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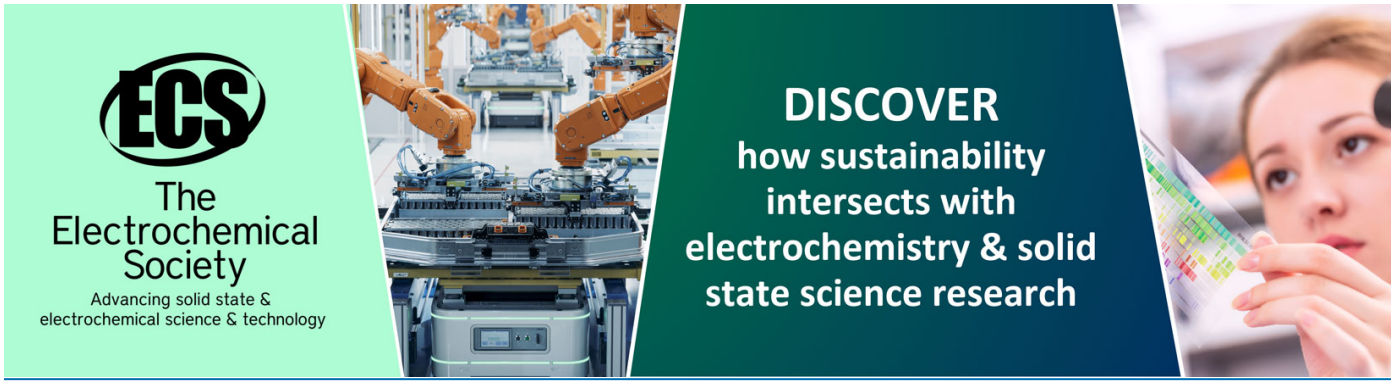

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Testing equations method for electrical energy measurements systematic errors detection and measurements results adjustment

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Abstract. State estimation theory is widely used for telemetry verification. Similar approaches can successfully be applied to electric energy measurements. Testing equations method was proposed in the frameworks of the state estimation theory and adopted for bad energy measurements detection. It is proposed to employ the modified testing equations method for detecting the systematic measurements errors of automatic electrical energy meter reading complexes. It is shown and confirmed that provided the statistical sample it is possible to detect and evaluate the systematic error, which, in turn, allows taking this error into account and adjusting the measurements results.

1. Introduction. Problem relevance

Economic efficiency is currently given the most attention in almost every industry field, and power engineering is not an exception. Scope of responsibility of grid companies includes electrical energy transportation from generation facilities to consumers. Hence, their main source of income is the fee received for energy transport. Electrical energy measurements obtained by means of energy metering systems constitute the basis of financial relations between the parties within wholesale and retail electricity markets.

Actual measurements sources are energy metering complexes installed at the borders of responsibility areas of various energy exchange participants. Due to electrical energy tariffs (i.e. prices for consumers) differentiation on an hourly basis, the automatic meter reading (AMR) systems are being widely deployed, expanded and advanced at a fast pace. AMR systems are intended to timely provide reliable electrical energy measurements data in order to properly establish the financial settlements between the energy exchange parties.

However, electrical energy measurements, besides typical errors, may contain bad data resulting from significant metering devices measurement errors, exceeding the admissible rates, as well as measurements data transformation distortions or communication channels noise and disturbances [1]. Energy flows measurements validity and accuracy monitoring is of paramount importance for any AMR system operation, which allows minimizing the financial risks for energy exchange participants in case of bad data occurrence within commercial measurements.

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As a matter of fact, electrical energy measurements do not reflect the true energy flow value corresponding to the metering complex installation point. Energy measurement, similar to any other one, can be generally represented by the sum of three quantities: true energy flow value W_i^{true}, which is actually unknown, and two measurement error components – systematic ζ_{Wi} and random σ_{Wi} errors:

$$W_i^{meas} = W_i^{true} + \zeta_{Wi} + \sigma_{Wi}. \quad (1)$$

Since the true energy flow value is unknown, its statistical parameters are, consequently, unknown, as well. Hence, it is of particular interest to estimate all values appearing in the expression (1) in order to improve measurements data reliability.

It is common knowledge that the closer the measured value is to the true one – the higher is the measurement accuracy. For this requirement to be met it is necessary that the metering complex measurement error would not exceed the sum of systematic and random errors, which constitutes the criterion of electrical energy measurement validity.

