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Investigation of Energy Commercial Metering set’s Elements Errors

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Introduction

Modern metering of electric power and energy in electricity market requires paying more attention to accuracy of metering systems and scientific reasoning of metering formal documents. Electric energy metering of proper accuracy is fairly complicated problem, which requires systematic attitude into various influencing factors and also compatibility of technical and organizational tasks. To achieve these tasks formal documents, practical experience, state of electric energy metering equipment, automated commercial metering and information systems design results, operational conditions of metering equipment, order of metrological maintenance and accuracy control and organization should be analyzed.

On the basis of performed scientific and experimental research analysis [1] it could stated, that current state of electric energy metering equipment not always satisfactory, and incorrect application of metrological rules and standards can cause incorrect energy metering. The reason of this can be incorrect evaluation of systematic errors, operation of current transformers (TA) in the area of low current and incorrect selection of secondary circuit load, overload or insufficient load of voltage transformers (TV) secondary circuits, voltage losses in the circuits connecting voltage transformers and energy meters, morally and physically old induction meters and etc.

Systematic errors of metering systems are caused not only by measuring transformers errors, but also by incorrect connection of current transformers secondary circuits and energy meters, low value of secondary circuit power factor, unequal phase load of measuring transformers, insufficient sensitivity of domestic meters and influence of magnetic and electromagnetic field on energy meters.

Errors of electric energy metering circuits

It is advisable to separate energy metering complex into metering circuits, energy meter and data transmission device (Fig. 1). Accuracy investigation of each part energy metering complex and determination or evaluation of compensation of systematic errors enables determination of random errors values not only for separate complex part, but also for the whole metering complex.

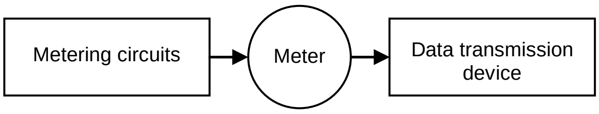

Fig. 1. Structure of energy metering complex

Investigating accuracy of energy metering complex it is important to determine the influence of measuring transformers errors and connection circuits’ parameters on energy metering accuracy, to present the methodology of increase of metering accuracy and to plan measures of systematic errors reduction or elimination. This is important, because the influence of metering circuits’ elements on the metering accuracy is crucial.

For evaluation of metering circuits measuring transformers errors’ margins the following equation could be used

$$\delta = \pm 1.1\sqrt{\delta_{\mathrm{I}}^2 + \delta_{\mathrm{U}}^2 + \delta_{\varphi\mathrm{I}}^2 + \delta_{\varphi\mathrm{U}}^2}\,, \tag{1}$$

here δ_{I} is the relative error of current measuring transformer; δ_{U} is the relative error of voltage measuring transformer; $\delta_{\mathrm{I}\theta}$ is the phase angle error of current measuring transformer; $\delta_{\mathrm{U}\theta}$ is the phase angle error of voltage measuring transformer; 1.1 is the factor evaluating peculiarities of metrological revise and errors of reference devices.

Using the values of accuracy classes in the proposed equation (1), it is possible to determine not actual, but permissible errors with rated parameters conditions. Besides, average square error with „±“ sign shows, that this random (symmetrical) error with zero systematic error value. Practically it is necessary to determine not marginal, but most probable errors’ values. Accuracy classes of metering devices show only the range of probable errors at the rated load, but the real load can vary in the wide range and errors can exceed the accuracy class significantly. Therefore it is important to determine real measuring transformers' current and voltage errors and also phase angle errors in the whole measured current and voltage range at the specific secondary load.

Ratio and phase angle errors of measuring transformers

Measuring transformers are one of the most important elements influencing energy metering errors. The loading of secondary circuits and the primary current value have the biggest influence on metrological characteristics of current transformers. Dependence of current transformers errors on the loading of secondary circuits is not linear because of the material qualities of magnetic circuit [2-4].

The lack of information about the current transformers errors appears in such cases, when secondary circuit loading is higher then rated or lower then permissible loading of 25 % rated value or minimal loading of 1 VA. Standards do not regulate the errors when primary circuit current is lower then 1 % or higher then 120 % of rated value.

The performed analysis of current errors and phase angle errors [2-4] (Fig. 2 and 3) of current transformers TOL10-1-300/5 manufactured in Russia, with accuracy class of 0.5 and rated secondary circuit load of 10 VA, show that having secondary circuit load equal to 0.25 S_N and 1.0 S_N current errors do not exceed standard values. Current errors vary from negative to positive values only having permissible load of 0.25 S_N.

