2025 IMEKO Joint Conference
TC8 - TC11 - TC25
Torino, Italy, September 14-17, 2025

Low frequency electromagnetic field measurements and conformity assessment

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Abstract **– The paper is related to measurements of power frequency (50 Hz) electric and magnetic fields. The measurements are carried out in order to check the compliance of the field levels with the reference levels prescribed by national and international legislation. For the purpose of the conformity assessment, it is necessary to evaluate the expanded measurement uncertainty for each particular case and to adopt the decision rule. It is analyzed how the expanded measurement uncertainty and the adopted decision rule affect the conformity assessment. The analysis is carried out on a set of several hundred measurements carried out in residential areas near overhead power lines and substations. Different decision rules are applied to the analyzed set of measurement results in order to check how the selection of decision rule affects the conformity assessment.**

I. INTRODUCTION

The topic of the paper is focused on measurements of low frequency electromagnetic fields, i.e. power frequency (50 Hz) electric field strength and magnetic flux density. The measurements are carried out in order to check the compliance of the field levels with the reference levels for the general public prescribed by national and international legislation. The reference levels for power frequency electric and magnetic fields prescribed by the ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines from 1998 [1] and 2010 [2], Recommendation 1999/519/EC [3], and Serbian legislation [4–6] are considered in the analysis. In order to provide the conformity assessment, it is necessary to adopt a decision rule and to evaluate the expanded measurement uncertainty for each particular case. In this paper, expanded uncertainty is evaluated for the case of measurements in the vicinity of overhead power lines (OHLs) and substations, taking into account the most important components of electric and magnetic field measurement uncertainty. It is analyzed how the evaluated expanded measurement uncertainty and the adopted decision rule affect the conformity assessment. The analysis is carried out on the set of several hundred measurements carried out in residential areas near overhead power lines and substations. The measurements are carried out in accordance with the requirements of the relevant standards [7–10], which define the requirements for measuring instruments [8] and measurement procedures [7, 9, 10]. According to the results of the previous research, transmission overhead power lines [11–13] and substations [14–17] are the most important sources of power frequency electromagnetic field due to their number, proximity to residential areas and field levels in their vicinity. Previous research has shown that the highest values of electric and magnetic fields are obtained near transmission overhead power lines. The zones of influence of these power lines from the standpoint of electric and magnetic fields are calculated in [11]. When it comes to substations, previous research has shown that the most unfavorable situation from the standpoint of exposure to magnetic field is when the substations are located inside buildings [14–16]. Levels of magnetic field which can occur in areas near these substations and possible mitigation solutions are analyzed in [14–16]. Since the 10/0.4 kV substations are frequently located inside buildings they represent significant source of power frequency magnetic field in the environment [15, 16]. For the aforementioned reasons, the measurement results obtained in the vicinity of the 110 kV, 220 kV and 400 kV transmission overhead power lines and 10/0.4 kV substations are selected for the analysis.

II. LEGISLATION ON PROTECTION OF THE GENERAL PUBLIC FROM NON-IONIZING RADIATION

Protection of the general public from non-ionizing radiation is regulated by national and international recommendations and rulebooks. Recommendation 1999/519/EC [3] establishes a framework for harmonized protection of the general public from non-ionizing radiation to which all the European Union countries should adhere in adopting national regulations. According to ICNIRP guidelines from 1998 [1] and Recommendation 1999/519/EC [3] the reference levels for power frequency (50 Hz) fields are 5 kV/m for electric field strength and 100 μT for magnetic flux density. In the ICNIRP guidelines from 2010 [2] the reference level for electric field strength is also 5 kV/m, while the reference level for magnetic flux density is 200 μT.

The Republic of Serbia fulfilled the requirements of [3] in 2009 by adopting national legislation on the protection of the general public from non-ionizing radiation, i.e. the Law on Protection from Non-Ionizing Radiation [4] and six rulebooks. Rulebook on Limits of Exposure to Non-Ionizing Radiation [5] established reference levels of exposure, which are 2 kV/m for electric field strength and 40 μT for magnetic flux density. These reference levels refer to power frequency (50 Hz) electromagnetic fields in increased sensitivity areas. According to the definition given in rulebooks [5] and [6], increased sensitivity areas are "residential areas where people can stay 24 hours a day; schools, homes, preschool institutions, maternity wards, hospitals, tourist facilities, and children's playgrounds; areas of undeveloped plots intended, according to the urban development plan, for the specified purposes, in accordance with the recommendations of the World Health Organization". Rulebook on Sources of Non-Ionizing Radiation of Special Interest, Types of Sources, Methods and Frequentness of their Testing [6] defines the concept of non-ionizing radiation source of special interest. According to this rulebook, sources of special interest are defined as "sources of electromagnetic radiation that can be harmful to people's health and are determined as stationary and mobile sources whose electromagnetic field in an increased sensitivity area amounts to at least 10% of the reference level prescribed for that frequency". For the power frequency field (50 Hz), 10% of the reference level amounts to 200 V/m for electric field strength and 4 μT for magnetic flux density. Owners of sources of special interest have the obligation to provide field testing once every four years.

