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Metrological Infrastructure for Measurement of High Voltages and Currents in Macedonia and Croatia

Marija Čundeva-Blajer[1], Ljupčo Arsov[1], Luka Ferković[2], Roman Malarić[2], Damir Ilić[2]

[1] Ss. Cyril & Methodius University, Faculty of Electrical Engineering and Information Technologies, Karpos II, b.b. POBox 574, 1000 Skopje, R. Macedonia, phone: +389 (0)2 3099162, fax: +389 (0)2 3064262, e-mail: mcundeva@feit.ukim.edu.mk
[2] Faculty of Electrical Engineering and Computing, University of Zagreb, Unska 3, HR-10000 Zagreb, Croatia, phone: +385-1-6129-753, fax: +385-1-6129-616, e-mail: roman.malaric@fer.hr

Abstract- In this paper, metrological infrastructure of Macedonia and Croatia will be presented in general, but more speciffically for measurement of high voltages and currents. As two countries become independent almost 20 years ago, they embarked on a similar metrological path, earning to strenghten international ties, to get more involved in organizations such as Euromet, to receive accreditation for the national measurement institutes, etc. However, as the two countries have emerging economies, it is sometimes difficult to develop all the necessary measurement methods, especially methods that need a lot of time and money to invest in, but are used very rarely. A work on two different measurement methods in our countries will be presented: a Rogowski coil (RC) being developed in Croatia and the current measurement unit (CMU) of a 20 kV combined current-voltage intrument transformer (CCVIT) in Macedonia.

I. Introduction

The metrological infrastructure in our two countries has similar backgrounds as we were not long ago part of the same country. However, each country has some particular problems that need to be solved. Since becoming independent countries almost at the same time 20 years ago, the two countries have had a different metrological path of development. Similarities and differences of this development will be presented in this paper, as well as possible cooperation possibilities between our two countries. In this paper the metrological infrastructure in Macedonia and Croatia for measurement of high voltages and currents, as high accuracy measurement of these quantities is rarely performed in the National Measurement Laboratories of our two countries will be presented. It is then difficult to invest and develop new methods for measurements that will be used rarely.

Primary electromagnetic laboratory in Croatia performs measurements of currents up to 20 A and voltages up to 10 kV. The measurements of higher voltages and currents are mostly specific in nature and are not in the primary research focus of PEL laboratory personnel, apart from research on Rogowski coil which is briefly described in this paper.
The Authorised Metrological Laboratory for Electromagnetic Quantities (AMLEQ) at the Faculty of Electrical Engineering and Information Technologies (FEIT) in Skopje performs the measurement of high currents and voltages by using the originally developed prototype of a combined current-voltage instrument transformer (CCVIT) with the following transformation ratios: 100 A/5 A for the current measurement core (CMC) and $(20000/\sqrt{3}):(100/\sqrt{3})$ for the voltage measurement core (VMC) of the CCVIT for 20 kV voltage level.

II. Metrological infrastructure in Macedonia

The Faculty of Electrical Engineering and Information Technologies in Skopje comprises the Authorised Metrological Laboratory for Electromagnetic Quantities, which is a part of the metrological infrastructure in the Republic of Macedonia. The Primary Laboratory for Electrical Quantities in R. Macedonia is at the Bureau for Metrology (BoM) of R. Macedonia. The AMLEQ as a part of the metrological infrastructure of R. Macedonia has the international traceability to the international primary standards (e. g. to the primary voltage standard at PTB in Germany). The accreditation processes in R. Macedonia is performed by the Institute of Accreditation of R. Macedonia (IARM). Still, the process of quality assurance in the field of metrology is continuous. AMLEQ tends to achieve an international accreditation according to the EN ISO/IEC 17025: 2005, [1].
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, [2]. These requirements should be fulfilled in steady-state as well as in transient regimes. The task to determine the metrological characteristics of the CCVIT for the purposes of its correct design and further metrological application is a very tedious job, because of its very complicated electromagnetic system, like in Figure 1. The full description has been previously published in [3].

