic, while the test presented in Fig. 10 considers voltage and current simultaneously distorted, but with different harmonic orders, as shown in “Appendix A”.

As noted in Figs. 8b, 9b and 10b, the results obtained are very similar (within the accuracy range of the laboratory arrangement) to those results shown in Fig. 7b. This indicates that the meters, in fact, follow the analytical formulation presented in the previous topic, including the physical and mathematical meaning from (11), from which the cross-multiplication of voltages and currents with dif-

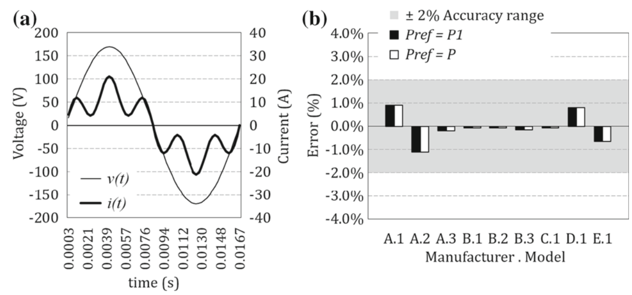

Fig. 9 *Test #3*—sinusoidal voltage and distorted current with unit power factor. **a** waveforms of voltage and current, **b** resulting errors

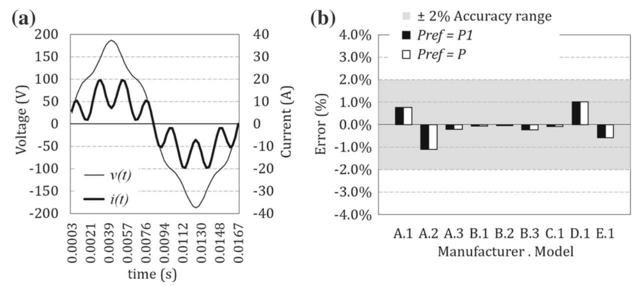

Fig. 10 *Test #4*—distorted voltage and current with different harmonic orders and unit power factor. **a** Waveforms of voltage and current, **b** resulting errors

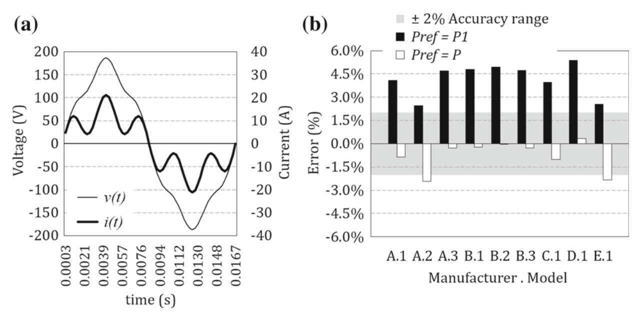

Fig. 11 *Test #5*—distorted voltage and current with same harmonic orders (fifth), unit power factor and harmonic power flowing from the source to the load. **a** Waveforms of voltage and current, **b** resulting errors

ferent harmonic orders does not result in the increasing (or decreasing) of the resulting active power.

The following tests were carried out with the goal of verifying the impact of the direction of the harmonic power flow in the measuring of active power. In these cases, both the voltage and the current have harmonics of the same order. Thus, the test presented in Fig. 11 considers the voltage and current waveforms with amplitudes of 10% and 50% of fifth harmonic (on the basis of the fundamental frequency), respectively, and the harmonic power flowing from the source to the load.

The results indicated in Fig. 11b show, as expected, that all the meters tested presented readings greater than the fundamental active power (P_1), as proposed by IEEE Std. 1459 [2].

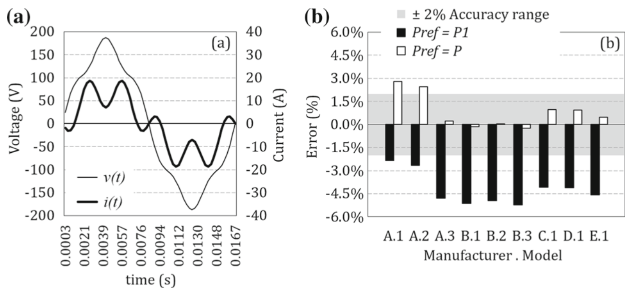

Fig. 12 *Test #6*—distorted voltage and current with same harmonic orders (fifth), unit power factor and harmonic power flowing from the load to the source. **a** Waveforms of voltage and current, **b** resulting errors

