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MODERN INSTRUMENTS FOR ELECTRICITY MEASUREMENT UNDER PRESENT SITUATION

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This paper refers to present concerns for the modernization of electricity metering in the general context of society modernization, in order to ensure consumer protection regarding trade based on accurate measurements. There are also treated specific aspects on modern means of electricity metering, from the perspective of technical requirements and the metrological requirements of specific normative documents. Electricity metering is conducted by various equipments, known as static meters, developed in recent years, incorporating electronic components. In recent years, the new type meters have progressed quickly, but their performances and functionalities are only partially known and used.

Keywords: static meters, perfomances

1. Introduction

Nowadays electricity is present in all fields, with a decisive role in the economic and the social environment. In our country, with the general process of modernization, the correct measurement of energy has become an increasingly important task due to both increased consumption and unit price and also due to promoted relevant legislation. The consequences of modernization were reflected even on the metering concepts used by specific scientific and practical approaches [1].

The electricity metering is an activity aimed to areas of commercial transactions and therefore all the stakeholders are interested: producers, importers, distributors, consumers and authorities. In measuring alternating current electrical energy there are used different types of measuring instruments. In addition to the traditional electricity meters, which represented the most common measuring instruments in use not long ago, there are the modern electronic meters called static meters [1], [2].

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But the energy quality measurement is the " the key" of fair collaboration between the producers and the users even under the transformations of the power systems.

In order to protect the users – the individuals and the businesses - from the effects of incorrect measurement, the electricity meters are considered instruments belonging to areas of public use, and therefore are subject to the legal metrological control.

In Romania, the Romanian Bureau of Legal Metrology (BRML) [3] provides legal metrological control of the measuring instruments, including electricity meters.

2. The modernization effects of the power system

The amount and the complexity of electrical equipment used by industrial and households increased enormously in recent years. The benefits of using these devices are great, but they bring additional problems. One of the problems is the grid behavior, as users of this new type are found in virtually all areas of the power system. They are constituted of electronic devices whose performance characteristics are influenced by disturbances in the power grid, moreover, they are themselves sources of harmful emissions, thus affecting the power quality.

Significant changes in the structure of power systems have led to the increased complexity of energy measuring, given the widespread presence of non-sinusoidal regime. The modern devices, based on the latest principles and manufacturing techniques, are those that have to work under these new conditions of power systems, and they have even led to important changes in the measurements.

BRML has issued type approvals, following assessments, for a significant number of types of instruments manufactured in Romania or by foreign producers [3]. Some of these measuring instruments are based on design principles currently ranked as the highest technical level in the field today. However, these powerful measuring systems are still scarcely distributed in the national power system.

3. Technical characteristics of static meters

For the manufacture of static meters, altough being in use for such a long period of time, there is still a living concern regarding their upgrade employing the most recent technologies in the fields such as integrated circuit electronics, signal sampling and data communications. The static electricity meter is, in fact, a complex device incorporated in a single unit design, of "regular" size, with special characteristics compared with the previous generation devices.

A few are mentioned, relevant for the measuring function: multifunctional device (multi – energy meters), measuring active and reactive energy for single-phase or three-phase; performance in terms of metrology (improved accuracy); allows viewing and storing measurement data; provides measurement information protection; remote communication using various communications media; billing depending on real time power usage, multi rates; able to pay with card of type "Pre – pay"; easy calibration; reduced power consumption; ability to simultaneously test multiple devices; the possibility to be part of complex systems for measuring, monitoring, telemetery and telecontrol. This modern metering means are able to provide details about the quality of electrical enery. In addition, static meters have to operate in the real electroenergetic system, in the distorted (nonsinusoidal) regime. Fig 1 illustrates schematically the functionalities of the static meter.

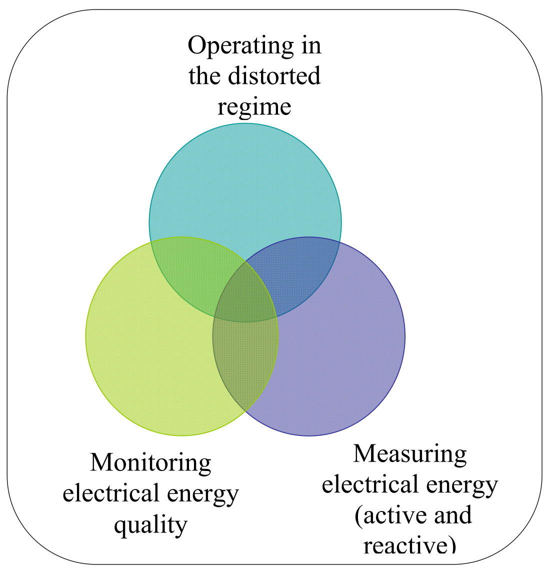

Fig. 1. The functionalities of the static meter

Many of the properties listed above have significant implications and side effects, but their detail is not the subject of this paper. In addition the use of static meters, from the “smart” generation as parts of complex and specialized systems, yields interesting effects [4], [5].

Static electricity meters are built making use of specialazed electronic components (such as analog-digital convertors, multiplicators, digital signal processor, EEPROM memory) – hardware elements – which convert the input curent and voltage to output pulses proportional to the electric energy (active and reactive) [1], [6].