As the statistical properties of measurement errors are unknown, the concept of maximum admissible relative measurement error of electrical energy metering complex was introduced in metrology practice. This figure corresponds to the limits of the measured parameter valid values range. The probability of the measurement value to fall within this range is 95 %.

2. Systematic errors detection and measurements results adjustment

In power engineering the state estimation theory is widely applied for the purposes of detecting bad data, evaluating errors as well as solving various other problems regarding measurements data verification [2–8].

Metrological techniques of detecting the excessive measurement errors of electrical energy metering complexes are quite difficult to implement on a practical level, especially when dealing with high-voltage installations. Therefore, applying the mathematical approach in order to detect the metering complexes, the measurement error of which exceeds the regulatory-specified limits, is prospective and promising [9].

Modern electrical energy metering systems provide sufficient measurement redundancy. State estimation theory application allows to choose the optimal allocation of AMR-complexes to provide observability and sufficient redundancy level [10]. Figure 1 show the most common metering system structure from 110 kV busbar downwards.

Level I of the test subnetwork metering system shown in figure 1 is the 110 kV busbar input – 110 kV lead-in. Level II comprises the 6/10 kV busbars input – 6/10 kV lead-in. Level III features 6/10 kV busbars feeders output. Level IV is formed by the total lower-level substations input, corresponding to each 6/10 kV busbar feeder. Level V incorporates the equivalent lower-level substations feeders output.

Measurements redundancy offers the possibility to derive a single energy flow based on different measurements sets, which enables obtaining several calculated estimated equivalents corresponding to each actual measurement expressed as a linear aggregate of other measurements [11].

One of numerous possible approaches to the construction of estimated equivalents expressions is the topological method.

The first stage is selecting the measurement, for which the estimated equivalents will be obtained; W_{13} is taken by way of example for the following examination. Then topology-based balance edges are formed in such a way that the desired energy flow could be derived from them. Figure 2 illustrates a series of balance edges plotted by dash lines. Technical losses of electrical energy values corresponding to the network elements crossed by an edge are added to the calculated estimate expression. Herein, the losses calculation method is not strictly determined and the selection of one is defined by a set of initial data available. The most commonly used method is the technical losses calculation based on the considered period average power.