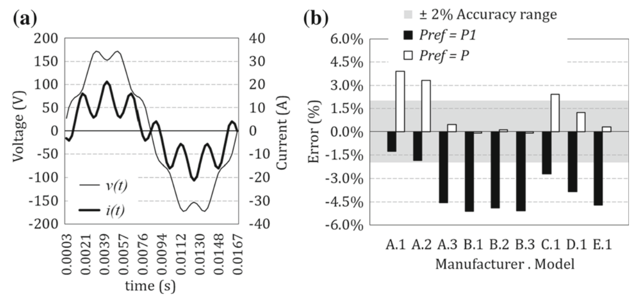

Fig. 14 *Test #8*—distorted voltage and current with same harmonic orders (seventh), unit power factor and harmonic power flowing from the load to the source. **a** Waveforms of voltage and current, **b** resulting errors

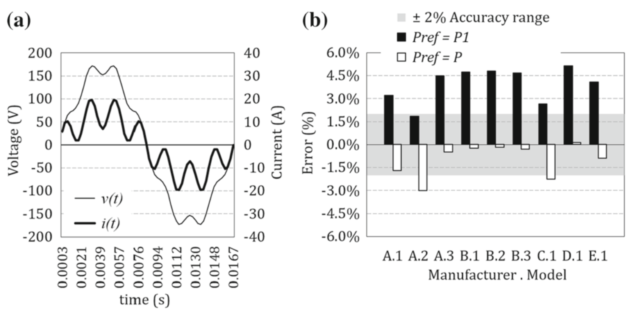

Fig. 13 *Test #7*—distorted voltage and current with same harmonic orders (seventh), unit power factor and harmonic power flowing from the source to the load. **a** Waveforms of voltage and current, **b** resulting errors

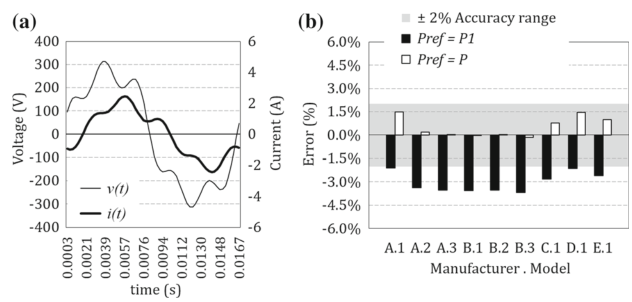

Fig. 15 *Test #9*—distorted voltage and current with third and fifth orders, fundamental power factor 0.85 lagging and harmonic power flowing from the load to the source. **a** Waveforms of voltage and current, **b** resulting errors

Furthermore, even when considering the theoretical active power (including harmonics) as the reference, two of the meters (A.2 and E.1) failed the test, suggesting that these meters were not designed to measure active power under distorted voltage and current conditions with the same level of accuracy.

Figure 12 shows the results obtained considering the same harmonic distortions of voltage and current of the previous test (in terms of amplitude), but this time the harmonic power is flowing from the load to the source, due to the 180° lag applied in the fifth harmonic current phasor.

In the same manner as shown in Fig. 11b, the results indicated in Fig. 12b show, once more, that all the meters tested presented errors greater than their accuracy range when considering the fundamental active power reference (P_1) and two of these (A.1 and A.2) failed when considering the theoretical active power (P) as the reference.

The next two tests are the same as Figs. (11) and (12), respectively, where just the harmonic frequencies of voltage and current were changed from the fifth to seventh order.

Considering the theoretical active power (P) as the reference, and the presence of harmonic frequencies in both voltage and current waveforms, the meter A.2 failed in all the tests carried out up to this point. At the same time, four of the nine meters tested (44.4%) failed in at least one of the tests performed. In the particular case of the test shown in Fig. 14, three of the meters were reproved when considering the theoretical active power (P) as the reference.

Test # 9, presented in Fig. 15, considers the presence of two different harmonic frequencies (third and fifth) in the voltage and current signals, with a power factor at the fundamental frequency of 0.85 lagging. In both frequencies, the harmonic power is flowing from the load to the source.

