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Characterization of multifunction meters based on integrated devices n the presence of harmonic distortion.

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Abstract- This paper is focused on the problem of the metrological characterization of multifunction static meters based on integrated devices, in both reference and actual operating conditions. The influence of the measurement transducers on the performance of such meters is also discussed. The analysis is supported by some experimental tests, which were carried out on a meter based on a commercial integrated device, both in the absence and in the presence of the measurement transducers.

I. Introduction

Nowadays, the development of integrated devices, which are able to implement simultaneously many measurement functions, has lead to the widespread use of static meters, for both firm and portable applications, which can perform the measurement of different electrical quantities, reducing the costs of the instruments. The metrological characterization of such meters has become a crucial issue, in both reference and actual operating conditions, i.e. in the presence of disturbances that can affect the power systems. As regard this, in most real cases, the meters are employed even in the presence of harmonic distortion.

Usually, the manufacturers declare the accuracy specifications of their own integrated devices, in accordance with the current standards. As regard the energy measurements, the standards [1-4] define the requirements that instruments have to comply with in sinusoidal conditions; moreover, they give the test conditions and the accuracy requirements that meters have to satisfy when some influence quantities change with respect to the reference sinusoidal conditions; these quantities are voltage variations, frequency variations, DC components in the current, etc. On the other hand, harmonic distortion is taken into account only for active energy meters, while it is not considered for the reactive energy meters [5, 6]. Thus, the accuracy specifications given by the manufacturer can lose their significance in the presence of harmonic distortion. Moreover, the performance of the meters are strongly related to the employed voltage and current transducers, whose behaviour can be negatively affected by the presence of nonsinusoidal signals.

This paper faces the problem of the metrological characterization of the multifunction static meters based on integrated devices, in both reference and actual operating conditions. The analysis is supported by several experimental tests, which were carried out on a meter based on a commercial integrated device. The first series of tests were carried out in sinusoidal conditions, both in the absence and in the presence of the measurement transducers. In detail, different transducers were used during the experimental tests. Moreover, the tests were repeated in nonsinusoidal conditions, in order to assess the effects of the harmonics on the performance of the meter. Again, the analysis was carried out both in the absence and in the presence of the transducers.

II. The device under test

The meter under test (MUT) employs the integrated device (ID) ADE 7753 by *Analog Devices* [7]. This is a single-phase multifunction metering integrated device, which incorporates two second-order 16-bit Δ-Σ A/D converters, a digital integrator (on channel 1), a temperature sensor, reference circuitry, and all the signal processing required to perform rms calculation on the voltage and current, active, reactive and apparent energy measurements and line-voltage period measurement (zero-crossing). The ADE7753 has two differential input channels (channel 1 for the current and channel 2 for the voltage), with two programmable gain amplifiers, and a selectable on-chip digital integrator, which provides a direct interface to di/dt current sensors (such as Rogowski coils). It provides a serial interface to read data and a pulse output frequency, which is proportional to the active power; various system calibration features (i.e. channel offset correction and phase and power calibration) ensure high accuracy (less than 0,1% declared error in active energy measurement). The block diagram of the ADE7753 is reported in the figure 2. The ID evaluates the RMS values of voltage (and current) by multiplying the signal by itself and by extracting the direct component by means of a low pass filter. The instantaneous power is generated by multiplying the current and voltage signals, p(t) = v(t) i(t); thus, the active power P is the dc component of p(t) and it is obtained by means of a low-pass filter. The reactive power Q is obtained in the same way of P, but, in this case, the current signal is preliminarily shifted by $\pi/2$ (the method implemented for the phase shifting is not declared [5, 8]) .