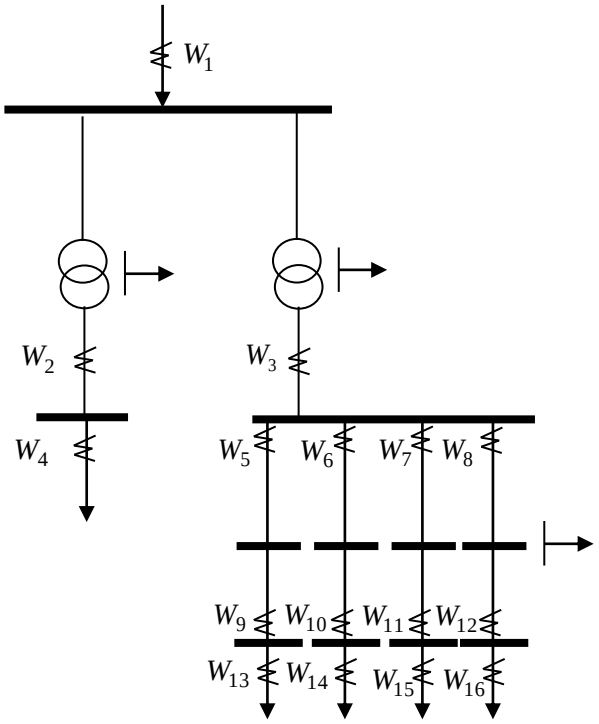

Figure 1. AMR system structure diagram

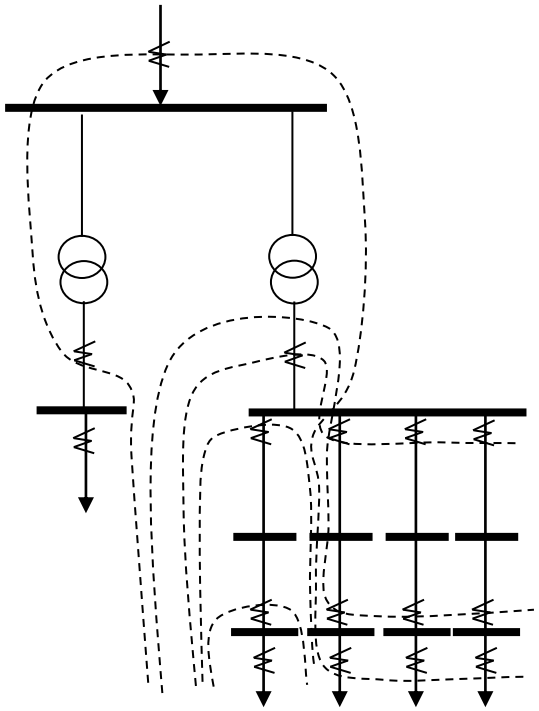

Figure 2. Balance edges corresponding to measurement 13.

The algebraic approach to the construction of similar expressions, worth noting as a more formalized one, was described in detail in [11–12].

State estimation theory is widely used to solve wide variety of electric power industry problems [13-14].

Several estimated equivalents are attributable to a single measured energy flow value W_{13} with the exact number being established on the basis of available redundancy level [11]. At that, the accuracy of the measurement itself accords with its metering complex accuracy rating.

After that the measurement calculated estimate is obtained from numerous estimated equivalents. First, the relative accuracy of W_i energy flow estimated equivalents, derived from testing equations, is to be defined.

The relative accuracy of each verifying equation is calculated according to

$$\delta_{W_i} = \sqrt{\sum_{j=1}^{n} a_j^2 \cdot \delta_{W_j}^2} \ , \tag{2}$$

where δ_{W_i} is the i metering compex accuracy rating.

The calculated estimate of energy flow value is the following:

$$W^{est_total} = \frac{\sum_{i=1}^{N} \frac{1}{D_i} W_i^{est}}{\sum_{i=1}^{N} \frac{1}{D_i}}. \tag{3}$$

Hence, the measured energy flows values W_i^{meas} are used as the initial data for the purpose of calculating their estimated equivalents W_i^{est}.

Deriving the measurement estimated equivalent based on the verifying equations system also allows to define the measurements errors corresponding to each time period under consideration.

The higher is the metering complexes accuracy – the less the difference ΔW between the measured W_i^{meas} and the estimated W_i^{est} energy flow values is to be. Therefore, the effective metering complex measurement error might be evaluated based on the relative estimation residual value $r^{est} = \left(\Delta W_i \Big/ W_i^{meas} \right) \cdot 100\%$. The the criterion of measurement validity is the expression

$$r_i^{est} \le \delta_{\lim_i}, \tag{4}$$

where $\delta_{\lim_i}$ is the maximum admissible measurement error of metering complex i.

Previous work [11] propose to apply the modified testing equations method for demanding energy measurements verification. Modern AMR-systems have quite voluminous archives of the measured electric energy on the specific time intervals to provide a sufficient statistical sample.

It is possible to accumulate the statistical parameters of every metering complex estimated errors as far as multiple time periods are available for analysis. The subsequent statistics processing is performed in order to detect and evaluate the systematic error of every single metering complex. The metering compelex systematic measurement error is determined by the estimation residuals series expected value.

Hence, the metering complex proper functioning criterion is the following inequation:

$$\bar{r}_i^{est} \le \delta_{\lim_i}, \tag{5}$$

where $\bar{r}_i^{est}$ is the relative estimation residuals series expected value corresponding to the W_i measurement; $\delta_{\lim_i}$ is the maximum admissible measurement error of metering complex i.

3. Case study. Method validation based on the test network

The equivalent circuit was formed for the test subnetwork and two sets of operation conditions different in terms of consumers load values were defined and computed by means of the specialized software package.

All metering complexes accuracy ratings were calculated under the assumption of their compliance with RD 34.09.101-94 requirements [13]:

$$\delta_W = \pm 1.1 \sqrt{\delta_I^2 + \delta_U^2 + \delta_m^2 + \delta_l^2}, \tag{6}$$

where δ_I and δ_U are the measurement errors of, correspondingly, voltage and current instrument transformers (GOST 7746-2001 and GOST 1983-2001), %; δ_m is the meter basic relative measurement error, %; δ_l is the error driven by the voltage loss on a connection line between the meter and the voltage instrument transformer, %.

The first three components in the metering complex maximum admissible error expression (6) were assumed to equal 0.5, and the voltage loss value of 0.25 % was adopted, which correspond to the accuracy ratings of the most common commercial metering complexes components in operation. The resulting maximum admissible relative error follows from here to be [16]

$\delta_W = \pm 1.1 \sqrt{0.5^2 + 0.5^2 + 0.5^2 + 0.25^2} = 1.134$.