Each meter model implements specific processes and algorithms for computing the electrical quantities: electric active or reactive power and energy. Thereby, with dedicated hardware and software elements, it undergoes the two steps of electricity metering: power computation and its time integration.

Static meters rely on conventional, “clasical” definitions of active and reactive electrical energy in the sinusoidal currents and voltages regime, as one can notice from reference documents [6], [7], [8], [9]. Yet the meters have to operate in the real non-sinusoidal regime.

They are tested to evaluate the effects of influence quantities, according to provisions and conditions from [6], [7], [8], [9]. For example the static meter for active energy is tested with harmonics (variation of the error due to harmonics):

- harmonic components in the current and voltage circuits;
- direct component and even harmonics in the alternative current circuit;
- odd harmonics in the alternative current circuit;
- sub-harmonics in the alternative current circuit [7].

The reactive power defined in the non-sinusoidal regime, in contrast to the sinusoidal regime, exhibits multiple definitions, being a subject widely debated in the literature [1].

There are no requirements imposed, in the specific regulations, regarding the computing equations [6], [7], [8], [9], [10], [11]. The manufacturers of metering equipments have implemented different formulas and algorithms, so as all the respective devices correspond to the requirements at all the performed evaluations.

Our country is in the same situation, the most widely used algorithms and equations (for two important manufacturers) are based on definitions formulated by the professor C.I. Budeanu and Fryze [1].

4. Metrological characteristics of the static meter

The static electricity meters, used in domains of public interest, showed a rapid evolution, the manufacturers seeking to meet current requirements of the users both in technical performance and metrological terms. Static meters are designed to ensure a high level of metrological protection so as the parties have confidence in the measurement results. There will be further approached specific aspects regarding issues related to errors. For the static electricity meters, the error is specified as a relative error, as a percentage error [1], [6]. To determine the percentage errors in electricity metering, using a static meter, the most used method is the method of the direct comparison with a standard meter. The relative error in energy measurement is given by the following relation:

$$\varepsilon = \frac{W_t - W_r}{W_r} \cdot 100 = \left(\frac{W_t}{W_r} - 1 \right) \cdot 100 \qquad [\%] \tag{1}$$

where:

W_t - energy measured and registered by the tested static meter;

W_r - energy measured and registered by the standard static meter (the reference). To test a static meter one has to use a build-in device (in accordance with the requirements of regulations) and the meter's constant, a specific constructive value (printed by the manufacturer on each housing unit or in the technical specifications). The energy measured by the meter in the time interval (t) is given by:

$$W = \frac{N}{C} \text{ [kWh]} \tag{2}$$

where:

W - electric energy measured by the meter in the time interval t [kWh],

N - count of pulses in the considered interval,

C - meter's constant [imp./kWh].

If in the prior relation of the relative error (1) one uses appropriate expression given by equation (2), it follows :

$$\varepsilon = \left(\frac{N_t}{N_r} \cdot \frac{C_r}{C_t} - 1 \right) \cdot 100 \, [\%] \tag{3}$$

where:

N_t - count of pulses of the tested static meter,

N_r - count of pulses of the standard static meter;

C_t - tested static meter's constant;

C_r - standard static meter's constant;

Knowing the number of pulses of the two meters and their constants, using equation (3) one can determine the relative percentage error in the measurement of electrical energy, under certain conditions. During metrological tests, specialized built-in electrical modules, of the standard (reference) meter, are computing the error (the reference meters are complex equipments that facilitate metrological tests). The results obtained – the values of the percentage error of the tested static meter - are shown on the display device fitted to the standard meter.

To illustrate the metrological behavior of the static electricity meter, there are presented the results of tests carried out employing meters of several types (considering the context provided by the assessments conducted when granting type approvals).

The first issue addressed concerns the differences between the errors in the measurement of the electrical energy, employing a traditional electromechanical meter, compared to the errors of a single-phase static meter, under similar conditions. The two meters used have similar characteristics and are suitable to be used in different applications, for industrial consumers as well as for households. The characteristics of this meters are:

- meter for direct connection,
- class index 2 for active energy,
- reference voltage, U_n=230 V,
- reference frequency, f_n=50 Hz,
- basic current, I_n=5 A,
- maximum current, I_{max}=30 A.

Thus, there have been determined the relative errors of the measured active energy, with values for the current in the range $0{,}1 \cdot I_b \leq I \leq I_{\max}$ and under different situations: reference conditions, voltage variations ±10%, frequency variations ±2% [4], [5]. Fig. 2 illustrates relative measurement errors when measuring active energy with the traditional electromechanical meter (type CD) and Fig. 3 the relative errors when measuring active energy with the single-phase static meter (type CSM) (with the characteristics mentioned above) and the input current value in the specified range of: $I = 0{,}1 \cdot I_b = 0{,}1 \cdot 5 = 0{,}5A; I = I_b = 5A; I = I_{\max} = 100A$

The bounds for the percentage error of a class index 2 meter, under variations of the current and under the reference conditions is ± 2,00%, when measuring active energy (according to the normative reference documents [7]). In the two figures, the meanings of notations for the percentage errors for the measured active electrical energy (A) are: terms of reference (ref), voltage variation of ±10%·U_n (U+ or U-) and frequency variation of ± 2%·f_n (f+ and f-).

