SECOND INTERLABORATORY COMPARISON PROGRAMME ON ELF EMF MEASUREMENTS PERFORMED IN GREECE

Abstract

Three years after the first interlaboratory comparison programme (ILC) for extremely low frequency electromagnetic fields (ELF EMF), twelve participating laboratories measured the values of electric and magnetic fields including frequency in three stages at specified positions and distances from the field sources. This paper presents the measurements procedure, the results and their evaluation calculating the z-scores, as well as proposals for the improvement on the implementation of the ELF ILC scheme.

Introduction

Every test laboratory should participate in interlaboratory comparison programmes (ILCs) in order to improve its performance and assess the reliability of the resultant measurement data by comparison with results from other participating laboratories. Interlaboratory comparison programmes are defined as the organization, performance and evaluation of calibration/tests on the same or similar calibration/test items by two or more laboratories under predetermined conditions. The type of ILC that must be applied to Electromagnetic Field Measurements (EMF) is a results comparison programme.

In a results comparison program, all participants measure the same EMF source, usually in normal work conditions. The ILC programme described in this paper has been set up to comply with the requirement of ISO/IEC 17025 and covers the two types of measurement (electric and magnetic field) which are described in IEC 61786.

Participants

Twelve laboratories (with sixteen groups) have participated in this interlaboratory comparison procedure. The participants have been randomly named as laboratories 1-16. Each group knows its number, but it does not know the numbers of the other groups.

Interlaboratory Comparison Scheme

The ELF ILC programme was carried out in three steps at the High Voltage Laboratory of the National Technical University of Athens (NTUA).

- During the first phase of the test, the electric field, created by a high-voltage transmission line, was measured. A setup with a scale transmission line supplied with 35 kV was properly formed at the High Voltage Laboratory of NTUA. A testing transformer with transformation ratio of 110V/55kV was used for the production of the high voltage. Between the low voltage network, by which the transformer was powered and the primary side of the transformer, a suitable stabilizer was placed, in order to prevent fluctuations in the network voltage from passing into the produced voltage, as well as a variac for changing the level of the produced high voltage. The measurement of the high voltage level was carried out on the low voltage side with an appropriate calibrated voltmeter. The fourteen measurement groups recorded the electric field at a height of 1m at three selected positions at specific distances from the transmission line. The majority of groups performed their measurements using a sensor connected via optical fiber with a fieldmeter. The sensor was introduced into the electric field on an insulating tripod and placed at a distance of ~ 5m from the fieldmeter so that the measurements would not be affected by the presence of the operators.

- During the second phase of the test, the magnetic field, generated by a double loop cable carrying 500A, was measured. The cable was connected to the secondary side of a current transformer (0-6000A), which provided the required value of the current. The transformer was supplied by the low voltage network through an autotransformer, which enabled varying the level of the produced current. A satisfying stability of the current during the magnetic field measurements was achieved by the continuous monitoring of the current using a digital multimeter connected via coaxial cable with a suitable calibrated clamp meter. For each current value, the sixteen measurement groups recorded the magnetic field at three selected positions at a height of 1m again with a sensor and a fieldmeter. This time the sensor was connected to the fieldmeter either directly or via optical fiber, depending on the type of the fieldmeter. Unlike the electric field, the magnetic field is not affected by the presence of the operator.
- During the third phase of the test, the magnitude and frequency of a uniform magnetic field, generated by a standard square 1 m X 1m coil, was measured. The multi turn magnetic field coil was connected with an AC source via an interface unit. The AC source provided the required value of the current free of harmonics and was supplied by the low voltage network. The whole test process was accurately controlled by a suitable software package, which enabled specifying the required field strength and frequency. Also, using the software package the uniformity of the magnetic field was maintained by the continuous automatic adjustment of the coil load current. The fourteen measurement groups recorded the magnitude and frequency of magnetic field at the centre of the standard coil with a sensor and a fieldmeter either directly or via optical fiber.

Results

Since there are no other spectral components in each measurement area apart from the fundamental frequency (of 50Hz in the two first stages and 127 Hz in the third stage) and the broadband results are very close to the corresponding band pass, the participants carried out the field measurements by selecting only one of the two measurement modes (broadband or band pass).

