The Reliability Evaluation of Measuring System Designed to Calibrate Direct Current Watt-Hour Meter

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Abstract. *The paper presents a method for evaluating the accuracy of indications of the direct current Watt-hour meters in a designed and constructed measuring system. Such measuring system is composed of two multi-function calibrators, and a specialised high-voltage attachment dedicated for this system, which makes it possible to generate direct voltages in a required range up to 4 kV with a suitably high precision. The authors described in detail particular elements of the measuring system together with the results of its calibration. The measurement results were completed with a presentation of uncertainty budgets, developed for all quantities measured.*

Keywords: Measuring System, Direct Current Watt-Hour Meter, Measurement Uncertainty

1. Introduction

The evaluation of metrological parameters of direct current Watt-hour meters is a complex measurement problem. In practice, calibration is frequently assumed as the proper form of such evaluation. The values obtained as result of calibration, associated with the uncertainty of determining them, should be defined in specified measuring points, according to respective standards and other supplementary documents. The paper presents a method for evaluating the parameters of DC Watt-hour meter LE3000plus. Meters of that type find application in measuring the power and energy of direct current in the railway traction network. These meters are modern, microprocessors measurement devices, equipped with an additional measurement interface that allows the remote transmission of registered measurement results. The evaluated Watt-hour meter of type LE3000plus consists of: high-voltage, measuring part LE3000plus_HVM, low-voltage, communication part - LE3000plus_KOM, measuring shunt, fiber optic cable connecting the high-voltage and low-voltage parts, GSM/GPS antenna, together with antenna wires. A detailed description of all the functions and potential of this meter is included in [1].

2. Measuring system

The measuring system consists of two multi-function calibrators, and a specialised high-voltage attachment dedicated for this system, which allows the generation of direct voltages in a demanded range of up to 4 kV with suitably high precision. Fig. 1 presents a diagram of the prepared measuring system for the testing of direct current Watt-hour meters together with the tested Watt-hour meter LE3000plus. The signal between terminals A and B corresponds, in working conditions, to the voltage drop on the external measurement shunt, and the signal between terminals A and C is the voltage corresponding actually to a high voltage in electrical traction. In the developed measuring system voltage U_{AB} attained small values, and therefore the costs of insulation between internal blocks of the measuring system were minimized. Terminal C of the developed measuring system is located on a high minus potential, of the order of 4 kV. The developed measuring system provides appropriate metrological parameters, minimum energy consumption from the supply network, as well as adequate separation of components. The determined relative value of expanded uncertainty of this part of the measuring system equals 0.06 % and it is stated in the current calibration certificate. In the original version of the system, during the determining of electrical energy values, time was measured with mechanical stopwatch. At the time measurement of the order of 30 min. with such stopwatch, the value of expanded uncertainty at a level of 0.12 s was achieved. A detailed description of these problems can be found in work [2].

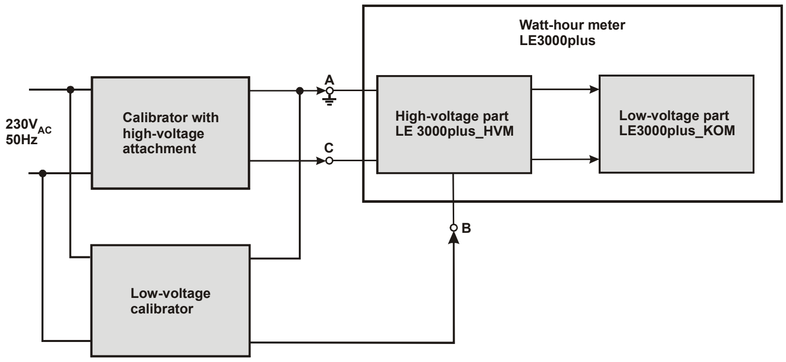

Fig. 1. Diagram of measuring system for testing the direct current Watt-hour meter

Essential modifications were introduced in the present version of measuring system, which enabled the energy measurement inaccuracies to be significantly limited. The modifications allowed the error related to the reaction time of the person conducting the measurements to be eliminated. High voltage obtained from the voltage calibrator with attachment is connected to the investigated meter for the whole duration of measurements. During normal work of a meter in railway traction network the load current is measured by the meter indirectly, through a voltage drop on the external shunt. In the measuring system the load current measured by the meter is simulated by the low-voltage calibrator, the output signal of which simulates the voltage drop from the shunt. The calibrator is equipped with a precise time distributor with a range of settings 1 ÷ 85 min. It generates a signal during a strictly specified time interval; in standard version it is a 15-minute interval. This calibrator, together with the time distributor that is its integral part, was calibrated in order to evaluate the inaccuracies of time and voltage measurement. The measurement uncertainty was determined according to the recommendations in document [3]. A detailed description of these problems can be found in work [4].

3. Experimental research

In the measuring system presented in Fig. 1, the Watt-hour meters of direct current LE 3000plus were calibrated. During this process, the indications of the same meter were compared with the settings on control devices. The readings were made from the display of the very meter, with resolution equal to 0.1 kWh. The results presented in the paper were based on high experience of the authors, who tested over 90 meters of class 0.5 and 1. For each meter, the test consisted in multiple measurements, necessary to evaluate the dispersion of results achieved, or, alternatively, to eliminate excessive errors, which made it possible to determine the standard uncertainty of type A. For each meter, the following quantities were measured: voltage, current, and energy imported from and exported to the network. Due to the limited publication space, only the results related to research on exported/imported energy have been discussed in the paper. It is authors' intention to present full results during the conference presentation. The import energy E_p of tested direct current energy meter LE3000plus was measured in test points, for specified values of current and voltage, in time $t = 0.25$ h. In order to increase the reliability, the measurements were carried out many times. Examples of results achieved are shown in Table 1.