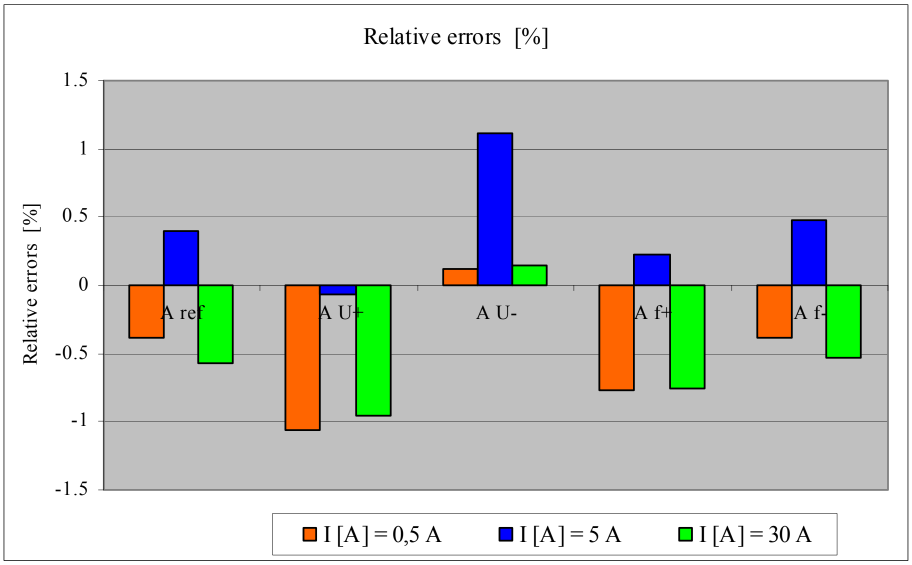

Fig. 2. The relative errors for the measurement of active energy – meter type CD.

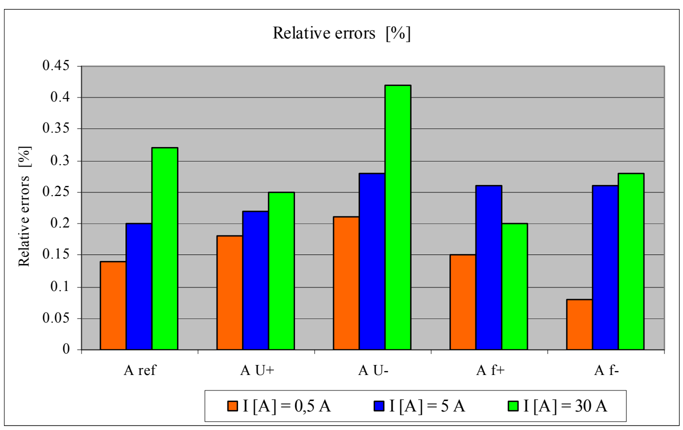

Fig. 3. The relative errors for the measurement of active energy - meter type CSM.

From the results of these tests it is found a different behavior of the meter type CSM compared to the meter type CD.

As can be seen from these figures, the errors determined are within the limits, for the entire range of the input current, for both meters. Also the errors for the meter type CSM are much smaller compared to those of the meter type CD (for example the errors “A ref” for the basic current, I_n=5 A).

For meter type CD the error sign alternates for the entire input current variation domain (in all the conditions under which the experiments were carried out). For meter type CSM the error sign is constant, in all situations (reference conditions, voltage variations ±10% and frequency variations ±2%).

The following are aspects of the behavior of different types of static meters, in various test conditions. When evaluating the performance of all meters there are checked all the technical and metrological conformances from normative documents (by determining errors and error variations due to the variation of influence quantities and verifing whether the results obtained are within the limits provided in the respective documents) according to strict procedures. In addition, to illustrate the behaviour of the static meters, these error values can be used to develop graphics:

$\varepsilon = f(I)$, which indicate errors (ε) and any error trends according to different values of the current (I) flowing through the investigated device [4].

Such graphics obtained for measurements of electrical active energy, for two static three-phase meters of different types (type CST1 and type CST2), but with similar characteristics, manufactured by two distinct Romanian producers, are presented in fig. 4 and in fig. 5. The conditions of measurement are:

- εref_cosφ=1 - error determined in reference conditions, for cos φ=1;
- εref_cosφ=0.5 - error determined in reference conditions, for cos φ=0,5;
- εu-_cosφ=1 - error determined in voltage variation condition with -10% from the nominal value, for cos φ=1, and
- εu-_cosφ=0.5 - error determined in voltage variation condition with -10% from the nominal value, for cos φ=0,5).

The characteristics of these meters are:

Three-phase static meter type CST1	**Three-phase static meter type CST2**
- meter for direct connection, - class index 0,2 for active energy, - reference voltage, U_n=3x230/400 V, - reference frequency, f_n=50 Hz, - basic current, I_n=30 A, - maximum current, I_{max}=100 A.	- meter for direct connection, - class index 1 for active energy, - reference voltage, U_n=3x230/400 V, - reference frequency, f_n=50 Hz, - basic current, I_n=5 A, - maximum current, I_{max}=100 A.