The summary of reference levels for power frequency (50 Hz) electric field strength and magnetic flux density according to Serbian and international regulations is presented in Table 1.

Table 1. Reference levels for power frequency (50 Hz) electric field strength and magnetic flux density according to Serbian and international regulations

	ICNIRP 1998 [1], Recommendation 1999/519/EC [3]	ICNIRP 2010 [2]	Serbian legislation [5]
Electric field strength	5 kV/m	5 kV/m	2 kV/m (200 V/m)
Magnetic flux density	100 μT	200 μT	40 μT (4 μT)

III. CONSIDERATION OF MEASUREMENT UNCERTAINTY WHEN ISSUING A DECLARATION OF COMPLIANCE

When conclusions on the compliance of a measured quantity with a certain specification are drawn on the basis of measurement results, it is necessary to take into account the measurement uncertainty. This is the case with electric and magnetic field testing, where, based on the obtained result, it is necessary to make a statement on compliance with the prescribed exposure limit. When the obtained result with expanded uncertainty is compared with the exposure limit, four cases, which are shown in Fig. 1, are possible.

From Fig. 1, it is clear that in the first case, there is compliance, since the result with expanded uncertainty included does not exceed the prescribed exposure limit. It is also clear that in the fourth case, compliance was not achieved, i.e. the prescribed exposure limit was exceeded. However, the question of interpreting compliance in the second and third cases arises. The statement of compliance in cases 2 and 3 depends on the adopted decision rule.

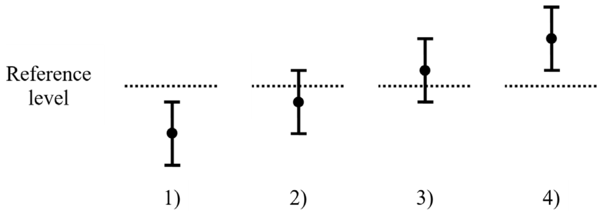


Figure 1. Four possible positions of measurement results and expanded uncertainty in relation to the prescribed exposure limit

In order to minimize the number of cases 2 and 3 in practice, it is necessary to reduce the expanded uncertainty, which is achieved by reducing or eliminating certain measurement uncertainty components that are subject to influence. In the case of electric field strength and magnetic flux density measurements, methods for reducing uncertainty components include, among other things, the application of correction factors to eliminate systematic effects, the selection of measuring instruments with higher accuracy, the calibration of measuring instruments in a laboratory that has lower calibration uncertainty, the application of an adequate measurement procedure, conducting measurements in adequate weather conditions, etc.

IV. RESULTS AND DISCUSSION

A. Methodology

The results obtained by measurements in residential areas in the vicinity of overhead power lines and substations are analyzed in this chapter. Regarding the measurement uncertainty, two cases are considered. In the first case the expanded measurement uncertainty is 5% and in the second case is 10%, both for electric field strength and magnetic flux density. The expanded measurement uncertainty takes into account all the uncertainty components originating from the calibration of the measuring system [18], positioning of the measuring probe and operator proximity effect in the case of electric field strength measurements [19]. The quantification of the measurement uncertainty component originating from operator proximity effect on the measurement results of electric field strength in the vicinity of overhead power lines for different distances between the operator and the measuring probe is given in [19]. The case when the expanded measurement uncertainty is 5% corresponds to the situation when the measuring system with lower uncertainty is used and when the influence of the operator on the results of electric field is eliminated by increasing the distance between the operator and the measuring probe. The case when the expanded measurement uncertainty is 10% corresponds to the situation when the measuring system with higher uncertainty is used and the influence of the operator is not eliminated entirely.

The obtained measurement results with expanded uncertainty are compared with the reference levels prescribed by both national and international legislation which are given in Table 1. Different decision rules are applied to the analyzed set of measurement results in order to check how the selection of decision rule affects the conformity assessment and the number of results which correspond to cases 1–4 is calculated.

B. Results reffering to overhead power lines

The analysis is carried out for the measurement results obtained in 417 increased sensitivity areas located in the vicinity of transmission overhead power lines. These increased sensitivity areas are located near 110 kV (137), 220 kV (183) and 400 kV (97) overhead power lines. For each increased sensitivity area, the highest measured values of electric field strength and magnetic flux density are taken into consideration. The obtained results are presented in Tables 2–7. The results in Tables 2–4 refer to the case when the expanded uncertainty is 5%, while the results in Tables 5–7 refer to the case when it is 10%. The numbers presented in Tables 2–7 refer to the number of results corresponding to cases 1–4.