Table 1. Results of calibrating LE3000plus meter at the measurements of import energy E_p.

Import energy measurement U = 3300 V, I = 1000 A, t = 0.25 h, E = 825 kWh								
U			I			E_p		
W_{wsk}	W_{zad}	Δ	W_{wsk}	W_{zad}	Δ	W_{wsk}	W_{zad}	Δ
V	V	V	A	A	A	kWh	kWh	kWh
3300.0	-3300.6	-0.6	-999.4	-1000.0	-0.6	824.5	825.33	-0.83
3300.0	-3300.6	-0.6	-999.4	-1000.0	-0.6	824.5	825.33	-0.83
3300.0	-3300.6	-0.6	-999.5	-1000.0	-0.5	825.0	825.33	-0.33

The export energy E_o, of the tested direct current energy meter LE3000plus was measured in a way similar to the measurements of import energy, and the measurements were repeated many times. Examples of measurement results are shown in Table 2.

Table 2. Results of calibrating LE3000plus meter at the measurements of export energy E_o.

Export energy measurement U = 3600 V, I = 1000 A, t = 0.25 h E = 900 kWh								
U			I			E_o		
W_{wsk}	W_{zad}	Δ	W_{wsk}	W_{zad}	Δ	W_{wsk}	W_{zad}	Δ
V	V	V	A	A	A	kWh	kWh	kWh
3600.0	-3601.0	-1.0	-999.0	-1000.0	1.0	-899.0	900.49	1.49
3600.0	-3600.8	-0.8	-999.1	-1000.0	0.9	-898.9	900.49	1.59
3600.0	-3600.8	-0.8	-999.0	-1000.0	1.0	-899.0	900.49	1.49

Correct values W_{zad} were given according to the setting adopted on the control equipment. Because according to the diagram shown in Fig. 1, the system works with the so-called “inverted mass”, in this case the indication error Δ takes a form according to equation (1):

$$\Delta = W_{wsk} - (-W_{zad}) \tag{1}$$

where W_{wsk} is the value indicated by the evaluated meter.

4. Uncertainty budget

Statement of all identified component standard uncertainties estimated with A and B Type methods is called uncertainty budget. The aim of creating the uncertainty budget is to prove that the combined uncertainty of measurement result u_c, was estimated in a matter-of-fact, penetrating and verifiable way. On that account, all the component uncertainties taken into consideration, also those with the value estimated as zero, should be listed in the budget. It is essential to assign a suitable type of probability distribution to particular component uncertainties in the uncertainty budget. From formula for energy it results, that in order to determine the value of combined standard uncertainty u_c, it is necessary to determine the values of partial derivatives in relation to voltage, current and time, which determine the values of sensitivity coefficients c_i.

Table 3 shows an example of uncertainty budget for the measurement of import energy, for test point E = 825 kWh. Quantities influencing the value of combined uncertainty put in the below table, denote respectively:

- E_{wsk} - value of indicated energy,
- $\delta\Delta_{rE}$ - correction resulting from the resolution of calibrated meter,
- $u(U)$, $u(I)$, $u(t)$ – uncertainties attributed to the measurements of voltage, current and time.

Table 4 presents the determined values of expanded uncertainty U, for the results of import energy measurement contained in Table 1.

Table 3. Uncertainty budget for selected measurement value of import energy

Quantity symbol	Quantity estimate	Standard uncertainty $u(x_i)$		Probability distribution	Sensitivity coefficient c_i		Part of combined uncertainty	
E_{wsk}	824.7	1.67E-01	kWh	Normal	1	kWh	1.67E-01	kWh
$\delta\Delta_{rE}$	0	2.89E-02	kWh	Rectangular	1	kWh	2.89E-02	kWh
$u(U)$	0	2.92E-01	V	Normal	0.250	kAh	7.30E-02	kWh
$u(I)$	0	6.64E-02	A	Normal	0.825	kVh	5.48E-02	kWh
$u(t)$	0	3.19E-07	h	Normal	3298.13	kVA	1.05E-03	kWh
$E_{wsk\ avg}$	824.7	-		-	-		1.92E-01	kWh

Table 4. Results of calibrating import energy for time t = 0.25 h.

Import energy measurement with U_n = 3300 V, I_n = 1000 A, t = 0.25 h			
Indicated value	Correct value	Indication error	Measurement uncertainty U
kWh	kWh	kWh	kWh
824.7	825.33	-0.67	0.54

For export energy measurements, contained in Table 2, the uncertainty budget was prepared similarly as for the import energy measurements. The results are shown in Table 5.

Table 5. Results of calibrating export energy for time t = 0.25 h.

Export energy measurement with U_n = 3600 V, I_n = - 1000 A, t = 0.25 h			
Indicated value	Correct value	Indication error	Measurement uncertainty U
kWh	kWh	kWh	kWh
-899.0	-900.49	1.53	0.22

5. Conclusions

The authors of the paper attempted to discuss complex problems of experimental research on direct current Watt-hour meters for voltage of the order of 4 kV. A designed and constructed measuring system was presented, consisting of two multi-function calibrators, a specialised high-voltage attachment dedicated for this system, in order to generate direct voltages in a demanded range of up to 4 kV with suitably high precision. The publication contains the results of experiments carried out on a numerous and representative set of direct current Watt-hour meters LE3000plus items, in the conditions of accredited laboratory. The testing of so large population of devices permitted the authors to draw reliable and objective conclusions. When selecting the measurement points of a meter tested in the measuring system, the authors took into account the conclusions drawn from the testing of meters in working conditions, installed in electrical locomotives during their normal work.

References

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