MAGNETIC FIELD CATEGORIZATION IN INDOOR MV/LV SUBSTATIONS BY THE STRUCTURE OF THE LOW-VOLTAGE CONNECTION

Kati KETTUNEN
Helen Electrical Networks Ltd – Finland
kati.kettunen@helsinginenergia.fi

Tommi KEIKKO
Tampere University of Technology – Finland
tommi.keikko@tut.fi

Martti HYVÖNEN
Helsinki Energy – Finland
martti.hyvonen@helsinginenergia.fi

Seppo VALKEALAHTI
Tampere University of Technology – Finland
seppo.valkealahti@tut.fi

ABSTRACT

Indoor MV/LV substation may cause higher magnetic field around it than the usual background field. LV connection is often the most important source of magnetic field in a substation. By knowing the structure and route of the connection it is possible to estimate the magnetic field level in rooms around the substation. The aim of the study was to categorize indoor MV/LV distribution substations by LV connection structure in Finland.

INTRODUCTION

Magnetic fields are an irremovable part of the use of electricity. Electricity is used everywhere in the modern society and components of distribution network may be located near people. Yet the voltage near residencies is typically low the current may be significant inducing significant magnetic fields. Indoor MV/LV substation, further called substation, is one component which may cause higher magnetic field around it than the usual background field. The owner of the electric network has to be aware of the environmental effects which are caused by its property. One way to increase the knowledge on the magnetic fields in and around substations is to evaluate the magnetic field with respect to the structure of the LV connection.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has published guidelines where limits to public exposure have been given [1]. Based on these guidelines European Parliament and Council gave the council recommendation on the general public exposure to electromagnetic fields in 1999 [2]. In Finland the Ministry of Social Affairs and Health (STM) gave a decree about the limitation of the public exposure to electromagnetic fields [3]. The decree is based on the council recommendation. Table 1 presents the public exposure limits which are to be followed in Finland. The limits concern exposure that last significant amount of time. If the time of exposure is temporary, the limits are five times larger.

Table 1: Public magnetic field exposure reference values. In calculating the magnetic flux density *f* is in Hz. [3]

Frequency range	Magnetic flux density (µT)
- 1 Hz	40000
1 - 8 Hz	40000/f²
8 - 800 Hz	5000/f
0.8 - 3 kHz	6.25

There have been several separate studies concerning magnetic fields around substations in Finland. These studies have usually addressed only to the substations of one city or company so a general view has been missing. To achieve a more comprehensive view on magnetic fields caused by substations five electricity companies from Espoo, Helsinki, Oulu, Turku and Tampere participated the project. The goal of the project was to make a categorization of indoor MV/LV transformer substations according to magnetic field exposure. The project was led by Finnish Energy Industries association and funded by Tekes (Finnish Funding Agency for Technology and Innovation).

EVALUATION AND METERING METHODS

An evaluation method has been used in Helsinki since 2002. This method was complemented in this study with an estimate of the magnetic field in the space above the substation. Only rms-values of the magnetic flux density were considered in this study. Magnetic field harmonic components were not observed.

The evaluation began with collation of the basic information of the substation. It includes the address and route to the substation. The age and the last date of renovation were needed for the optimization of the further operations. The layout plan or the instrumentation plan was needed for the measurement purposes. The loading curve was needed to find the best time for the evaluation. The load should be as high as possible at the time of the evaluation. In the residential areas evaluations had to be made in the evenings because the load is often highest at that time of the day.

At the substation the first task was to check what kind of rooms and spaces were around the substation. If there were not such rooms or spaces where people stay significant time, the further evaluation was not done. The next task was to check that the layout or the instrumentation plan was correct. The distances from the low-voltage connection to the roof of the substation and to the floor of the room above the substation were measured. The load current was either checked from the meters in the low-voltage switchgear or measured with current meter. Because the load current was not measured simultaneously with the magnetic flux density, minor errors were caused.