As shown in Fig. 15b, all the meters considered in Test #9 presented errors within their accuracy range for the theoretical active power (P) reference.

Based on the results presented so far, it is not possible to predict the measuring errors for the different active energy meters, considering different harmonic distortion conditions. However, these same results reinforce the adherence of the physical meaning proposed by IEEE Std. 1459 [2] for the active power, with the behavior of the commercial meter under non-sinusoidal conditions.

Finally, the test shown in Fig. 16 reproduces one of the tests carried out in [16], in which errors of up to 500% were recorded in the readings on commercial active energy meters, considering the specific situation presented in Fig. 16a. The voltage waveform considered in Test#10 considers the typical harmonic distortions observed in low-voltage distribution systems, and the current waveform is the result of the simul-

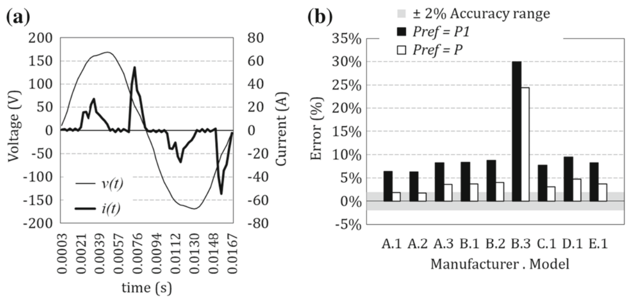

Fig. 16 *Test #10*—voltage with typical harmonic distortions observed in low-voltage distribution systems and current resulting from the simultaneous operation using different light bulbs technologies. **a** Waveforms of voltage and current, **b** resulting errors

taneous operation of different technologies of light bulbs, including LEDs, compact fluorescent lamps and incandescent lamp bulbs with a dimmer.

Although the results shown in Fig. 16b are far from the results presented in [16], all the meters (with only two exceptions) failed the test. In the worst case, verified for meter B.3, an error of almost 25% was verified when considering the theoretical active power (P) as the reference.

Additionally, as noted in Fig. 16b, meter A.2 was one of the meters that showed readings within its precision range, even though it failed in all previous tests. These results suggest that each manufacturer implements its active energy measurement protocols in different ways, since there is no standard protocol for the measurement of active energy in non-sinusoidal conditions. The deviations between the meters monitoring the same voltage and current signal show the total lack of isonomy currently verified in the active energy metering and billing processes around the world.

4 Conclusion

More than a century after the publication of the first studies on the subject, the lack of isonomy in active energy metering remains to the present and without standardization. The results of the tests performed in this study show that meters from different brands and models present different results (and out of the accuracy range) when monitoring the same voltage and current signals in non-sinusoidal conditions. The accuracy range indicated by the manufacturers cannot be considered when these meters operate under distorted conditions of voltage and current, such as those found in the real world. In a specific test, which considered the typical harmonic distortions found in low-voltage systems and the current waveform resulting from the simultaneous operation of different lamp bulb technologies, measurement deviations up to 25% were verified.

Another important aspect shown in the study was the excellent adherence of the active power physical meaning proposed by IEEE Std. 1459, in non-sinusoidal conditions, with the qualitative results presented by different active energy meters.

The authors hope that this information update on the performance of active energy meters under non-sinusoidal conditions will encourage further studies and contribute to the development of new standards for active energy metering for billing purposes.

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Appendix A: Data associated with the tests performed