For a static single-phase meter type CSM1, which is manufactured in two versions for direct connection (V1 and V2, which differ in some electronic components implementing additional facilities, the formulas, algorithms and software being the same, according to the manufacturer's documents), there are shown in graphics fig. 6 and fig.7 the errors determined for reactive energy measurements.

In addition, for the measurement of reactive energy, there are shown in fig. 8 and in fig. 9 the graphical representations of errors determined for two different types of three-phase static meters (type CST3 and CST4), in various conditions:

- εrref_sinφ=1 - error determined in reference conditions for sin φ=1;
- εrref_sinφ=0.5 - error determined in reference conditions for sin φ=0,5;
- εru+_sinφ=1 – error determined in conditions of +10% voltage variation from nominal value, for sin φ=1
- εru+_sinφ=0.5 - error determined in conditions of +10% voltage variation from nominal value, for sin φ=0,5.

The main characteristics of the meter type CST3 are:

- meter for indirect connection,
- class index 2 for reactive energy
- reference voltage, U_n=3x230V/400 V,
- reference frequency, f_n=50 Hz,
- basic current, I_n=5 A,
- maximum current, I_{max}= 6 A. The difference for the CST4 consists of:
- maximum current, I_{max}=10 A.

CST4 is one of the most advanced three-phase static meter on the field today. For this meter fig. 10 illustrates its measuring errors in various conditions, for active energy (notations similar to the previous ones).

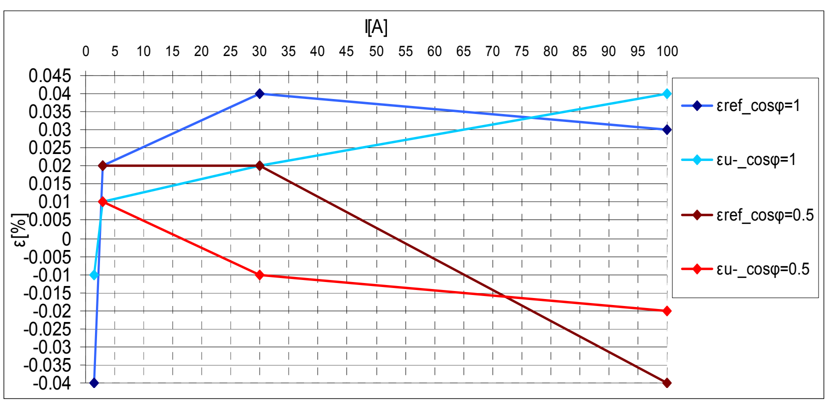

Fig. 4. Graphical representation of the errors evolution due to -10% voltage deviation from the reference voltage, for active energy measurement – meter type CST1

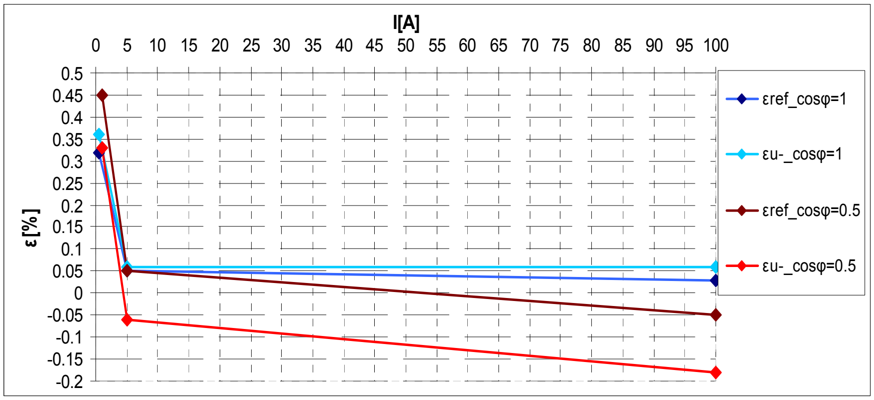

Fig.5. Graphical representation of the errors evolution due to -10% voltage deviation from the reference voltage, for active energy measurement – meter type CST2

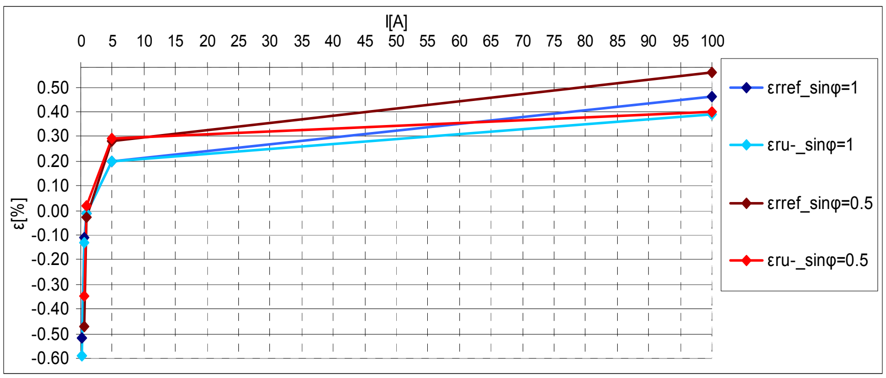

Fig. 6. Graphical representation of the errors evolution due to -10% voltage deviation from reference voltage, for reactive energy measurement - meter type CSM1/V1