With increasing secondary load of current transformer current errors begin to exceed the standard ranges in the whole primary current range and move to the negative zone with increasing trend. The growth of the negative error is very noticeable in the low current zone and can reach the value of 6 % (Fig. 2).

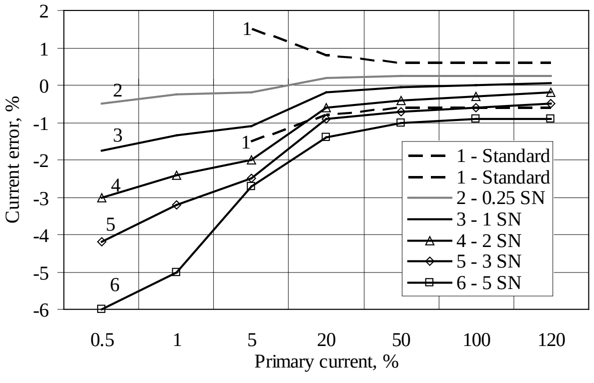

Fig. 2. Current errors of current measuring transformer TOL10-1

Phase angle errors of investigated current transformers are positive in the whole secondary circuit load and do not exceed standard values. More noticeable dependence of phase angle on current transformer secondary circuit load starts with decreasing primary current till 20 % rated value and increases dramatically in the zone of low primary current (0.5–5 %) (Fig. 3) and can reach the value of 200 min.

Power lines' flows of power companies' change because of uneven development of economy or redistribution of territorial loads, therefore current in some power lines is increasing and in the other ones – is decreasing. These changes influence the shift of operating point into low current zone and sometimes into zone exceeding rated current. Errors of measuring transformers with magnetic circuit made of electrical steel in this zone increase dramatically. The other shortage of these current transformers is small possibility of secondary current limiting when primary current exceeds security factor of measuring devices. Trying to extend the measurement ranges of current transformers and to achieve high accuracy and security of measuring devices, magnetic circuit amorphous alloy for the current transformer metering winding is used. Accuracy class of such transformers reaches 0.2 S and the range of current measurements is extended from 1 % to 120 % of rated current, and the transformation ratio of transformer can be varied easily. Trying to evaluate the errors of current transformers with amorphous alloy magnetic circuit investigation of 0.2 S accuracy class current transformer EJOF was performed. Current and phase angle errors were determined for the secondary circuit load 0.4 S_N and S_N (S_N=2.5 VA) with transformation ratio 100/1 A (Fig. 4 and 5).

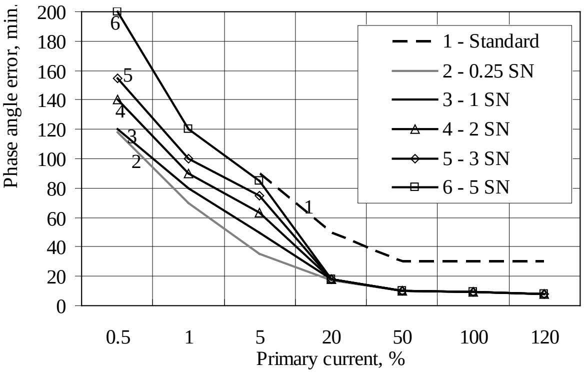

Fig. 3. Phase angle errors of current measuring transformer TOL10-1

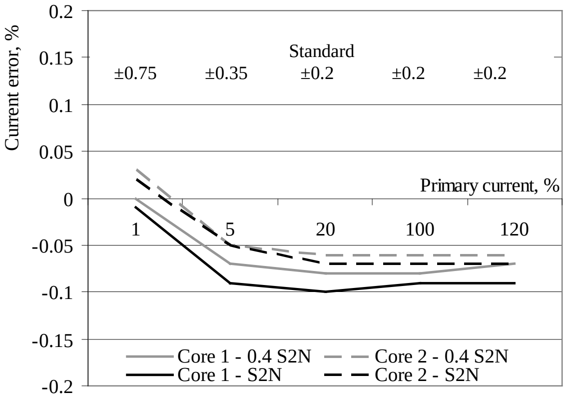

Fig. 4. Current errors of 0.2 S accuracy class current transformer EJOF with the secondary circuit load 0.4 S_N and S_N and transformation ratio 100/1 A

Investigation results show that errors of current transformers with amorphous alloy magnetic circuit are not only less (Fig. 4) then errors of current transformers with electrical steel magnetic circuit, but even changing their character. In the zone of low currents errors have the trend to increase and to reach positive values. With the decreasing secondary circuit load of current transformer, current errors are decreasing and for different magnetic circuits are not equal (Fig. 4).