The method was validated on the basis of the 24-hour time period, of which the two sets operation conditions were simulated during 12 hours each.

The estimation expressions system involves the electrical energy losses corresponding to the test subnetwork equivalent circuit components. It is proposed to calculate the losses based on the mean power value during the analyzed time period. Table 1 shows the comparison of the accurate losses, defined as the difference between the simulated energy flow values at the beginning and at the end of the transmission lines, and the losses calculated based on the mean power value, with the power flows being impacted by simulated measurement errors within the rated accuracy range and mean voltage values and equivalent circuit parameters being used.

Table 1. Energy losses values comparison.

$N_{beginning}$	N_{end}	Accurate losses	Losses based on mean power value	Relative error, %
1	2	0.01	0.01	-3.84
1	3	0.00	0.00	13.72
3	4	0.04	0.03	-16.26
3	5	0.19	0.15	-17.65
3	6	0.03	0.02	-31.12
3	7	0.10	0.10	-0.47
4	8	0.00	0.00	0.00
5	9	0.00	0.00	0.00
6	10	0.00	0.00	0.00
7	11	0.00	0.00	0.00

700 30-minute simulations were performed for the purpose of testing the systematic error detection method.

In practice it is rather difficult to accurately calculate the technical losses value for a time period due to the following reason. Technical losses comprise two components: load-based and semi-constant. The primary uncertainty source is the calculation of corona losses, which are heavily dependent upon environment conditions – temperature and humidity.

Moreover, in case the load-related losses calculation is based on the element resistance, its value is not exactly known as well. Under typical operation conditions the losses level commonly amounts for

Table 2. Verifying equations calculation results and their errors.

Verifying equation number	Estimate	Error, kW·h	Error, %
1	3.384	0.038	1.134
2	3.323	0.038	1.134
3	3.398	0.045	1.322
4	3.443	0.452	13.134
5	3.362	0.479	14.244
6	3.435	0.457	13.298
7	3.507	0.465	13.264
8	3.354	0.484	14.414
9	3.499	0.470	13.424
10	3.426	0.492	14.355
11	3.418	0.496	14.522
12	2.432	1.213	49.868
13	2.351	1.239	52.715
14	2.424	1.217	50.219
15	2.496	1.226	49.110
16	2.343	1.239	52.896
17	2.488	1.230	49.449
18	2.415	1.252	51.856
19	2.407	1.257	52.216

1–5 % relative to the element flow, hence the maximum losses calculation error is considerably lower than the metering complex maximum admissible error.

The losses calculation error of 20 % is adopted for the test case. The calculation is done based on the accurate losses value at the first stage.

19 verifying equations were constructed for W_{13} measurement using the algorithm described in [10] with the error in kW·h and on a percentage base being defined. The resulting values are listed in table 2.

The calculated estimate of the energy flow value is obtained using (3): $W_{13} = 3.363$. The energy flow estimated eqivalent maximum admissible error in the considered exmple is $\delta_{est} = 0.67\%$, which is almost half as large as the metering complex measurement error. The actual relative difference between the estimate and the true values equals 0.10 % while the difference between the measured and the true values reaches 0.70 %.

The similar approach applied to the losses based on the mean power value revealed the insignificance of the losses calculation method for the final outcome.

The same calculations were performed for 700 half-hour periods. The systematic of error of 13 % was intentionally included into the measurements series. Part of the results are shown for illustrative purposes in table 3.

The average estimation residuals obtained for all considered periods equals 11.5 %, which is close to the predefined systematic error.

The estimation residuals series expected value is the evaluation of the metering complex measurement error constant component. Therefore, the described methodology provides the possibility to adjust every metering complex measurements without expensive and time-consumig metrological calibration procedures. Furthermore, this method enables detecting the metering complexes requiring the exceptional calibration, which makes it unnecessary to calibrtate all metering complexes. However, it is impossible to adjust the commercial electrical energy maesurements by means of introducing the correction indexes due to the lack of legal framework, i.e. the regulations in this field.

The accumulated statistics and estimated equivalents calculations based on the verifying equations method allows to evaluate the systematic error of any single metering complex. This results in potential decrease of regular calibration costs by means of detecting the metering complexes, characterized by measurement errors exceeding the admissible value.