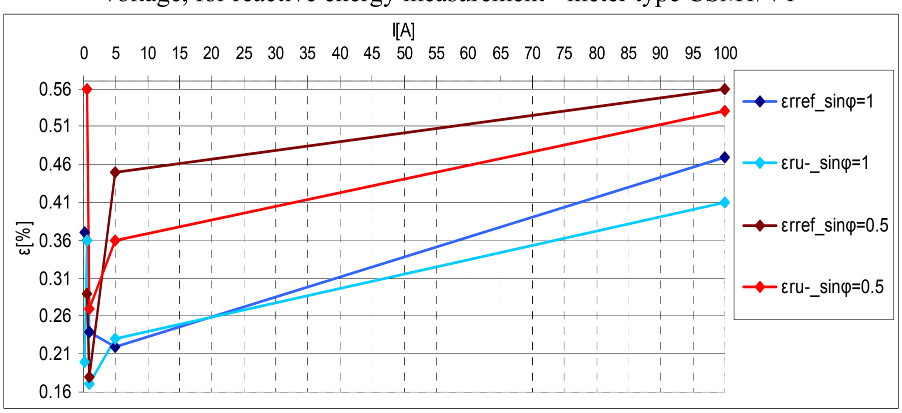

Fig. 7. Graphical representation of the errors evolution due to -10% voltage deviation from reference voltage, for reactive energy measurement - meter type CSM1/V2

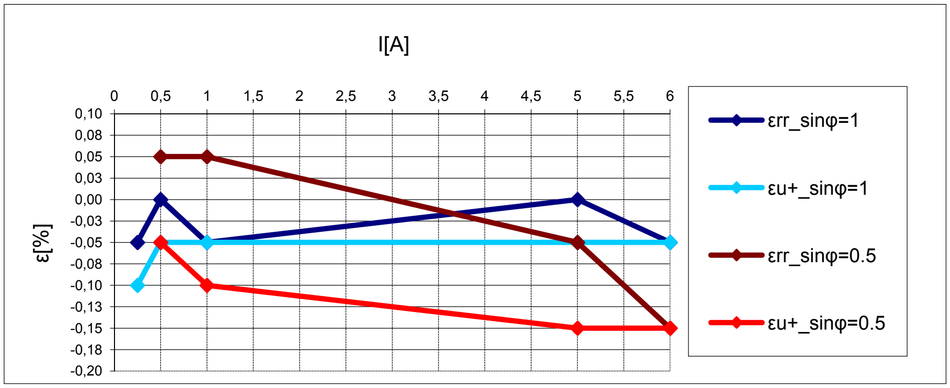

Fig.8 Graphical representation of the evolution of errors due to +10% voltage variation from reference voltage, for measuring reactive energy – meter type CST3

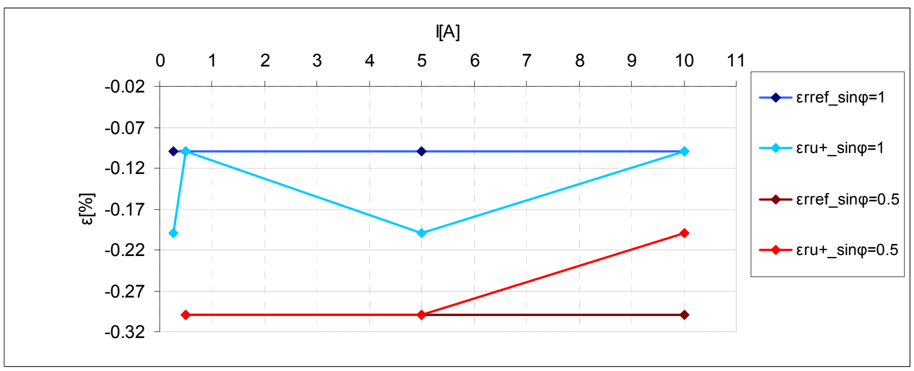

Fig.9. Graphical representation of the evolution of errors due to +10% voltage variation from reference voltage, for measuring reactive energy – meter type CST4

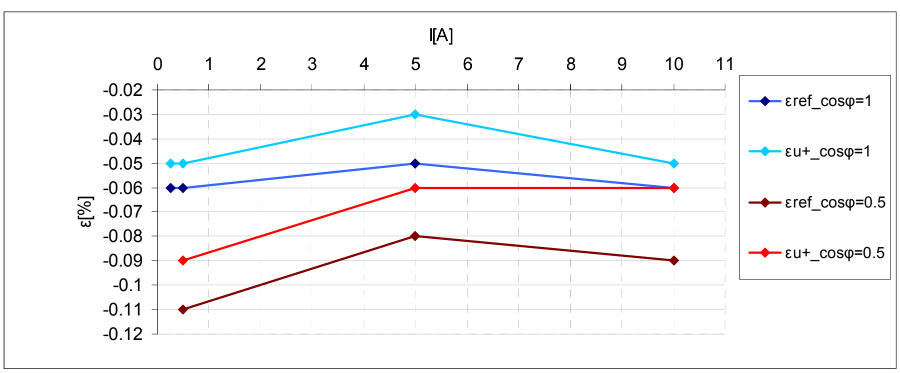

Fig.10. Graphical representation of the evolution of errors due to +10% voltage variation from reference voltage, for measuring active energy – meter type CST4

In addition to the provisions of the related measurement procedures [10], [11], the determined error values as well as error variations will be plotted in several charts:

$\Delta\varepsilon = f(I)$, error variation with respect to the input current.