Phase angle errors of current transformers with amorphous alloy magnetic circuit are less (Fig. 5) and have the same character as current transformers with electrical steel magnetic circuit. Phase angle errors are positive and more evenly depend on current transformers secondary circuit loading in the whole primary current zone (Fig. 5).

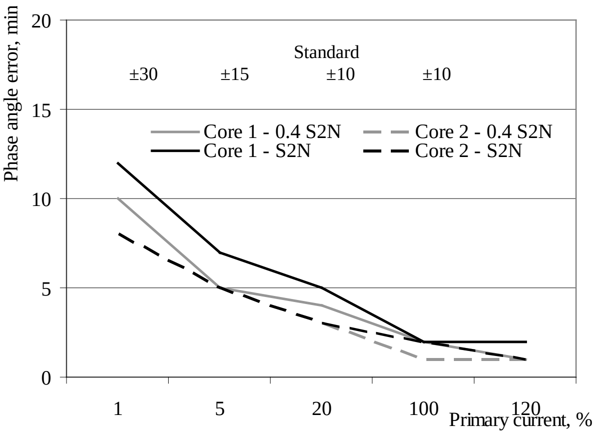

Fig. 5. Phase angle errors of 0.2 S accuracy class current transformer EJOF with the secondary circuit load 0.4 S_N and S_N and transformation ratio 100/1 A

The performed investigation and the obtained results show that means of accuracy enhancement used for current transformers with electrical steel magnetic circuit may be not suitable for current transformers with amorphous alloy magnetic circuit. Despite of the differences, all investigations prove the dependence of current transformers current and phase angle errors on secondary circuit loading. The correct selection of current transformers secondary circuit loading may be one of the means of energy metering accuracy enhancement and elimination of systematic errors.

Therefore it is necessary to know not only standard errors margins of current transformers, but also real errors' values for the appropriate secondary circuit loading provided in the standard, i. e. 0.25 S_N–0.5 S_N–0.75 S_N–1.0 S_N. It is also advisable to determine these errors for the lower secondary circuit loading (from 0 to 0.125 S_N).

The other main energy metering circuit device is voltage transformer, which is also has an influence on energy metering accuracy by its voltage and phase angle errors. Investigation of EJOF 0.2 accuracy class voltage transformer, which rated loading is 5 VA and transformation ratio 110 000/100 V, was performed for the determination of real voltage transformers errors. Voltage and phase angle errors were determined at the zero and rated voltage transformer secondary circuit loading and rated primary and secondary winding loading, i. e. 5 VA and 10 VA respectively (Fig. 6).

The investigation results show that voltage transformer voltage error does not depend on voltage level and for the zero loading is close to accuracy class positive value. The error is decreasing with the increasing load and this decrease depends on the second load of the secondary circuit (Fig. 6).

It was also tested that phase angle errors for this type of transformers is equal to zero.

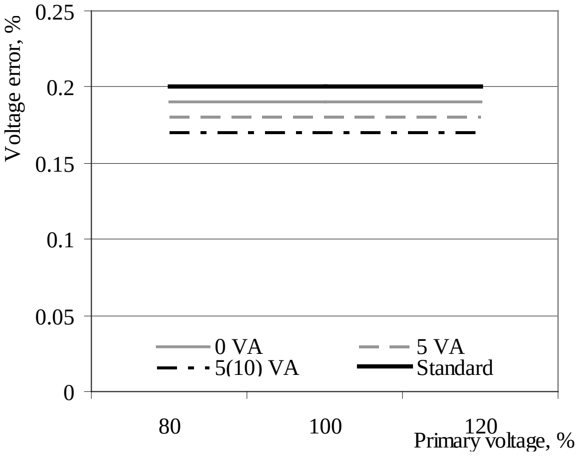

Fig. 6. Voltage errors of 0.2 accuracy class voltage transformer EJOF with zero and rated secondary circuit load

Influence of measuring transformers secondary errors on energy metering accuracy

Current transformers positive phase angle errors, voltage transformers positive voltage errors and measured power line load character can have a significant influence on energy meters connected through measuring transformers metering accuracy. EJOF type current and voltage transformers ratio errors and phase angle errors having active–inductive and active–capacitive line load were used for energy metering accuracy investigation.