The statistical sample sufficiency is determined by the measurement interval length. In modern AMR-systems carrying out such calculations in online mode together with the previous results will allow monitoring the current state of the concrete AMR-complex.

The method allow to optimize the list of current metrological verification.

4. Conclusion

Methods of measurements verification based on the testing equations system showed good performance considering the test subnetwork. The testing equations method enables detecting the measurements containing bad data.

Verifying equations might be constructed on the basis of the testing equations system for the critically important commercial electrical energy measurements. Utilizing the verifying equations method allows to verify the key measurements in order to reduce the grid companies financial risks.

Table 3. Verifying equations calculation results and their errors.

Parameter	Period 1	Period 2	Period 3	Period 4	…..	Period 700
W_{13}^{meas}, kW·h	0.113339	0.113565	0.113452	0.111870		0.044974
δ^{meas}, %	1.13	1.13	1.13	1.13		1.13
$W_{13}^{est_total}$, kW·h	0.099353	0.100785	0.098752	0.099769		0.039740
r^{est}, %	12.3	11.3	13.0	10.8		11.2

Systematic error evaluation gives the opportunity of adjusting the metering system measurement data.

References

[1] Pazderin A, Samoylenko V, Localization of non-technical energy losses based on the energy flow problem solution. *Proceedings of the 6th IASTED Asian Conference on Power and Energy Systems, AsiaPES 2013*, pp.100-103, (2013).
[2] Abur A, Exposito A G, *Power System State Estimation*. Marcel Dekker inc., New York, (2004)
[3] A. Monticelli, *State Estimation in Electric Power Systems – a Generalized Approach*. Norwell, M A: Kluwer, (1990)
[4] Schweppe F, Douglas J, Rom D, Power System State Estimation, Part I - Exact Model, *IEEE Transactions on Power Apparatus and Systems*, **PAS-89**, pp. 120-125, (1970)
[5] Schweppe F, Douglas J, Rom D, Power System State Estimation, Part II - Approximate Model, *IEEE Transactions on Power Apparatus and Systems*, **PAS-89**, pp. 125-130, (1970)
[6] Monticelli A, Electric Power Syaytem State Estimation. *Proceedings of the IEEE*, vol. 88, no.2, pp. 262-282, (February 2000)
[7] Monticelli A, Wu F F, Yen M, Multiple Bad Data Identification for State Estimation by Combinatorial Optimization. *Proceedings of the PICA Conference*, pp. 452-460, (1985)
[8] Nian-De X, Shi-Ying W, Er-Keng Y, A new approach for Detection and Identification of Multiple Bad Data in Power System State Estimation. *IEEE Transactions on Power Systems*, **PAS-101, no. 2**, pp.454-462, (1982)
[9] Gamm A, Kolosok I, *Bad data detection in measurements in electric power system*. Nauka, Novosibirsk, Sib. Enterpr. RAS, (in Russian), (2000).
[10] Pazderin A, Egorov A, Eroshenko S. The energy meters allocation in electric systems on the basis of observability theory, *9th Conference on Environment and Electrical Engineering, EEEIC 2010* 5489950, pp. 167-170, (2010).
[11] Kochneva E, Pazderin A, Sukalo A, Testing equation method modification for demanding energy measurements verification. *Proceedings 1st International Conference on Measurement Instrumentation and Electronic, ICMIE*, (2016).
[12] Pazderin A, Kochneva E, Bad data validation on the basis of a posteriori analysis. *Proceedings of the IEEE International Energy Conference ENERGYCON 2014*, pp. 386-391, (2014).
[13] Berdin A, Bliznyuk D, Kovalenko P, Estimating the instantaneous values of the state parameters during electromechanical transients, *International Siberian Conference on Control and Communications, SIBCON 2015 – Proceedings* 7147001 (2015).
[14] Kovalenko P, Berdin A, Bliznyuk D, Plesnyaev E, The flexible algorithm for identifying a disturbance and transient duration in power systems, *Proceedings of International Symposium on Industrial Electronics, INDEL*, (2016).
[15] Plesniaev E, Pazderin A, Analysis of the computation techniques for energy flow problem solving. *Proceedings of the International Conference on Computer as a Tool II EUROPCON 2005*, pp.1469-1472, (2005).
[16] RD 34.09.101-94. *Typical instruction for electricity metering in its generation, transmission and distribution.* M. ORGRES, S. (in Russian) (1995)

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