The MUT is a three-phase demo-board, built by *Layer Electronics*, which was designed for an application on an UPS system with V_{NOM}/V_{MAX} = 230/290 V (RMS), I_{MAX}=36A (RMS), f_{LIN} = 50 Hz ± 15%, class 2 accuracy. It is provided with a microcontroller ATMEL – ATmega32, current and voltage transducers and an analogue circuitry for signal conditioning; in detail, there were three current hall sensors (*Telcon* HTP-50, I_N = 50 A, turns ratio 2000:1, overall accuracy 0,5%, linearity 0,1% I_N) and three voltage transformers (VT) (TIN 51, V_1/V_2 = 230/10 V/V, class 2 accuracy, produced by *Layer Electronics*). Furthermore, in order to analyse the influence of different voltage transducers on the performance of the MUT, the VT on phase R was substituted with a voltage hall sensor R (*LEM*, LV25-P, V_{PN} = 10÷500 V, I_{PN} = 10 mA, conversion ratio 2.500:1.000, overall accuracy 0,9%, linearity <0,2% I_{PN}). The system allows the on-line calibration of voltage, current, active power and apparent power; on the contrary, the calibration of the reactive power is not possible; thus, it was preliminarily adjusted via software.

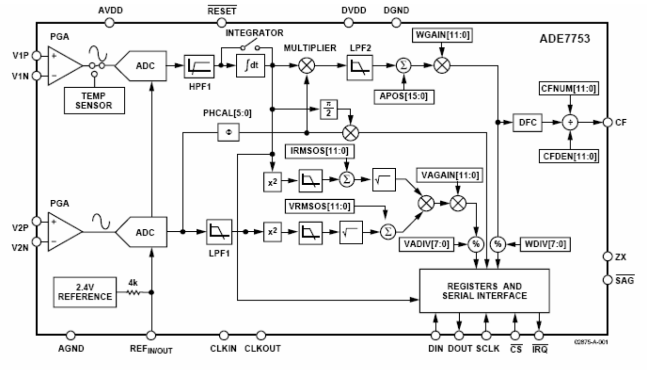

Figure 1: Block diagram of ADE7753

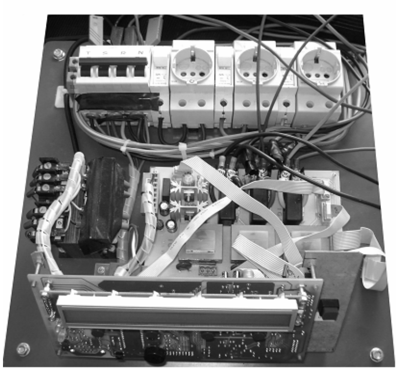

Figure 2: Meter under test

III. Experimental tests

The employed ID support the specifications of the current Standards for static meters for active and reactive energy [1-4]. Thus, the experimental tests were carried out in accordance with these Standards, for sinusoidal conditions. Moreover, the tests were repeated also in the presence of harmonics on voltages and currents, in order to assess the metrological characteristics of the MUT also in nonsinusoidal conditions.

In detail, for the metrological characterization of the metering equipments, the aforesaid standards define the requirements that the instruments have to comply with in sinusoidal conditions, while they do not take into account the presence of harmonic distortion on voltages and/or currents [5, 8]. Only for the active energy meters an accuracy test in the presence of harmonics is considered in [2-3]. On the contrary, the Standards for the reactive energy meters refer to “*a conventional definition of reactive energy for sinusoidal voltages and currents containing only the fundamental frequency*”.

In accordance with the Standards, the accuracy specifications of the MUT were evaluated by means of the percentage error *e%* [1], which is defined as follows:

$$e\% = \frac{W_r - W_t}{W_t} \cdot 100 \qquad (1)$$

where W_r is the energy registered by the meter and W_t is the “*true energy*”. The same standard states that, “*since the true value cannot be determined, it is approximated by a value with a stated uncertainty, that can be traced to standards agreed upon between manufacturer and user or to national standards*”.

For the measurement of the active energy (or power), the percentage error was evaluated assuming as true value the total energy, related to both the fundamental and the harmonic components of active