Each participating laboratory submitted the measured values of electric field strength (E_1, E_2 and E_3) produced by a transmission line at each position and their uncertainties (UE_1, UE_2 and UE_3). These values for the first stage are presented in Table 1.The measurement values that were recorded by each participating laboratory for the second and third stages (B_1, B_2, B_3, B_4 and f_4) with their expanded uncertainty (UB_1, UB_2, UB_3, UB_4 and Uf_4) are presented in Table 2. Also, the average value μ and the standard deviation σ for all measurement scenarios are shown in Tables 1 and 2.

Laboratory	**Position 1**		**Position 2**		**Position 3**	
	E_1 [kV/m]	**UE_1 [%]**	**E_2 [kV/m]**	**UE_2 [%]**	**E_3 [V/m]**	**UE_3 [%]**
1	5,910	14,70	1,470	14,71	234,8	14,70
2	4,970	3,02	1,230	3,25	246,0	3,25
3	5,040	6,3	1,240	6,3	245,0	6,3
4	4,924	5,0	1,218	5,0	241,2	5,0
5	5,214	8,92	1,267	8,92	253,9	8,36
6	4,557	7,7579	1,179	7,7579	237,3	7,7579
7	3,629	4,1	1,658	4,1	246,0	4,1
8	4,940	6,32	1,216	6,32	241,6	6,32
9	5,611	37,00	1,375	37,01	268,2	37,02
10	4,998	18,30	1,233	8,27	242,8	6,35
11	5,026	3,9	1,237	3,9	245,5	3,9
12	3,908	4,5	0,923	4,5	180,0	4,5
13	4,946	6,5	1,223	6,5	243,5	6,5
14	5,062	6,7	1,238	6,7	244,0	6,7
Parameters						
μ	**4,910**		**1,265**		**240,7**	
σ	**0,583**		**0,163**		**19,18**	

Table 1: Measurements of Electric Field (E)

	Position 1		**Position 2**		**Position 3**		**Position 4**			
Laboratory	**B_1 [µT]**	**UB_1 [%]**	**B_2 [µT]**	**UB_2 [%]**	**B_3 [nT]**	**UB_3 [%]**	**B_4 [µT]**	**UB_4 [%]**	**f_4 [Hz]**	**Uf_4 [%]**
1	61,05	14,70	2,226	14,70	530,0	14,78	1,200	14,71	127,0	1,18
2	59,20	3,55	2,230	3,14	590,0	5,08	1,160	2,59	127,5	1,18
3	60,52	5,17	2,295	5,17	501,0	5,17	1,170	5,17	127,5	0,4
4	58,85	5,0	2,216	5,0	475,9	5,0	1,182	5,0	127,0	0,4
5	58,29	4,11	2,104	3,76	665,0	3,76	1,190	6,36	127,0	0,4
6	58,15	6,6435	2,089	6,6435	818,8	6,6435	1,159	6,6435	125,0	6,250
7	62,33	3,92	2,240	3,92	513,0	3,92	1,160	3,92	127,0	0,8
8	57,01	5,94	2,159	5,94	803,8	5,94	1,173	5,94	127,0	3,0
9	59,77	38,99	2,216	39,05	646,6	42,84	1,190	38,96	115,5	11,69
10	58,83	7,325	2,031	5,196	827,8	6,952	1,190	5,944	127,5	0,4

11	60,40	2,5	2,277	2,5	522,5	2,5	1,164	2,9	127,67	1,0
12	58,88	3	2,320	3	450,0	3	-	-	-	-
13	60,25	5,5	2,161	5,5	538,0	5,5	1,180	5,5	127,0	0,8
14	59,79	5,5	2,180	5,5	483,0	5,5	1,167	5,5	127,0	0,8
15	63,60	5,5	2,255	5,5	548,0	5,5	1,180	5,5	127,0	0,8
16	60,06	9,5	2,400	9,5	600,0	9,5	-	-	-	-
Parameters										
μ	**59,81**		**2,212**		**594,6**		**1,176**		**126,19**	
σ	**1,620**		**0,092**		**124,83**		**0,013**		**3,141**	

Table 2: Measurements of Magnetic Field (B)

Z scores

In this ILC programme, the performance of the laboratories was evaluated based on the z score that was defined by the following formula:

$$z = \frac{x - X}{s} = \frac{x - \mu}{\sigma}$$

where :

x – participant’s individual reported value,
X – assigned value,
s – standard deviation for proficiency assessment.