Magnetic flux density was measured from two different points of views. The first measurements represented the magnetic flux density inside the roof of the substations and the second the magnetic flux density at the floor of the room above the substation. The measurements were made lengthwise the LV connection at intervals of 0.5 to 1 meter. Measurement point 1 was under or on the side of the LV connection at the same distance from the LV connection than the distance between the LV connection and the roof of the substation. Measurement point 2 was under the LV connection at the same distance to the low-voltage connection than the distance from the floor of the room above the substation to the LV connection. Primarily the measurements were made under the low-voltage connection and only if that was not possible then from the side of the LV connection. Example of a measurement under the LV connection is illustrated in figure 1.

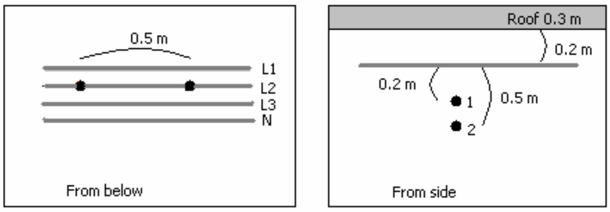

Figure 1: An example of the measuring points and distances in the vicinity of the LV connection.

The results of the evaluations were documented in a measuring record with the basic information and pictures of the substation. The results were also collected in a table for further analysis.

The evaluations of indoor MV/LV substations were made by HelenService in Espoo, Helsinki, Oulu and Turku. The meter was EnviroMentor Field Finder. In Tampere the evaluations were made by Tampereen Vera Ltd and the meter was Radisans Innova ML-1.

Because the load currents were different in different evaluations, the measured magnetic flux densities were scaled to correspond actual maximum current, transformer nominal current and reference current of 100 A. Scaling to actual maximum current describes the present worst magnetic field situation. Nominal current describes the worst possible magnetic field situation, if transformer is not overloaded. The reference current is used to compare the categories (structures) with the same load.

STUDIED SUBSTATIONS

In all 53 substations were evaluated. Companies chose about 10 of their typical substations. The results of 50 evaluations were examined. The results of three substations were not analyzed because the measurements were not extensive enough. The types and amounts of examined substations are presented in figure 2. The categories are based on previous studies at Helsinki, where 334 substations were evaluated from 2002 to 2005.

Same substation structures (categories) are in use in every city, only the amount of substations in categories varies. For example the structure "bus bars near ceiling" is common in Helsinki but rarely used in other cities. The reason is probably that in Helsinki the loads of substations are usually higher than in other cities. The structures of the substations are such similar in different cities, that the categorization model is valid in all cities. The number of studied substations in different categories is shown in figure 2.

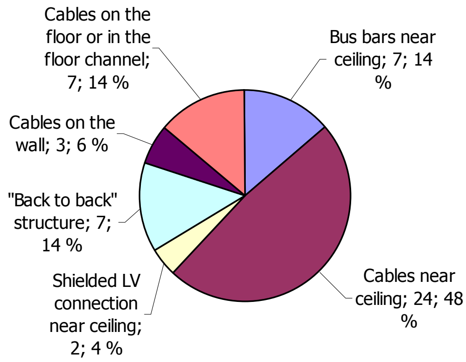

Figure 2: Number of examined substations in categories.

The categorization and criticality is analyzed based on the situation in Finland, where the substations locate on the ground or in an underground floor of the apartments. Situations, where public could be exposed to magnetic fields under the substations, are not considered.

CATEGORIZATION MODEL

The LV connection is usually the most important source of magnetic fields in a substation because it transmits the highest current. In this project the model utilized previously in Helsinki is expanded to fit in the variety of substations in all participating companies. The categorization model is presented in figure 3.

The categorization is primarily based on the distance between the LV connection and the roof of the substation. Structure of LV connection and possible shielding are the other classification principles.

If the LV connection is near ceiling, categories are further divided according to shielding. Shielding has to be made in magnetic field point of view. Otherwise the LV connection is treated as unshielded, e.g., the shielding is of metal wire-netting or plexiglass. The unshielded LV connections near ceiling are further divided to two; bus bar and cable connections.