Vector diagram of primary and secondary windings' current and voltage of electric power line with lagging current over voltage, is shown in Fig. 7. Positive phase angle error of current transformer at low primary current is much higher then voltage transformer phase angle error. Having active–inductive load of controllable connection, angle between current and voltage at measuring transformers secondary circuits is decreased ($\varphi_2<\varphi_1$) (Fig. 7).

When voltage transformer phase angle error is negative, the angle φ_2 of secondary circuits is decreasing even more. This angle decrease at the secondary circuit influence that active energy is measured with positive error and reactive energy with negative and increase the power factor of power line ($\cos\varphi_2>\cos\varphi_1$).

In case of inductive load character measuring transformers' secondary circuit angle between voltage and current, despite the voltage phase angle error direction, can be determined as follows

$$\varphi_2 = \varphi_1 - \delta_{\varphi \mathrm{I}} + \delta_{\varphi \mathrm{U}} , \tag{2}$$

here φ_1 is the angle between voltage and current in measuring transformers primary circuits.

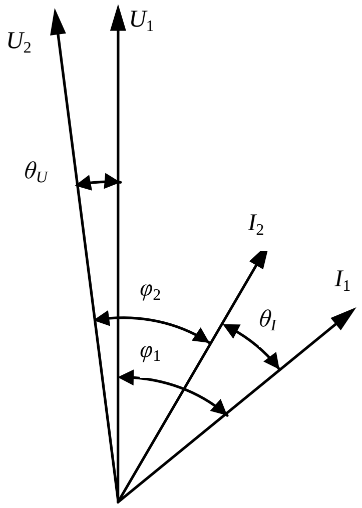

Fig. 7. Vector diagram of currents and voltages with lagging current over voltage

Calculation results investigating EJOF type 0.2 S accuracy class current and 0.2 class voltage measuring transformers influence of phase angle errors on energy metering accuracy are provided in Fig. 8 and 9.

Calculation results show that measuring transformers' phase angle errors do not have influence on energy metering accuracy when load is active (Fig. 8), but with decreasing power factor and current, influence of phase angle errors is getting bigger Fig. 8 and 9 and always are positive. So the conclusion could be that with inductive power line load readings of the power meter would always be increased.

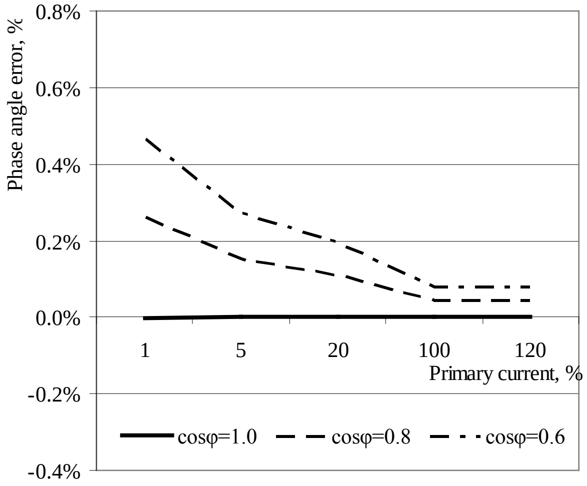

Fig. 8. Influence of measuring transformers‘ phase angle errors on energy metering accuracy, having inductive power line load

Influence of measuring transformers‘ phase angle errors on energy metering accuracy can be determined

$$\delta_\varphi = \frac{\cos\varphi_2 - \cos\varphi_1}{\cos\varphi_1}\cdot 100\% \,. \tag{3}$$

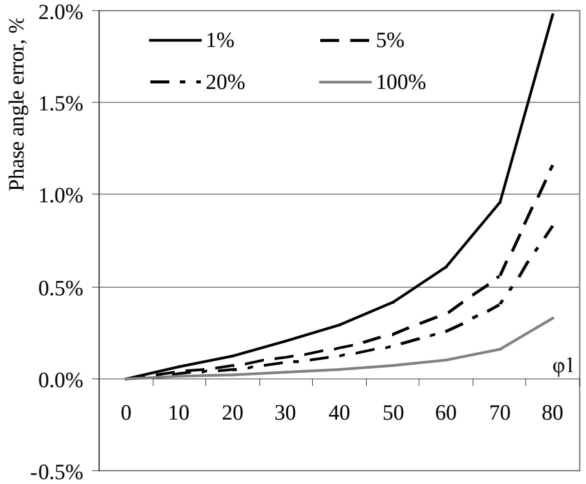

Fig. 9. Influence of measuring transformers‘ phase angle errors on energy metering accuracy, depending on power factor

