Development of Precise Measurement Methods of Electrical Quantities in Macedonia and Croatia

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Abstract. *In this paper two high precision methods developed at the National laboratories of Macedonia and Croatia for the measurements of electrical quantities will be presented. The metrological infrastructure is primarily located in the Laboratories for Electrical Measurements at the Faculty of Electrical Engineering and Information Technologies-Skopje, R. Macedonia and the Faculty of Electrical Engineering and Computing-Zagreb, R. Croatia. Both laboratories tend to become complementary regional centres of metrology in the field of electrical quantities and have developed original methods for precise electrical measurements, which will be described in this contribution. An emphasis in this article will be given on precise measurements of high voltages, currents and resistances.*

Keywords: electrical measurements, CAD, instrument transformer, resistance measurements

1. Introduction

The development of high precision methods for measurements of electrical quantities suitable for national calibration laboratories is time consuming and costly. Therefore a mutual bilateral scientific project between the Faculty of Electrical Engineering and Information Technologies-Skopje, R. Macedonia (FEIT) and the Faculty of Electrical Engineering and Computing-Zagreb, R. Croatia (FER) has been launched, supported by the governments of the both countries, for metrological research and development of methods and procedures for electrical measurements. The Laboratories for Electrical Measurements at FEIT and FER are part of the metrological infrastructure for electrical quantities of the both countries, which has been described in the first part of this contribution. Two very different high precision methods will be presented in this paper: measurements of high currents and voltages at FEIT and measurements of resistances at FER.

2. Development of methods for precise electrical measurements at AMLEQ, Macedonia

The Authorised Metrological Laboratory for Electromagnetic Quantities (AMLEQ) at FEIT-Skopje is a part of the metrological infrastructure in R. Macedonia, as described in the first part of this contribution. At the AMLEQ a prototype of a combined current-voltage instrument transformer (CCVIT) for measurement of high voltages and currents has been developed. The CCVIT must comply with the rigorous metrological requirements of the IEC 60044-3 standard, [1]. The CCVIT is very complex electromagnetic system compring: current measurement core (CMC) and voltage measurement core (VMC) with four windings and two magnetic cores. The full geometrical and electromagnetic description of the CCVIT, as well as the thorough FEM-3D analysis of its electromagnetic field distribution has previously been given in [2]. The electromagnetic analysis has been done for the calculation of the main contribution factors to the CCVIT uncertainty budget, the leakage reactances of the four CCVIT windings, [2]. The main metrological parameters of the CCVIT are: p_u VMC voltage error, p_i CMC current error, δ_u VMC phase displacement error, δ_i CMC phase displacement error. The optimisation objective function f_{opt} minimises the CCVIT measurement errors (p_u VMC voltage error at rated regime, $p_{u0.25}$ VMC voltage error at 0,25 of rated load, p_i CMC current error at rated regime). The GA program maximises f_{opt}, therefore f_{opt} is defined as in (1).

$$f_{opt} = \frac{1}{1+|p_i|} + \frac{1}{1+|p_u|} + \frac{1}{1+|p_{u0.25}|} + \frac{1}{1+|p_u + p_{u0.25}|} \quad (1)$$

The phase displacement errors of the both measurement cores are restrictive functions in the mathematical model. The FEM-3D results have been input data into the genetic algorithm. In the mathematical model of the CCVIT all quantities which affect the objective function are made to be dependent on the 11 optimisation variables. The results derived by the GA optimisation process are the so called *optimal design project*.

A prototype of the CCVIT has been realised in the Instrument transformer production company, EMO A. D.-Ohrid, R. Macedonia. High voltage testing has been done over the prototype according to the IEC 60044-3 standard, [1]. The comparison of the metrological characteristics at different working regimes of the both measurement cores of the initial and optimal design project and the prototype are given in Tables 1 and 2.

Table 1. Comparison of the design and the experimental VMC parameters (CMC at rated regime)

$\frac{U_u}{U_{ru}}$	Initial (Analytical + FEM-3D)		Optimal (FEM-3D+GA)		Prototype (experiment)	
	p_u	δ_u	p_u	δ_u	p_u	δ_u
	[%]	[min]	[%]	[min]	[%]	[min]
0,2	-7,64	-181,68	-5,56	-188,61	-1,338	-23,72
0,4	-5,18	-148,82	-3,38	-150,91	-0,855	-16,97
0,6	-3,75	-111,58	-2,07	-112,91	-0,631	-13,52
0,8	-2,96	-89,43	-1,34	-90,46	-0,53	-12,1
1,0	-2,47	-75,48	-0,86	-75,44	-0,465	-11,2
1,2	-2,10	-64,00	-0,53	-64,80	-0,429	-10,97