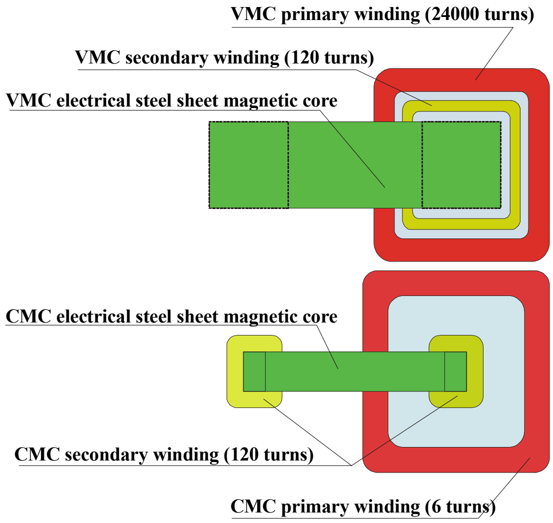

Figure 1. Electromagnetic system of the CCVIT in AMLEQ, Skopje

The initial metrological analysis of the CCVIT starts with the application of the finite element method (FEM) in the three-dimensional domain in order to derive the leakage reactances of the four windings of the CCVIT as in [3]. The leakage reactances are the main contribution factors of the measurement uncertainty budget of the CCVIT and its four main metrological parameters (p_u-VMC voltage measurement error, δ_u-VMC phase displacement error, p_i-CMC current measurement error and δ_i-CMC phase displacement error). The CCVIT metrological optimal design (the assurance of the minimum of the four measurement parameters in absolute value) is done by application of the genetic algorithm (GA), [3]. The input variables in the GA optimisation process are 11 geometrical and construction parameters of the CCVIT. The FEM results are an input data in the GA originally developed program and the analysis is fully non-linear. Two design projects have been derived: *initial* and *optimal* (ideal design project, with no restrictions for a prototype realisation). 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, [2]. The derived metrological parameters of the CCVIT in steady-state regime for the two design projects and the prototype are given in Table 1.

Table 1. CCVIT Steady-state metrological parameters at rated regimes of the both measurement cores

	p_u [%]	δ_u [min]	p_i [%]	δ_i [min]
Initial design	-2,42	-74,23	-0,68	0,57
Optimal design	-0,77	-72,57	-0,0000135	2,59
Prototype (experiment)	-0,47	-11,20	-0,22	1,10

The CCVIT metrological improvement is obvious from Table 1. At the initial design project: the VMC is accuracy class 3 and the CMC is accuracy class 1. At the optimal design project: the VMC is accuracy class 1 and the CMC is accuracy class 0,1. Finally, at prototype: the VMC is accuracy class 0,5 and the CMC is accuracy class 0,5.
A thorough transient analysis of the CCVIT has also been done by using a universal transformer model in the Matlab/Simulink program, [4]. The full model will be given in the extended version of the paper. 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 for three different in-rush moments (β-phase angle of the CCVIT input voltage)

at rated load of the both cores. The analysis has been done for industrial frequency of 50 Hz. Some of the results for the peak values of the voltage and current error (for the most rigorous moment at ¼, of the input voltage period, i.e. at t=5 ms) of the CCVIT transient analysis are given in Table 2.

Table 2. CCVIT Transient metrological parameters at rated regimes of the both measurement cores

	Initial design project			Optimal design project		
β [rad]	0	π/4	π/2	0	π/4	π/2
p_u [%]	-17,5	-10	-4	-11,5	-4	-2,5
p_i [%]	-19	-16	-11	-17,5	-16	-10,5

From the results in Table 2 it can be concluded that the CCVIT metrological improvement has also been achieved from transient regimes' aspect, by application of the above universal analysis and design methodology.

III. Metrological infrastructure in Croatia

Primary electromagnetic laboratory of Croatia (PEL) is operating as part of Department of Electrical engineering fundamentals and measurements, Faculty of Electrical Engineering in Zagreb, Croatia (FER). It is national measurement and calibration laboratory for electrical quantities since 2006, after acquiring accreditation in accordance with the 17 025 from German DKD service. PEL personnel, mainly comprising from university professors and associates have developed many precise measurement methods for measurement of electrical quantities that are now the core of PEL accreditation service. In addition to PEL, Department for high voltage and power engineering at the same Faculty has accredited laboratory from Croatian accreditation agency according to 17 025 standard, [1]. This laboratory unlike PEL is accredited exclusively for high voltage testing of electrical equipment with power frequency AC voltage and measurement of 50 Hz electromagnetic fields.