Test number	Harmonic order	rms Voltage (V)	Angle (°)	rms Current (Amp)	Angle (°)
#1	1	120.0	0.0	10.0	0.0
#2	1	120.0	0.0	10.0	0.0
	5	12.0	0.0	–	–
#3	1	120.0	0.0	10.0	0.0
	5	–	–	5.0	0.0
#4	1	120.0	0.0	10.0	0.0
	5	10.0	0.0	–	–
	7	–	–	5.0	0.0
#5	1	120.0	0.0	10.0	0.0
	5	12.0	0.0	5.0	0.0
#6	1	120.0	0.0	10.0	0.0
	5	12.0	0.0	5.0	180.0
#7	1	120.0	0.0	10.0	0.0
	7	12.0	0.0	5.0	0.0
#8	1	120.0	0.0	10.0	0.0
	7	12.0	0.0	5.0	180.0
#9	1	120.0	0.0	10.0	-32.0
	3	12.0	10.0	1.0	145.0
	5	24.0	45.0	2.0	170.0
#10	1	120.0	0.0	10.0	329.4
	3	1.380	166.8	8.416	292.8
	5	4.656	217.8	6.995	29.4
	7	0.780	272.3	5.313	36.5
	9	0.648	235.5	3.694	92.0
	11	0.804	50.0	2.618	141.1
	13	0.573	66.8	2.566	199.1
	15	0.030	325.8	0.792	310.7
	17	0.134	217.1	2.587	315.8
	19	0.076	189.9	1.031	63.9
	21	0.031	11.8	2.249	71.6
	23	0.028	241.3	0.726	147.9
	25	0.045	178.1	1.468	185.2
	27	0.003	180.3	0.864	260.6