power. However, with respect to the measurement of the reactive energy, there is a lack of an univocally defined measuring metric to be adopted in the presence of harmonic distortion [5, 8]. On the other hand, it is not possible to define the quantity to be assumed as a "reference energy" for the evaluation of the percentage error. Thus, for the measurement of the reactive energy in nonsinusoidal conditions, the percentage error was calculated with respect to the reactive energy related to the fundamental components of voltages and currents, assumed as conventional "true value" $W_t = W_1$.
The experimental tests were carried out by means of a power calibrator Fluke 6100A Electrical Power Standard, with the "Energy" option, which allowed one to have a fully independent control of voltages and currents during the tests, by connecting the voltage and current terminals of the calibrator respectively to the voltage and current circuit terminals of each MUT. The calibrator gave the "true values" which were used as reference for the evaluation of the percentage errors. The MUT displays directly the measured values.
The first series of tests was performed in sinusoidal conditions, both in the absence and in the presence of the measurement transducers, with the nominal voltage $V_n = 230$ V, different values of current, in the operating range of the MUT, and power factor $\cos\varphi$: $\cos\varphi = 1$, $\cos\varphi = 0{,}5$ and $\cos\varphi = 0{,}25$ inductive (i), $\cos\varphi = 0{,}8$ and $\cos\varphi = 0{,}25$ capacitive (c), for active power measurements [2-3]; $\sin\varphi = 1$ $\sin\varphi = 0{,}5$, $\sin\varphi = 0{,}25$, both inductive and capacitive for reactive power measurements [4]; $\cos\varphi = 0{,}8$i and $\cos\varphi = 0{,}9$i ($\sin\varphi = 0{,}6$i $\sin\varphi = 0{,}447$i), corresponding to a reactive energy respectively equal to 75% and 50% of the active energy (that are the thresholds of penalties for the reactive energy consumption in Italy) [5]. The obtained results are reported in the figures 4 and 5, respectively in the absence and in the presence of the measurement transducers (in the figure 5, TIN and LEM refer to the measurement performed with the voltage transformer and the voltage hall sensor respectively).
As expected, in the sinusoidal case, the MUT showed percentage errors below the class limits. The measurement of reactive power showed the worst behaviour, because of the unfeasibility of calibration of this measurement. As regard the measurement of voltage, current and frequency, the displayed results were always equal to the generated values, for less than the resolution of the display itself (three-digits).

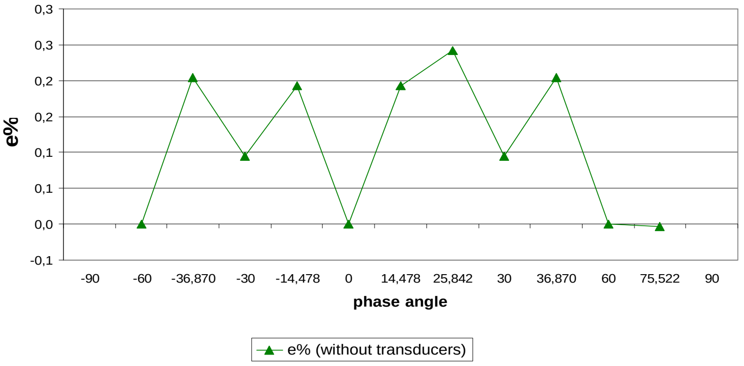

Figure 4a): Experimental results for active power in the absence of the measurement transducers.
Sinusoidal test conditions, V = 230 V, I = 16 A

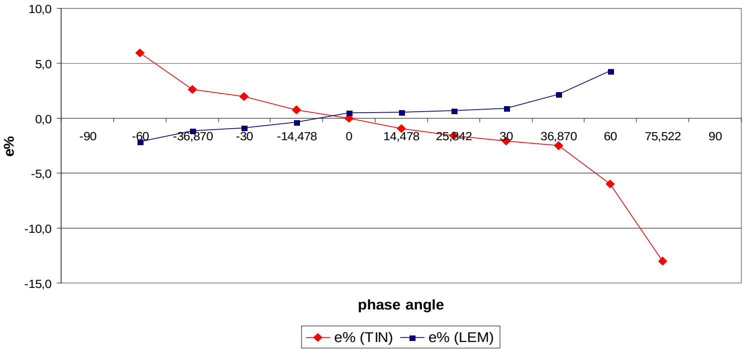

Figure 4b): Experimental results for active power in the presence of the measurement transducers.
Sinusoidal test conditions, V = 230 V, I = 16 A