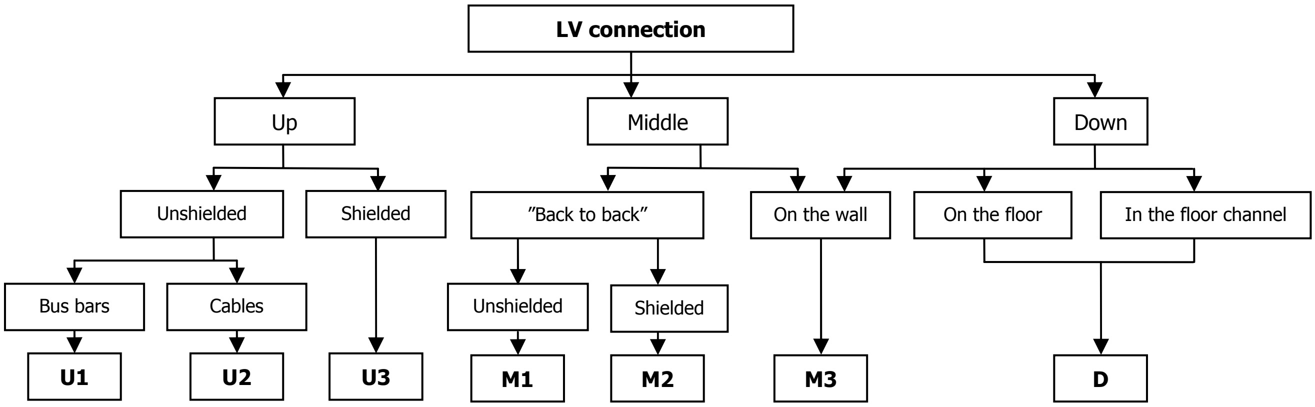

Figure 3: The categorization of the indoor MV/LV substations according to the low-voltage connection.

The LV connections placed vertically in the middle of the substation are divided to two categories. "Back to back" – structure means that the transformer and LV switchgear are placed next to each other and the LV connection is short and not located close to the ceiling. The other option is that the LV connection is placed on the wall of the substation. "Back to back" –structure may be unshielded or shielded.

If the LV connection is considered to be down, it can be either on the floor or in the floor channel. They are put in the same category, because they both create a very small magnetic field on the space above the substation. There is also a possibility that the low-voltage connection is going partly on the floor and partly on the wall. These kinds of structures are placed to the previously introduced category "on the wall".

There are always substations which have features from several categories of the model. In these cases it has to be considered which features are the most significant with respect to the room above or next to the substation.

CRITICALITY OF THE CATEGORIES

The criticality of the categories was analyzed by the results of the evaluations. The measured magnetic fields were scaled to be commensurate and they are shown in table 2. From every category there are shown the range of magnetic fields if there were more than one metering.

Based on the results the category U1 is the most critical. It is very likely that in above all substations of type U1 the public magnetic field exposure reference value (100 µT for 50 Hz) is exceeded. The only exceptions are substations where room is very high. Also substations of category U2 may cause at full load magnetic fields at the floor of the room above, which exceed the reference value. The distance between the LV connection and the floor above is very important in these categories.

In category U3 it is possible but not probable that the public reference values are exceeded outside the substation. It is very important that the casing is carried out with proper methods. If the reason for casing is shielding only from contact, the substation was categorized as U1 or U2.

Table 2: Evaluated magnetic field values for the measured substations.