Investigating energy metering accuracy all ratio and phase angle errors should be taken into account. This could be expressed by the following equation

$$\delta_P = \left(\left(U + \delta_{\mathrm{U}}\right)\left(I + \delta_{\mathrm{I}}\right) \frac{\cos\left(\varphi + \delta_{\varphi \mathrm{U}} - \delta_{\varphi \mathrm{I}}\right)}{\cos\varphi} - 1 \right) \cdot 100\% \,, \tag{4}$$

here U and I is the voltage and current of primary circuit in per units; δ_{U} and δ_{I} is the determined relative errors of voltage and current measuring transformers; φ is the lagging angle of current over voltage of primary circuit current; $\delta_{\varphi\mathrm{U}}$ and $\delta_{\varphi\mathrm{I}}$ is the determined phase angle errors of voltage and current measuring transformers.

Based on real characteristics of measuring transformers ratio and phase angle errors and (Eq. 4) energy metering accuracy calculations were performed (Fig. 10).

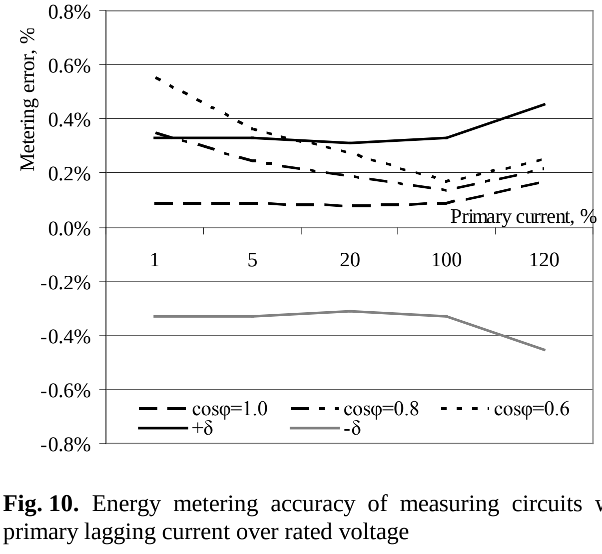

Fig. 10. Energy metering accuracy of measuring circuits with primary lagging current over rated voltage

Calculation results show that influence of measuring transformers current and voltage errors and phase angle errors on energy metering accuracy depends on phase angle errors values, primary current and power factor. In this case metering error is positive in the whole current range. Having active load, metering error does not exceed 0.1 %, when primary current varies from 1 % to rated value. Metering error increases in the low current zone with decreasing power factor. The obtained results show that energy metering errors have systematic component and evaluation of it could let to increase metering accuracy. In this case the determined energy metering errors are in the positive zone, obtained by the equation (1) (Fig. 10, solid lines).

Having capacitive character of power line's load and with leading current over voltage, then vector diagram of current and voltage is as shown in Fig. 11.

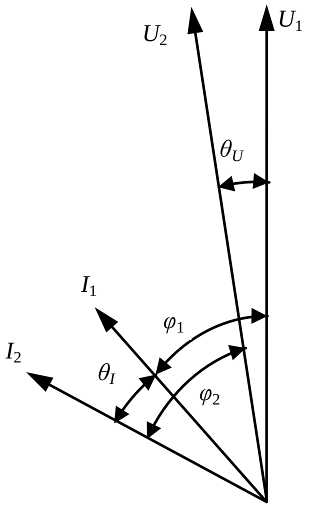

Fig. 11. Vector diagram of currents and voltages with leading current over voltage

As we know positive phase angle error of current transformer at the low primary current level is bigger then voltage transformer phase angle error, which can be even zero. Having active–capacitive load of controllable connection, angle between current and voltage at measuring transformer secondary circuit will increase ($\varphi_2 > \varphi_1$) (Fig. 11).