Table 2. Comparison of the design and the experimental CMC parameters (VMC at rated regime)

$\frac{I_i}{I_{ri}}$	Initial (Analytical + FEM-3D)		Optimal (FEM-3D+GA)		Prototype (experiment)	
	p_i	δ_i	p_i	δ_i	p_i	δ_i
	[%]	[min]	[%]	[min]	[%]	[min]
0,2	-1,08	0,25	-0,86	22,61	-0,66	8,3
0,4	-0,81	6,38	-0,12	10,02	-0,46	5,3
0,6	-0,76	3,55	-0,07	3,43	-0,34	3,1
0,8	-0,72	1,23	-0,03	3,87	-0,27	2
1,0	-0,68	0,32	-0,01	3,47	-0,22	1,1
1,2	-0,65	1,27	0,00	2,92	-0,18	0,6

A thorough transient analysis of the CCVIT has also been done by using a universal transformer model in the Matlab/Simulink program, [3]. The results from the FEM-3D analysis and the construction parameters derived from the GA optimal design are an input data for the CCVIT transient analysis. The main metrological characteristics of the CCVIT are derived for the most common transient regime, the *in-rush regime,* of the initial and the optimal design project at rated load of the both cores and industrial frequency of 50 Hz. The results confirm the metrological improvement of the optimal CCVIT during the transient regimes in comparison to the initial design project, as shown in Figures 1-4. Some of the results for the peak values of the voltage and current error (for the most rigorous moment at β=0, of the input voltage period, i.e. at t=5 ms) of the initial and the optimal design project of the CCVIT transient analysis are comparatively given in Table 3. It can be concluded that the CCVIT metrological improvement has been achieved from transient regimes' aspect, by application of the above universal analysis and design methodology.

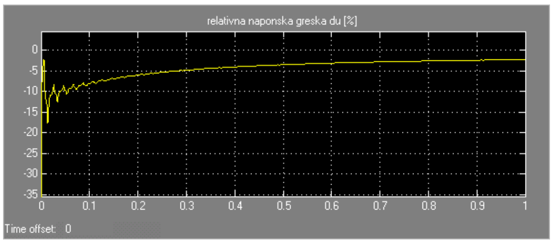

Fig. 1. Metrological transients of the initial CCVIT design project voltage error

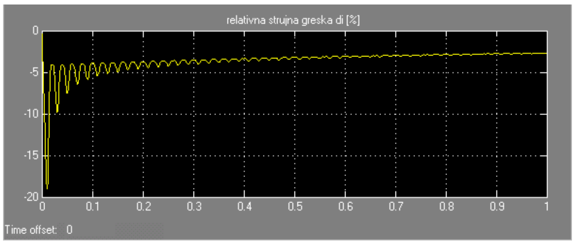

Fig. 2. Metrological transients of the initial CCVIT design project current error

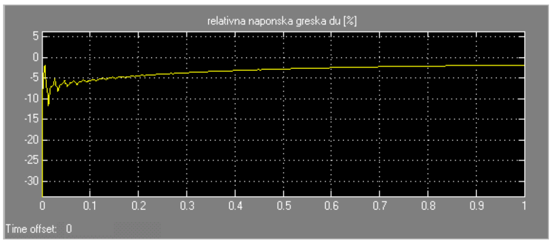

Fig. 3. Metrological transients of the optimal CCVIT design project voltage error

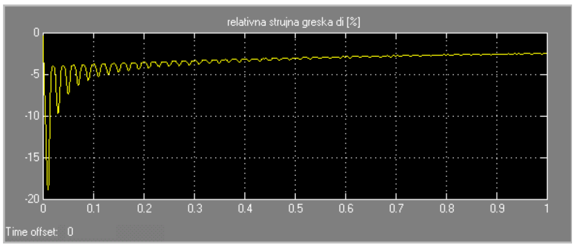

Fig. 4. Metrological transients of the optimal CCVIT design project current error

Table 3. Comparison of the CCVIT transient metrological parameters at rated regimes of the both cores

	Initial design project	Optimal design project
β [rad]	0	0
p_u [%]	-17,5	-11,5
p_i [%]	-19	-17,5

3. Development of high accuracy resistance standard measurement at PEL, Croatia

The resistance standards are compared with digital voltmeter method already described in several papers [4, 5]. Whole measurement process is automatized using personal computer. Recently the software has been rewritten from Pascal to Labview (Fig. 5.).