As estimates of the assigned value and variability were chosen the mean value μ and standard deviation σ of the participant’s results.

The following classification of the result of a participating laboratory may be defined as:

- $|z| \leq 2$: satisfactory result
- $2 < |z| < 3$: area considered to give “warning signal”,
- $|z| > 3$: area considered to give “action signal”.

At each stage of the experiment (E or B measurement), the z scores of the participating teams are calculated for each measurement position. The z scores of all laboratories for electric and magnetic measurements are shown in figures 1 and 2, respectively.

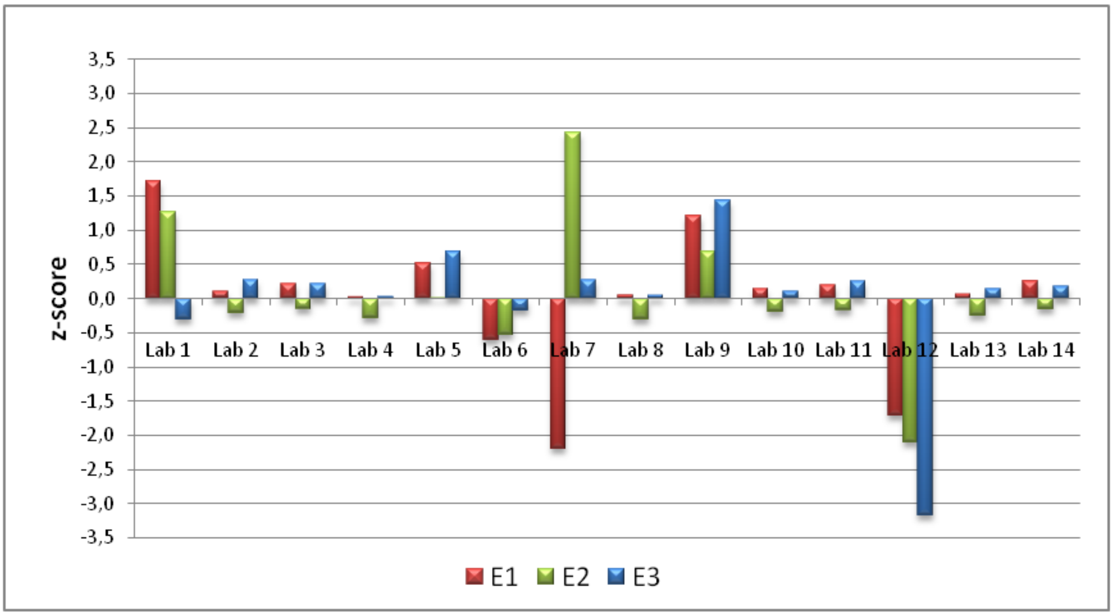

Figure 1: Z-scores for measurement of Electric Field (E)