Table 2. The results obtained for 110 kV OHLs, U = 5%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	65	1	5	66
	2 kV/m	136	1	0	0
	5 kV/m	137	0	0	0
Magnetic	4 μT	134	0	1	2
	40 μT	137	0	0	0
	100 μT	137	0	0	0
	200 μT	137	0	0	0

Table 3. The results obtained for 220 kV OHLs, U = 5%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	44	1	1	137
	2 kV/m	172	1	4	6
	5 kV/m	183	0	0	0
Magnetic	4 μT	140	5	4	34
	40 μT	183	0	0	0
	100 μT	183	0	0	0
	200 μT	183	0	0	0

Table 4. The results obtained for 400 kV OHLs, U = 5%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	12	0	1	84
	2 kV/m	86	0	2	9
	5 kV/m	97	0	0	0
Magnetic	4 μT	73	1	2	21
	40 μT	97	0	0	0
	100 μT	97	0	0	0
	200 μT	97	0	0	0

Table 5. The results obtained for 110 kV OHLs, U = 10%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	62	4	9	62
	2 kV/m	136	1	0	0
	5 kV/m	137	0	0	0
Magnetic	4 μT	134	0	2	1
	40 μT	137	0	0	0
	100 μT	137	0	0	0
	200 μT	137	0	0	0

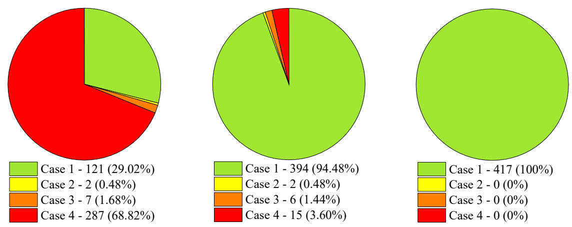
Table 6. The results obtained for 220 kV OHLs, U = 10%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	41	4	3	135
	2 kV/m	171	2	5	5
	5 kV/m	183	0	0	0
Magnetic	4 μT	139	6	5	33
	40 μT	183	0	0	0
	100 μT	183	0	0	0
	200 μT	183	0	0	0

Table 7. The results obtained for 400 kV OHLs, U = 10%

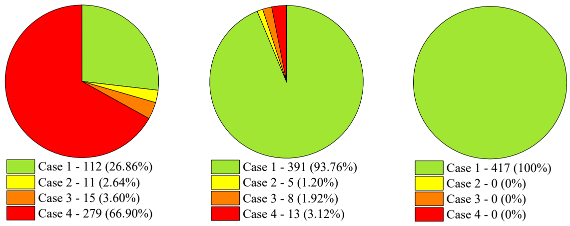
Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Electric	0.2 kV/m	9	3	3	82
	2 kV/m	84	2	3	8
	5 kV/m	97	0	0	0
Magnetic	4 μT	72	2	3	20
	40 μT	97	0	0	0
	100 μT	97	0	0	0
	200 μT	97	0	0	0

The results given in Tables 2-7 are summarized in Figs. 2–5, where the numbers of cases are obtained by summing the results for overhead lines of all three voltage levels.



a) 0.2 kV/m   b) 2 kV/m   c) 5 kV/m

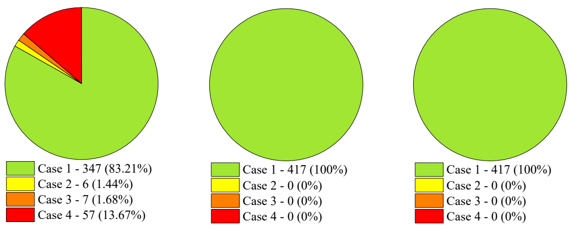
Figure 2. The results of electric field strength for overhead power lines of all voltage levels, U = 5%



a) 0.2 kV/m b) 2 kV/m c) 5 kV/m

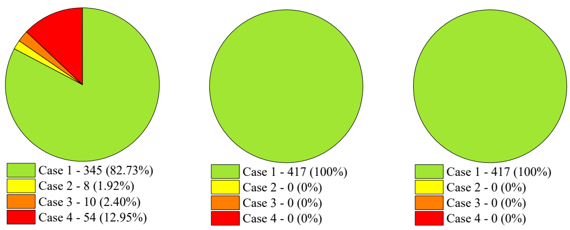
Figure 3. The results of electric field strength for overhead power lines of all voltage levels, U = 10%