Fig. 2. PEL, Zagreb

The Institute of electrical power industry and energy, based in Zagreb, has several departments, and one of them, department of high voltage and measurements has test laboratory specialized for different field and laboratory testing and measurement of electrical equipment used in electrical power industry. Also, Koncar Institute, a part of larger Koncar group which is a leading company in Croatia for production of electrical equipment have two laboratories accredited for measurement of electrical quantities, one of them is a general calibration laboratory and the other high voltage laboratory specialized for different testing and measurement of power transformers that are produced by Koncar company. However, only PEL is primarily scientific and research laboratory where new measurement methods are developed.

One such research recently has been the development of Rogowski coil. A Rogowski coil is well-known current-to-voltage transducer, and in order to use it for the high-accuracy measurement of AC current (at power supply frequency) all influencing quantities and their contribution have been analysed [5, 6]. The measured deviation of the mutual inductance of realized model is in very good agreement with the theoretical prediction, which gives possibility to the construction of sensor for laboratory application.

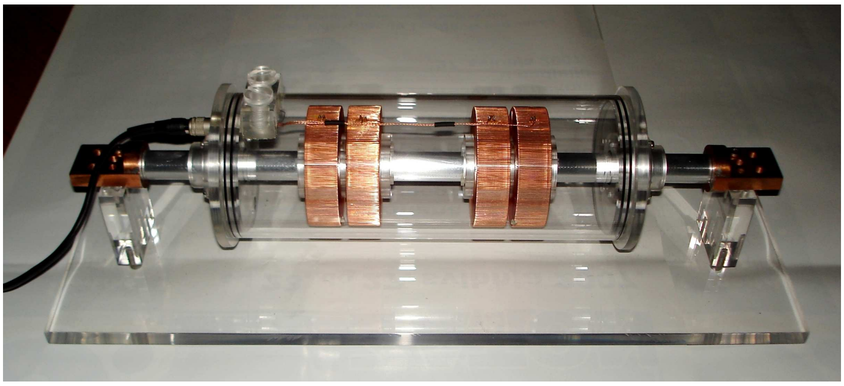

Fig. 3. Rogowski based AC current transformer in PEL, Zagreb

Thus, this research results in precise measuring transformer (Fig.3), which is based on rigid Rogowski coils in astatic coupling and designed for AC current measurement in range of 0,1 A to 20 A and frequencies up to 1 kHz. The relative uncertainty of measurement achieved by this transformer is in order of 0,01 %, but in further work even better results are possible. However, momentary research in this field is also concentrated on method for precise AC power measurements by composite measuring transformer, partially based on Rogowski coil.

IV. Metrological Cooperation between Macedonia and Croatia

To strengthen the cooperation between the Primary Electromagnetic Laboratory (PEL) in Zagreb and Laboratory for Electrical measurements in Skopje a bilateral project has been approved by two governments entitled: “Metrological research and development of methods and procedures for measurement of electromagnetic quantities”. The project will include joint research of measurement methods, inter-laboratory comparison of methods developed at both laboratories, as well as inter-laboratory comparison with the measurement systems of third parties (scientific centres). It will also include visits by scientists from both countries that will be beneficial to both countries. The main objective of this international project is the improvement of the metrological infrastructure in both countries, especially in the scientific area of electromagnetic quantities’ metrology, dissemination of the knowledge in metrology and introduction of the best laboratory praxis and international traceability at both research centres.

V. Conclusions

In the paper metrological infrastructure for measurement of high voltages and currents in R. Macedonia and R. Croatia, has been described. The originally developed methodologies for high current measurements have been given. The procedure for their development included modern numerical and stochastic optimisation methods for achieving the lowest possible metrological uncertainty. This scientific approach is universal and can be applied to the development and improvement of other metrological procedures.

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