Fig. 11 illustrates, for the meter type CST4, the chart of error variation due to voltage variation, measuring active energy, while fig. 12 is for reactive energy. These charts map the errors resulted from ±10% voltage variation from reference voltage, both for cos φ=1 and cos φ=0,5, as well as for sin φ=1 and sin φ=0.5. The „ctrafo …" and „cdirecta …" notations are indicating the connection mode of the tested meter.

All the figures, fig. 4 to fig. 12 highlight static meter's behaviour under various conditions. All these graphical representation show that the determined errors for the static meters, in the respective conditions, are well within the bounds imposed by the applicable reference documents.

Also it is noticeable that the error values form curves sugesting distinct „evolutions", related to each distinct constructive model. For static meters with similar parameters, under similar test situations, the behavior is different and the graphs obtained show that (fig. 4 and fig. 5; fig. 8 and fig. 9). This difference in behavior for the static meters are due to specific conceptual elements of each device type, both hardware and algorithmical as well as formulas implementing them.

The fig. 6 and fig. 7 accounting for a single type of meter, having two constructive versions for direct connection, show the importance of the constructive elements and their influence to the meter's behaviour.

It can be said that, in addition to the effects due to different algorithms implemented in the static meters, for reactive energy computation, there are other effects due to electronic components selected by each manufacturer. The formulas and algorithms stored in the non-volatile memory of the meter are equaly important as the related hardware items. This feature has been notified for the last generation of static meters as well [4], [5]. Proper billing of the electricity is strongly related to the accuracy of measurement of the installed electricity meters.

Energy measurement accuaracy is important for households billing as well as for balances of energy or its transit through the electricity transmission system. In the case of static meters, the high accuracy class, is perhaps, the most important gain. The accuaracy class of modern static meters represents an important gain, because scientists have developed advanced equipment, with accuracy class of 0,2S and 0,5S for the active energy and, respectively, with accuracy class of 2 and 3 for reactive energy. Thus, for any instrument in general and in particular for a static meter the accuracy of the meter is described quantitatively by the error of the measurement, the accuracy class being higher when the error is reduced [1].

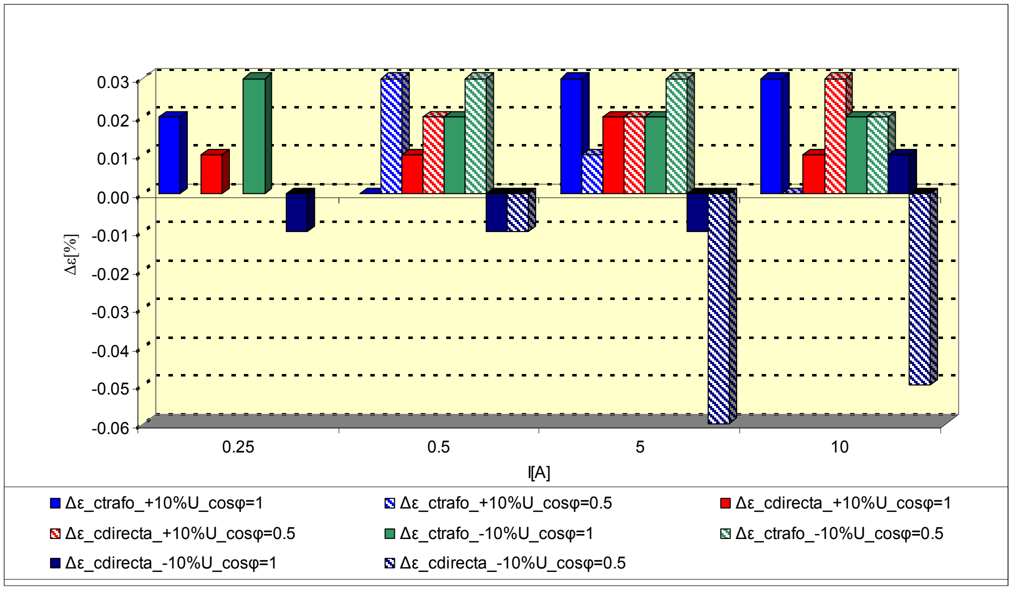

Fig.11. The chart of the errors variation due to ±10% voltage variation from reference voltage, for measuring active energy – meter type CST4