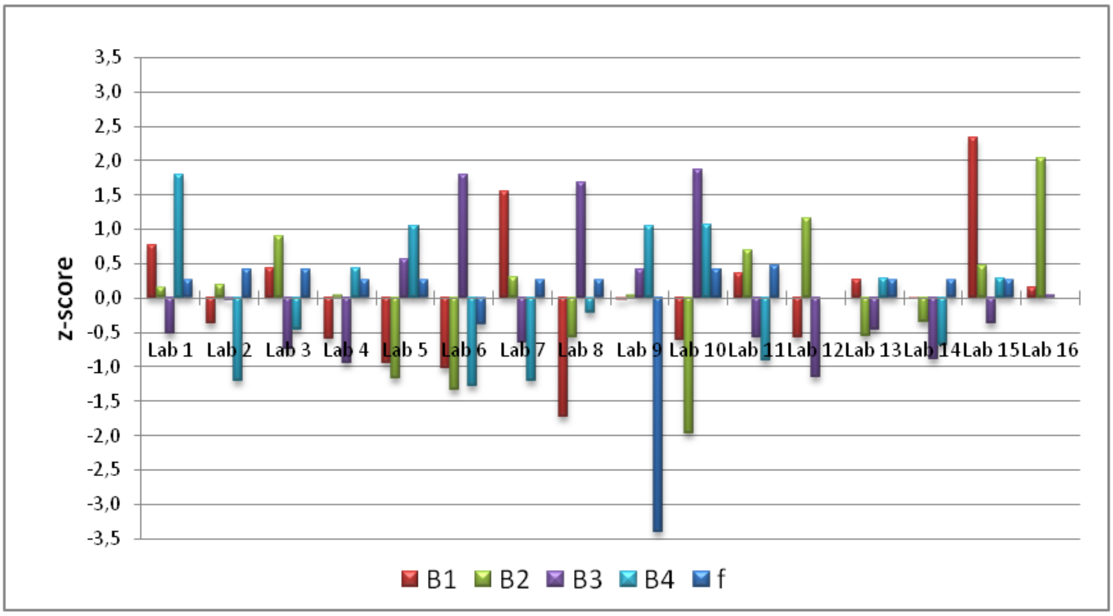

Figure 2: Z-scores for measurement of Magnetic Field (B)

Conclusions

The purpose of the presented analysis was to describe the organisation and execution of the second round of an ELF ILC scheme and to assess its overall function by detecting weaknesses of the predetermined measurement procedures and inaccuracy factors within the laboratories.

The proposals derived from the first round for the improvement of the overall procedure have been implemented in this second scheme which has therefore proven to be very effective:

- Special attention was given at keeping both the voltage and current sources as stable as possible. This was achieved in three test phases by use of a voltage stabilizer, a clamp meter in conjunction with a digital multimeter for continuous monitoring of the current and a software package for the continuous automatic adjustment of the coil load current.
- A significant increase in the number of participants in this round was enabled because the participants were asked to deliver their results in only one of the two measurement modes (either broadband or band pass).

All the laboratories that had participated in the first ELF ILC scheme (four accredited laboratories consisting of five measuring teams) have also participated in this second round. A comparison between rounds of the scheme by using an aggregated performance statistic would not be suitable, because both the test levels and the measuring teams -defined as the unique combination of equipment and operator- are not identical. An attempt to examine only the influence of the equipment, by counting the number of test levels where $|z|>2$, shows that the majority of the first rounds' participants (where no one had been evaluated with a $|z|>2$) have received warning and/or action signals in this second round.

This finding along with the fact that even accredited laboratories with recently calibrated instruments have received $|z|\geq 3$ proves the necessity of the scheme.

Based on the calculations of the z scores and their depiction in bar charts, the evaluation of the performance of the participating laboratories can be determined as:

- From Tables 1 and 2 it is concluded that the participants have demonstrated a better performance when measuring the magnetic field, as no $|z|\geq 3$ have occurred. Nevertheless, Laboratories 15 and 16 have received some warning signals, possibly due to a lack of calibration (Lab 16) or to a false processing of the recorded field (high reported narrow band B1 measurement of Lab 15).
- All laboratories have achieved a satisfying performance at the B4 measurement. This proves how strongly the evaluation of a laboratory is affected by the stability of the field source. Only Laboratory 9 has reported a non acceptable value for the frequency measurement. An inappropriate setting/adjustment of the instrument could be a possible error source.
- The $|z|>2$ values Laboratory 12 has received for the measurements of the electric field are indicators of a systematic error (bias) caused by the instrument. The measuring instrument used by Laboratory 12, in particular, requires the presence of the operator very close to the equipment, thus resulting to a distortion of the electric field. The warning signals of Laboratory 7 could be attributed to calibration factors or possible operator mistakes.