Cate-gory	Number of measured substations at point 1	Magnetic flux densities at point 1 (µT)			Number of measured substations at point 2	Magnetic flux density at point 2 (µT)			
		Scaled to actual maximum current	Scaled to nominal current	Scaled to 100 A		Scaled to actual maximum current	Scaled to nominal current	Scaled to 100 A	Notice
U1	6	113.0-619.7	108.6-1068.3	15.0-92.5	4	52.9-195.3	104.7-336.6	8.1-29.1	
U2	2	21.8-318.0	22.1-450.5	3.1-39.0	1	4.0-97.1	4.5-186.9	0.5-16.2	
U3	2	29.3-77.6	47.0-102.1	5.7-6.5	1	23.4	37.5	5.2	
M1	4	5.7-107.2	9.3-138.2	0.8-19.1	1	2.2	3.6	0.3	
M2	3	5.8-41.1	10.8-47.8	0.7-6.6	1°	3	5.6	0.4	° Measured at the floor above
M3	3	1.1-119.9	1.3-125.4	0.1-17.4	1*	36.3	37.9	5.3	* Measured behind the wall
D	7	1.4-33.0	2.4-46.1	0.3-4.0	1	0.9	1.8	0.2	

Table 3: Summary of the categories and estimate of the magnetic field level around the substations.

Category	Description	Magnetic fields at the rooms around the substation caused by LV connection	Need for evaluation	Notice
U1	Bus bars near ceiling	Reference levels are possibly exceeded	Necessary	
U2	Cables near ceiling	Reference levels are possibly exceeded	Necessary	
U3	Shielded LV connection near ceiling	Reference levels are unlikely exceeded	Unnecessary	Shielding must be continuous and done on the point of view of magnetic fields.
M1	Transformer and LV switchgear "back to back", unshielded	Reference levels are unlikely exceeded	Unnecessary	Evaluation is necessary if the LV connection is connected on the ceiling or the room of the substation is very low.
M2	Transformer and LV switchgear "back to back", shielded	Reference levels are unlikely exceeded	Unnecessary	Evaluation is necessary if the room of the substation is very low.
M3	Cables on the wall	Reference levels unlikely exceeded above, possibly behind the wall	Necessary if public stay behind the wall	It is important to know the route of the cables to find out the possible rooms of high magnetic fields.
D	Cables on the floor or in the floor channel	Reference levels are not exceed	Unnecessary	The magnetic field caused by other devices at the substation is more important.

Magnetic fields in substations in categories M1, M2 and M3 do not usually exceed public reference values. If the substation is placed on a very flat room, also these categories may be critical. One this kind of substation was found from both categories M1 and M3.

Public reference values were not exceeded with category D, when only the LV connection was observed. In these kinds of substations the other devices in substations are more significant sources of magnetic fields for the room above. It is even possible that transformer or low-voltage switchgear causes magnetic fields, which exceed the public reference values. In this project the other sources but the LV connection were not studied.

SUMMARY

Indoor MV/LV substations can be categorized on magnetic field point of view by the structure of the LV connection. The idea of categorization was to find out how probable it is to have magnetic fields higher than the public reference levels in spaces around the substation. However, by knowing the category of the LV connection, one cannot be absolutely sure that the public reference levels are not exceeded. There are other factors, which affect a lot to the magnetic field around the substation, like the distance from the LV connection to the floor above or to the wall next to the substation. Also loads and phase distances affect the magnitude of the magnetic field. In the table 3 there is an approximative summary of the magnetic field levels in substations based on the categorization. Approximation was carried out by comparing measured magnetic field to the public exposure reference levels. The examination considered only the structure of the LV connection. However, one can conclude that the categorization of substations by the type of the LV connections is valid and can be a useful tool in daily work in electric distribution companies.

The decision whether a single substation should be evaluated and further improved depends on many factors. Magnetic field public exposure reference levels are one edge condition. The others are economical or technical conditions, which depend on the way of action of the electric distribution company.

REFERENCES

[1] ICNIRP, 1998, "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz) ", Health Physics, vol. 74, 494-522.

[2] European Council, 1999, Recommendation (1999/519/EC) on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), 12 p.

[3] Ministry of Social Affairs and Health (STM) of Finland, 2002, Decree (294/2002) “on the limitation of exposure of the general public to non-ionizing radiation”, 17 p. (in Finnish and Swedish)