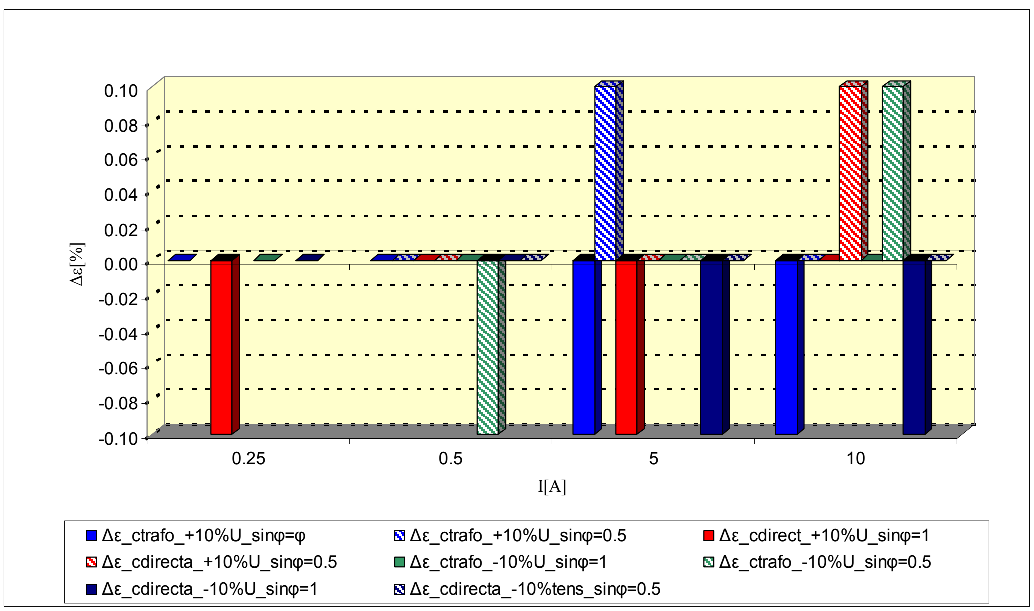

Fig.12. The chart of the errors variation due to ±10% voltage variation from reference voltage, for measuring reactive energy – meter type CST4

On the other hand, as shown in [12], it is considered the error as having a random component and a systematic part. Also, the random error is assumed to be caused by unpredictable variations of influence quantities [12]. Random error assessment is conducted by repeating measurements, but to assess the systematic error, more information is needed about the metering.

The experimental standard deviation $s(q_k)$, for a series of n measurements of the same measurand, characterizes the results dispersion and is given by [12]:

$$s(q_k) = \sqrt{\frac{\sum_{k=1}^{n}(q_k - \overline{q})^2}{n-1}} \tag{4}$$

where:

$s(q_k)$ – is the experimental standard deviation,

q_k - is the result (value) of the k-th measurement,

$\overline{q}$ - is the arithmetic mean of the *n* results considered.

The experimental standard deviation of the mean is [12] :

$$\frac{s(q_k)}{\sqrt{n}} \tag{5}$$

This is an estimate of the standard deviation of the distribution of the average ($\overline{q}$).

To investigate the static meter type CSM1 in measuring the active energy, it is determined the experimental standard deviation $s(q_k)$ based on the relation (4) for a total of n=25 measurements of the same measurand carried out for the following cases:

a) the investigated static meter type CSM1 is under reference conditions.

The characteristics of this static meter are:

- meter for direct connection,
- class index 1 for active energy, and 2 for reactive energy,
- reference voltage, U_n=230 V,
- reference frequency, f_n=50 Hz,
- basic current, I_n=5 A,
- maximum current, I_{max}=100 A.

For the 25 measurements there are determined 25 values (results) for q_k and also computed their arithmetic mean $\overline{q}$=0,21688 %. Also there are calculated, in order, $(q_k - \overline{q})$ and $(q_k - \overline{q})^2$ for each appropriate measurement q_k of the n =25. The experimental standard deviation is determined by the relation (4):

$s(q_k) = 0{,}01051$ %.

The experimental standard deviation of the mean is:

$$\frac{s(q_k)}{\sqrt{n}} = \frac{0{,}01051}{\sqrt{25}} = 0{,}00210\%$$

b) the non-sinusoidal input current of the meter is I = 24,796 A, characterized by the current waveform distortion factor: THD_I =25,218 %, containing, besides the fundamental harmonic, the 3-rd order harmonic (of amplitude 25% from the fundamental), 5-th order harmonic (of amplitude 7% from the fundamental), and the 7-th order harmonic (of amplitude 2% from the fundamental). During the test, the static meter has been powered at sinusoidal reference voltage.

The total distortion factor (THD_I sau THD_U) is one of the most important indicators that define the deviation from the sinusoidal curve of the analyzed electric size (current or voltage). In literature [1] it is considered that for most distribution networks, the most common values are around THD_I=20÷30%. Following the same steps as in case a) the experimental standard deviation is computed using relation (4).

It follows: $\overline{q} =$ 0,27292%, $s(q_k)$ = 0,00655% and the $\frac{s(q_k)}{\sqrt{n}} = 0{,}00131\%$

Fig. 13 and fig. 14 illustrate the results distribution for the n=25 measurements conducted for the static three-phase meter type CSM1, for the tests from case a) and case b).