From the results referring to electric field strength presented in Figs. 2 and 3, it can be concluded that there were not any increased sensitivity areas where the results exceeded the reference level of 5 kV/m (Figs. 2c and 3c), so 100% of the results correspond to Case 1. When the results are compared with the reference level of 200 V/m, the majority of results correspond to Case 4, while the total number of results corresponding to Cases 2 and 3 is less than 2.2% when the expanded uncertainty is 5%, i.e. less than 6.3% when the uncertainty is 10%. When the results are compared with the reference level of 2 kV/m, the majority of results correspond to Case 1, while the total number of results corresponding to Cases 2 and 3 is less than 2% when the expanded uncertainty is 5%, i.e. less than 3.2% when the uncertainty is 10%. The total number of Cases 2 and 3 increases with the increase of expanded uncertainty, as expected.



a) 4 µT b) 40 µT c) 100 µT, 200 µT

Figure 4. The results of magnetic flux density for overhead power lines of all voltage levels, U = 5%



a) 4 µT b) 40 µT c) 100 µT, 200 µT

Figure 5. The results of magnetic flux density for overhead power lines of all voltage levels, U = 10%

From the results referring to magnetic flux density presented in Figs. 4 and 5, it can be concluded that there were not any increased sensitivity areas where the results exceeded the reference levels of 40 µT, 100 µT and 200 µT, so 100% of the results correspond to Case 1. When the results are compared with the reference level of 4 µT, the majority of results correspond to Case 1 as well, while the total number of results corresponding to Cases 2 and 3 is less than 3.2% when the expanded uncertainty is 5%, i.e. less than 4.4% when the uncertainty is 10%.

C. Results reffering to substations

The analysis is carried out for the measurement results obtained in 34 increased sensitivity areas located in the vicinity of 10/0.4 kV substations. For each increased sensitivity area, the highest measured value of magnetic flux density is taken into consideration. The obtained results are presented in Tables 8 and 9.

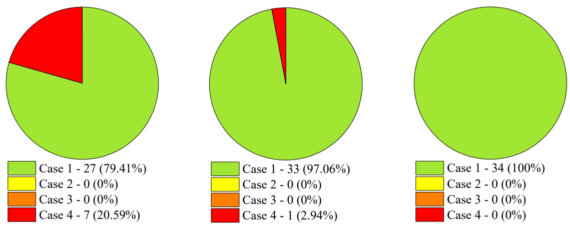
Table 8. The results for 10/0.4 kV substations, U = 5%

Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Magnetic	4 µT	27	0	0	7
	40 µT	33	0	0	1
	100 µT	34	0	0	0
	200 µT	34	0	0	0

Table 9. The results for 10/0.4 kV substations, U = 10%

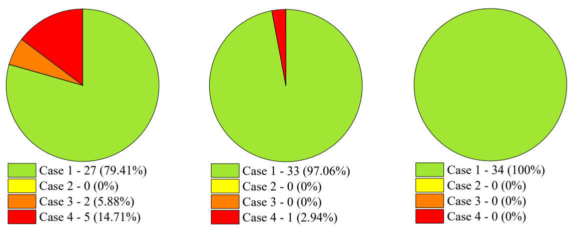
Field	Ref. level	Case 1	Case 2	Case 3	Case 4
Magnetic	4 µT	27	0	2	5
	40 µT	33	0	0	1
	100 µT	34	0	0	0
	200 µT	34	0	0	0

The results presented in Tables 8 and 9 are summarized in Figs. 6 and 7.



a) 4 µT b) 40 µT c) 100 µT, 200 µT

Figure 6. The results of magnetic flux density for substations, U = 5%



a) 4 µT b) 40 µT c) 100 µT, 200 µT

Figure 7. The results of magnetic flux density for substations, U = 10%

It can be concluded that there was not any increased sensitivity area where the results exceeded the reference level of 100 µT and 200 µT (Figs. 6c and 7c), while there was only 1 result that exceeded the reference level of 40 µT. In the situation when the results are compared with the reference level of 4 µT, the majority of results correspond to Case 1, while the total number of results corresponding to Cases 2 and 3 is 0 when the expanded uncertainty is 5%, i.e. it is less than 5.9% when the uncertainty is 10%.

V. CONCLUSION

The analysis presented in the paper shows how the expanded measurement uncertainty and the adopted decision rule influence the conformity assessment. This influence is demonstrated on a large set of results of electric field strength and magnetic flux density measurements performed in 417 residential areas located in the vicinity of 110 kV, 220 kV and 400 kV transmission overhead power lines and 34 residential areas located in the vicinity of 10/0.4 kV substations. Decreasing the expanded measurement uncertainty is very important, especially when the measurement result is compared with a lower reference level. Expanded measurement uncertainty can be decreased by applying appropriate measuring procedures and by eliminating certain components of measurement uncertainty, like those originating from the positioning of the measuring probe and operator proximity effect in the case of electric field measurements.

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