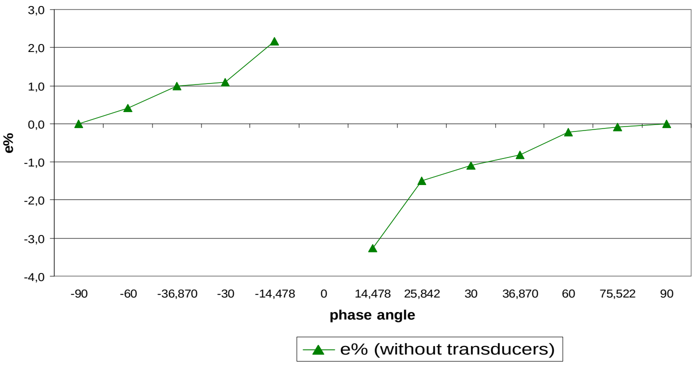

Figure 5a): Experimental results for reactive power in the absence of the measurement transducers. Sinusoidal test conditions, V = 230 V, I = 16 A

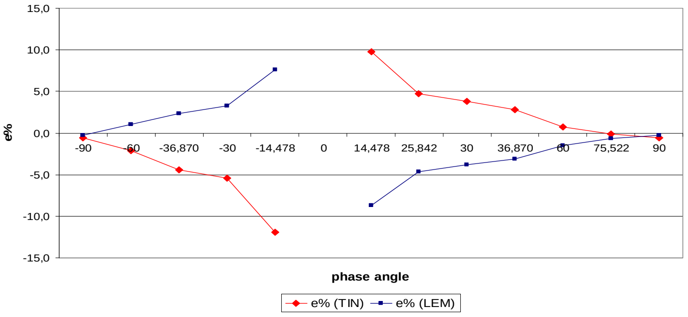

Figure 5b): Experimental results for reactive power in the presence of the measurement transducers. Sinusoidal test conditions, V = 230 V, I = 16 A

The same tests were repeated in nonsinusoidal conditions (in this case the angle φ was referred to the displacement between the fundamental components of voltages and currents). A known harmonic content was introduced on voltages and currents, by means of the power calibrator. Several waveforms for voltages and currents were considered. Some of the obtained results are reported in the figure 6 and 7. Figure 6 refer to the tests with I = 16 A, with a 5th harmonic on both voltage and current, THD$_V$=10% and THD$_I$=40%, phase angle between voltage and current harmonics equal to zero (in accordance with the accuracy test in the presence of harmonics reported in [2-3]).

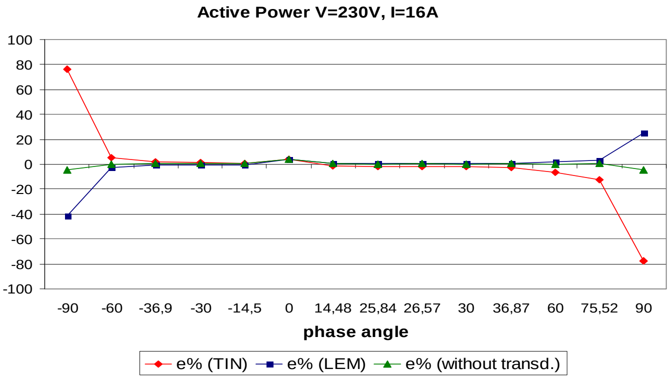

Figure 6a): Experimental results for active power.
Test conditions: V = 230 V, I = 16 A, 5th harmonic on both voltage and current, THDV=10% and THDI=40%, phase angle between voltage and current harmonics equal to zero

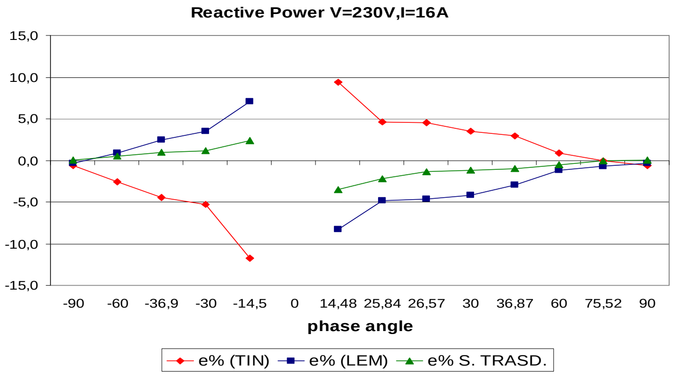

Figure 6b): Experimental results for reactive power.
Test conditions: V = 230 V, I = 16 A, 5th harmonic on both voltage and current, THDV=10% and THDI=40%, phase angle between voltage and current harmonics equal to zero

Figure 7 refer to the tests with I = 16 A, $sin\varphi$ inductive, with a 3rd harmonic on both voltage and current, THD_V=10% and THD_I=40%, phase angle between voltage and current harmonics equal to zero ($sin\varphi$ = 1 – 0,6 – 0,5 – 0,447 – 0,25 inductive).