By analyzing the above results one should observe:

- the average relative error values determined in a) and b) are different;
- the presence of the distorted current affects slightly the determined relative error;
- individual results are slightly different in values; this proves the influence of random quantities variations.

It is noted again that modern equipment for electricity metering hold excellent constructive and technical performances.

In terms of the provisions of the regulations, static electricity meters have high accuracy, with determined error values much lower than the maximum provided by the reference normative documents, and the small value of dispersion contributing to validate metrological performances.

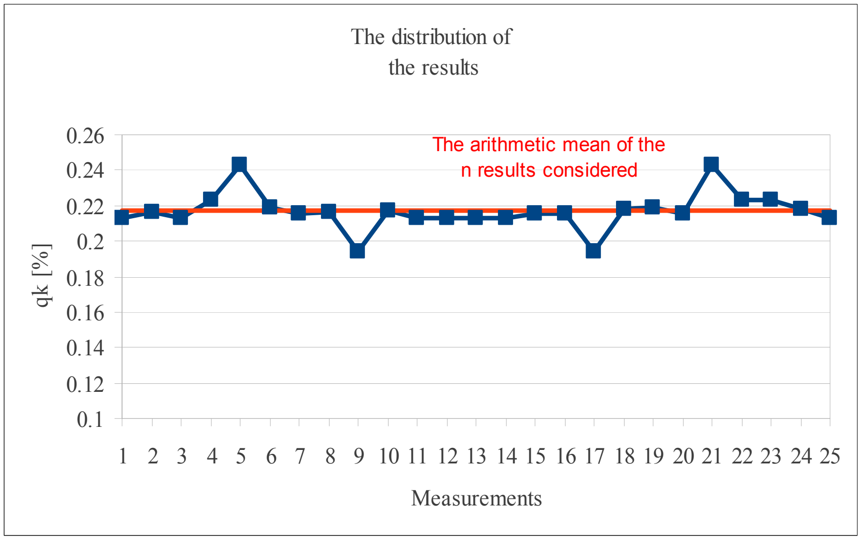

Fig. 13. The distribution of the results for *n*=25 measurements - meter type CSM1 (under reference conditions)

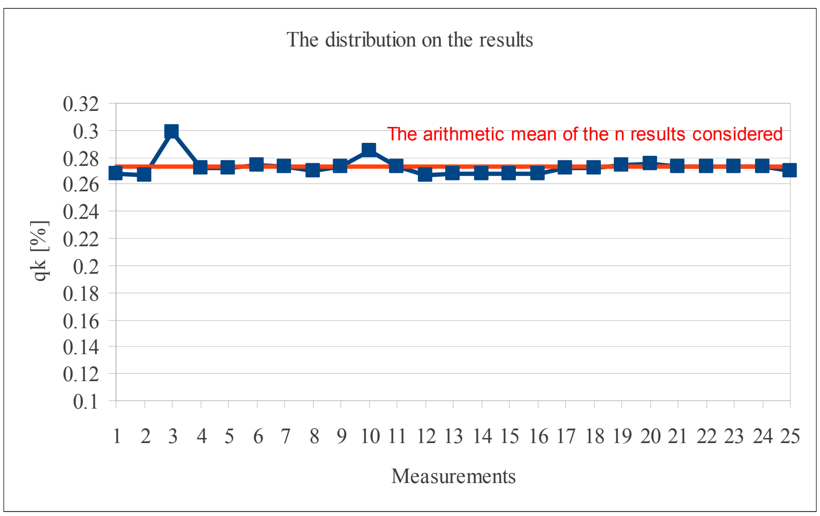

Fig. 14. The distribution of the result for n=25 measurements – meter type CSM1 (for THD_I =25,218 %)

6. Conclusions

Since new trends and regulations in the field of electricity require flexible structures for measuring and monitoring, leading to a flexible and modern energy management, it is expected that these devices are capable to help achieve these goals.

The test results presented in this paper highlight the performance of modern meters, designed to measure electric energy in the present power systems. However, the issues highlighted show that using static electricity meters can significantly improve the quality of measurements. Because the “fundamental feature of a measurement is accuracy” [1], users of measuring instruments are mostly concerned of the metering accuracy.

Static meters are modern measuring instruments, characterised by new performances and because they perform accurate measurements, they show a degree of consistency close to the true value of energy consumed. Using static meters, starting with the management of individual consumption by responsible actions and awareness of electricity use by each entity, and multiple convergent actions, you get to reduce energy consumed.

The static meters for measuring electricity provide functionalities and features that are not fully operated in common use. These devices are used in practice in many cases, just as traditional electromechanical meters, to indicate the electrical energy consumed. The new functionalities static meters perform are not sufficiently known and hence are not used (eg. facility to track consumption by recording the load curve, consumption adaptation for some hourly intervals with differentiated fees). Monitoring electrical energy consumption remotely, via dedicated systems that are relying on measurements information provided by the static meter of each user (qualitative and quantitative parameters of the recorded energy) represents an opportunity that should be increasingly used.

Relevant authorities and other stakeholders should conduct actions and awareness programs to inform about their consequences of implementation and to encourage the use of solutions for "smart metering".

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