Appendix B: Numerical results of the tests performed

Test	Meter	Reference		P_{Meas} (W)	Error (%)		Test	Meter	Reference		P_{Meas} (W)	Error (%)	
		P_1 (W)	P (W)		$P_{\text{ref}} = P_1$	$P_{\text{ref}} = P$			P_1 (W)	P (W)		$P_{\text{ref}} = P_1$	$P_{\text{ref}} = P$
#1	A.1	1200.0	1200.0	1209.89	0.82	0.82	#6	A.1	1200.0	1140.0	1171.87	**– 2.34**	**2.80**
	A.2	1200.0	1200.0	1187.71	– 1.02	– 1.02		A.2	1200.0	1140.0	1168.07	**– 2.66**	**2.46**
	A.3	1200.0	1200.0	1198.15	– 0.15	– 0.15		A.3	1200.0	1140.0	1142.39	**– 4.80**	0.21
	B.1	1200.0	1200.0	1199.16	– 0.07	– 0.07		B.1	1200.0	1140.0	1138.48	**– 5.13**	– 0.13
	B.2	1200.0	1200.0	1199.38	– 0.05	– 0.05		B.2	1200.0	1140.0	1140.48	**– 4.96**	0.04
	B.3	1200.0	1200.0	1197.67	– 0.19	– 0.19		B.3	1200.0	1140.0	1137.32	**– 5.22**	– 0.24
	C.1	1200.0	1200.0	1199.07	– 0.08	– 0.08		C.1	1200.0	1140.0	1151.18	**– 4.07**	0.98
	D.1	1200.0	1200.0	1211.58	0.96	0.96		D.1	1200.0	1140.0	1150.65	**– 4.11**	0.93
	E.1	1200.0	1200.0	1192.62	– 0.62	– 0.62		E.1	1200.0	1140.0	1145.25	**– 4.56**	0.46
#2	A.1	1200.0	1200.0	1190.40	0.80	0.80	#7	A.1	1200.0	1260.0	1238.46	**3.21**	– 1.71
	A.2	1200.0	1200.0	1210.82	– 0.90	– 0.90		A.2	1200.0	1260.0	1222.26	1.86	**– 3.00**
	A.3	1200.0	1200.0	1202.40	– 0.20	– 0.20		A.3	1200.0	1260.0	1253.79	**4.48**	– 0.49
	B.1	1200.0	1200.0	1201.08	– 0.09	– 0.09		B.1	1200.0	1260.0	1256.93	**4.74**	– 0.24
	B.2	1200.0	1200.0	1200.62	– 0.05	– 0.05		B.2	1200.0	1260.0	1257.64	**4.80**	– 0.19%
	B.3	1200.0	1200.0	1202.52	– 0.21	– 0.21		B.3	1200.0	1260.0	1256.08	**4.67**	– 0.31
	C.1	1200.0	1200.0	1200.93	– 0.08	– 0.08		C.1	1200.0	1260.0	1231.68	**2.64**	**– 2.25**
	D.1	1200.0	1200.0	1189.32	0.89	0.89		D.1	1200.0	1260.0	1261.63	**5.14**	0.13
	E.1	1200.0	1200.0	1207.08	– 0.59	– 0.59		E.1	1200.0	1260.0	1248.96	**4.08**	– 0.88
#3	A.1	1200.0	1200.0	1189.08	0.91	0.91	#8	A.1	1200.0	1140.0	1184.55	– 1.29	**3.91**
	A.2	1200.0	1200.0	1213.20	– 1.10	– 1.10		A.2	1200.0	1140.0	1177.63	– 1.86	**3.30**
	A.3	1200.0	1200.0	1202.40	– 0.20	– 0.20		A.3	1200.0	1140.0	1145.23	**– 4.56**	0.46
	B.1	1200.0	1200.0	1200.84	– 0.07	– 0.07		B.1	1200.0	1140.0	1138.72	**– 5.11**	– 0.11
	B.2	1200.0	1200.0	1200.84	– 0.07	– 0.07		B.2	1200.0	1140.0	1141.41	**– 4.88**	0.12
	B.3	1200.0	1200.0	1201.92	– 0.16	– 0.16		B.3	1200.0	1140.0	1138.94	**– 5.09**	– 0.09
	C.1	1200.0	1200.0	1200.93	– 0.08	– 0.08		C.1	1200.0	1140.0	1167.48	**– 2.71**	**2.41**
	D.1	1200.0	1200.0	1190.40	0.80	0.80		D.1	1200.0	1140.0	1153.93	**– 3.84**	1.22
	E.1	1200.0	1200.0	1207.80	– 0.65	– 0.65		E.1	1200.0	1140.0	1143.54	**– 4.71**	0.31
#4	A.1	1200.0	1200.0	1190.76	0.77	0.77	#9	A.1	1017.7	981.6	996.23	**– 2.11**	1.49
	A.2	1200.0	1200.0	1213.20	– 1.10	– 1.10		A.2	1017.7	981.6	983.46	**– 3.36**	0.19
	A.3	1200.0	1200.0	1202.40	– 0.20	– 0.20		A.3	1017.7	981.6	981.77	**– 3.53**	0.01
	B.1	1200.0	1200.0	1200.84	– 0.07	– 0.07		B.1	1017.7	981.6	981.49	**– 3.55**	– 0.02
	B.2	1200.0	1200.0	1200.60	– 0.05	– 0.05		B.2	1017.7	981.6	981.71	**– 3.53**	0.01
	B.3	1200.0	1200.0	1202.64	– 0.22	– 0.22		B.3	1017.7	981.6	980.18	**– 3.68**	– 0.15
	C.1	1200.0	1200.0	1200.93	– 0.08	– 0.08		C.1	1017.7	981.6	989.13	**– 2.80**	0.76
	D.1	1200.0	1200.0	1187.88	1.01	1.01		D.1	1017.7	981.6	995.91	**– 2.14**	1.45
	E.1	1200.0	1200.0	1206.84	– 0.57	– 0.57		E.1	1017.7	981.6	991.25	**– 2.60**	0.98
#5	A.1	1200.0	1260.0	1249.02	**4.09**	– 0.87	#10	A.1	988.9	1033.2	1052.32	**6.41**	1.85
	A.2	1200.0	1260.0	1229.47	**2.46**	**– 2.42**		A.2	988.9	1033.2	1051.58	**6.33**	1.78
	A.3	1200.0	1260.0	1256.36	**4.70**	– 0.29		A.3	988.9	1033.2	1070.72	**8.27**	**3.63**
	B.1	1200.0	1260.0	1257.32	**4.78**	– 0.21		B.1	988.9	1033.2	1071.82	**8.38**	**3.73**
	B.2	1200.0	1260.0	1259.48	**4.96**	– 0.04		B.2	988.9	1033.2	1075.40	**8.74**	**4.08**
	B.3	1200.0	1260.0	1256.57	**4.71**	– 0.27		B.3	988.9	1033.2	1285.68	**30.01**	**24.43**
	C.1	1200.0	1260.0	1247.35	**3.95**	– 1.00		C.1	988.9	1033.2	1065.48	**7.74**	**3.12**
	D.1	1200.0	1260.0	1264.34	**5.36**	0.34		D.1	988.9	1033.2	1082.78	**9.49**	**4.80**
	E.1	1200.0	1260.0	1230.64	**2.55**	**– 2.33**		E.1	988.9	1033.2	1071.25	**8.32**	**3.68**

Highlighted values indicate results out of the accuracy range

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