If phase angle of voltage transformer were negative, the angle φ_2 of the secondary circuit would increase even more. This angle decrease at the secondary circuit influence that active energy is measured with negative error and reactive energy with positive and decreases the power factor of power line ($\cos\varphi_2 < \cos\varphi_1$). This leads to situation that for the capacitive power line load, readings of the power meter would be decreased. In this case measuring transformers' secondary circuit angle between voltage and current, despite the voltage phase angle error direction, can be determined as follows

$$\varphi_2 = \varphi_1 + \delta_{\varphi \mathrm{I}} - \delta_{\varphi \mathrm{U}}\,. \tag{5}$$

In case of capacitive load character energy metering accuracy could be evaluated by such expression:

$$\delta_{\mathrm{P}} = \left((U + \delta_{\mathrm{U}})(I + \delta_{\mathrm{I}}) \frac{\cos(\varphi - \delta_{\varphi \mathrm{U}} + \delta_{\varphi \mathrm{I}})}{\cos\varphi} - 1 \right) \cdot 100\%\,. \tag{6}$$

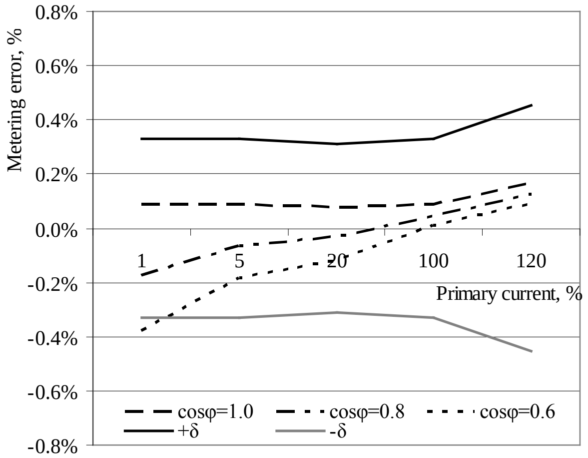

Fig. 12. Energy metering accuracy of measuring circuits with primary leading current over rated voltage

Calculation results show that energy metering accuracy depends on phase angle errors, primary current value and power factor. But in this case metering error is positive in high current zone and with decreasing current it moves to the zone of negative errors. Metering error, having the active load, is the same value as in case of inductive load. But with decreasing primary current and decreasing power factor energy metering error moves to the zone of negative errors. In this case the determined energy metering errors are more precisely limited by the range calculated according to equation (1) (Fig. 12, solid lines).

Conclusions

1. Energy metering complex is proposed to divide into separate parts and metering accuracy to investigate for each part separately.
2. Influence of metering circuit devices' errors on energy metering accuracy was determined and calculation methodology was presented.
3. It was determined that having inductive load character, energy metering errors are positive and readings of energy meters are increased.
4. Having capacitive load character, energy metering error is positive in high primary current zone and negative in low primary current zone.
5. In case of active load, energy metering errors are minimal and do not exceed 0.1 % in the range from zero to rated current value.
6. It was determined that energy metering error has systematic component, evaluation of which could let to increase the accuracy of energy metering.

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Metering of electric power and energy in electricity market requires paying more attention to accuracy of metering systems and scientific reasoning of metering formal documents. Electric energy metering of proper accuracy is fairly complicated problem, which requires systematic attitude into various influencing factors and also compatibility of technical and organizational tasks. Errors of electric energy metering circuits are investigated and their dependence on power network operational regimes, current and voltage transformers measured values and character, value of secondary circuits load are determined in this paper. Accuracy of energy metering is investigated and methodology of increase of commercial metering circuits' accuracy is proposed. Ill. 12, bibl. 7 (in English; abstracts in English and Lithuanian).

R. P. Deksnys, R. Staniulis. Elektros energijos apskaitos komplekso elementų paklaidų tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 10(106). – P. 51–56.

Elektros galios ir energijos apskaita rinkos sąlygomis kelia didesnius reikalavimus matavimo sistemų tikslumui ir elektros apskaitos norminių dokumentų moksliniam pagrindimui. Reikiamo tikslumo elektros energijos apskaita yra gana sudėtinga problema, reikalaujanti sisteminio požiūrio į daugelio įtakos turinčių veiksnių įvertinimą ir techninių bei organizacinių uždavinių suderinimo. Ištirtos elektros energijos apskaitos matavimo grandinių paklaidos ir nustatyta jų priklausomybė nuo elektros tinklo darbo režimų, srovės ir įtampos transformatorių matuojamų parametrų dydžio ir pobūdžio bei antrinių grandinių apkrovos dydžio. Darbe tirtas elektros energijos apskaitos tikslumas ir pateikta elektros energijos komercinės apskaitos matavimo grandinių tikslumo didinimo metodologija. Il. 12, bibl. 7 (anglų kalba; santraukos anglų ir lietuvių k.).