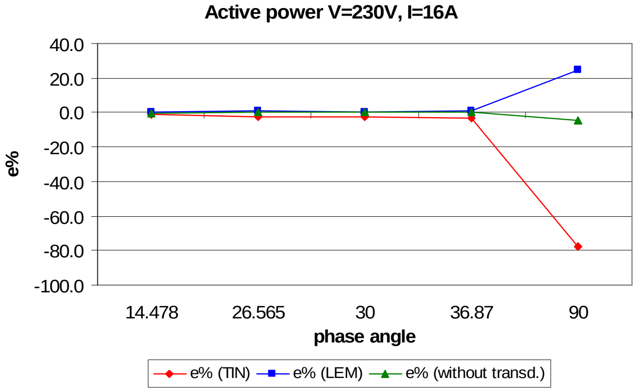

Figure 7a): Experimental results for active power.
Test conditions: V = 230 V, I = 16 A, 3rd harmonic on both voltage and current, THDV=10% and THDI=40%, phase angle between voltage and current harmonics equal to zero

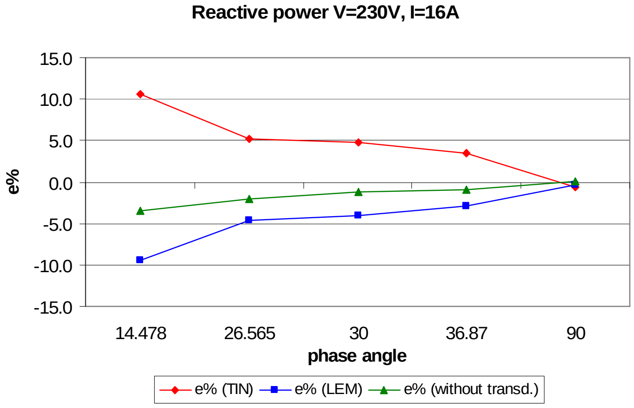

Figure 7b): Experimental results for reactive power.
Test conditions: V = 230 V, I = 16 A, 3rd harmonic on both voltage and current, THDV=10% and THDI=40%, phase angle between voltage and current harmonics equal to zero

As shown in the figures, in the presence of harmonic distortion, the percentage error of the MUT was out of the class limits in some cases. This is mainly due to the characteristics of frequency response of the employed transducers [9]. Moreover, as regard the reactive power, the values of the percentage errors depend not only on the transducers but also on the modalities of measurement implemented in the ID [5, 8] and on the unfeasibility of calibration.

IV. Conclusions

The metrological characterization of multifunction static meters based on integrated devices, in both reference and actual operating conditions is still an open issue. In the paper an experimental analysis has been presented, which was performed on a commercial integrated device, in both sinusoidal and distorted conditions and both in the absence and in the presence of the measurement transducers.

The obtained results showed that the behaviour of the meters can be strongly influenced by the harmonics on voltage and current, depending on the operating principle of the meters, which is not always declared by the manufacturer. As regard this, a more complete standardization is needed. The standards should define the metrological characteristics of the meters in the presence of harmonic distortion, as well as some proper accuracy tests for their verification. On the contrary, standing the current situation, the manufacturers are allowed to implement different operating principles of construction of the meters, which are all in accordance in sinusoidal conditions, but they can give non compatible results in the presence of harmonics. Moreover, in most cases the manufacturers do not specify the operating principle of the meters, thus it is even more difficult to assess the metrological characteristics of the electricity metering equipment.

Finally, the experimental results showed that the performance of the meters are strongly related to the employed voltage and current transducers, whose behaviour can be negatively affected by the presence of nonsinusoidal signals.

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