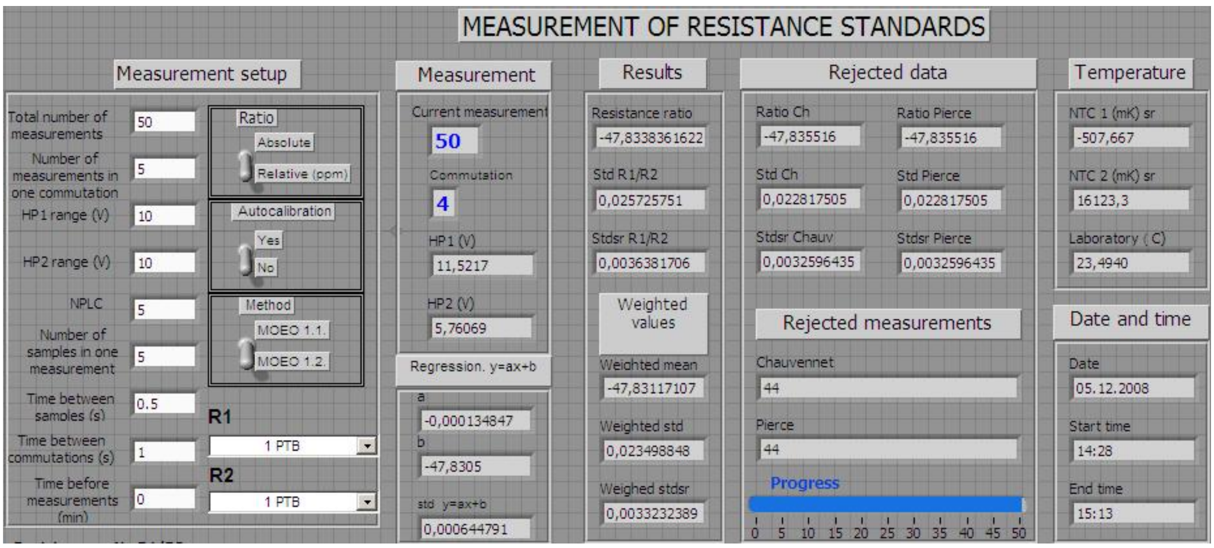

Fig. 5. Labview front panel for the measurement of resistance standards

This is offering new possibilities, especially in graphical presentation of the data. Also the data rejection methods developed by Pierce and Chauvennet are used to reject some data that are off limits. The front panel contains all the necessary data for the measurement report, including measurement setup, results, time and date, standards temperature, etc.... The results are presented graphically even during the measurement which greatly enhances the measurement process. The results obtained with this method are very good. The standard deviation of such comparison is usually less than 0,01 ppm (Fig. 6.). Each ratio consists of four measurements, as DVMs are interconnected to each resistance and also the current is reversed. This gives the possibility to calculate the standard deviation of each measurement (red line in Fig. 6). Any deviation from usual measurements can be thus easily monitored. In the end the weighted mean and standard deviation can be calculated which is usually gives better results than normal average ratio.After ratio is determined, then the standard resistance value of unknown standard is easily calculated using the known value of resistance standard used for comparison.

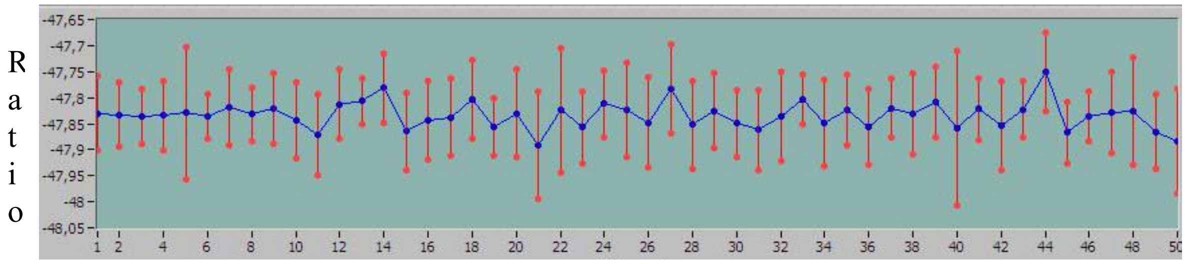

Fig. 6. Comparison of two 10 kΩ resistance standards.

4. Conclusion

The first part of the paper has presented the metrological infrastructure for electrical quantities in the R. of Macedonia and the R. of Croatia. The original and metrologically verified methods for precise electrical measurements at two laboratories have been presented in the second part of this contribution. The precise methods for measurements of high voltages, current and resistance are original. The methodology for estimation of the uncertainty budget is advanced, computer aided, universal and can be applied for verification of other procedures for precise electrical measurements. The optimisation techniques can be applied reduction of the contribution factors to the unceratinty budgets of the measurements' methods.

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