POWER FREQUENCY MAGNETIC FIELDS FROM IN-HOUSE SECONDARY SUBSTATIONS

E. Salinas(1), L. Aspemyr(2), J. Daalder(3), Y. Hamnerius(4), J. Luomi(5).

(1), (3), (5) Department of Electric Power Engineering, and (2), (4) Department of Electromagnetics,
Chalmers University of Technology,
412 96 Gothenburg, Sweden

INTRODUCTION

A study is presented of 50 Hz magnetic fields originating from a secondary substation located in the cellar of a municipal library. Concern for the public health of the persons frequenting the reading room of this library initiated the analysis, which was made in co-operation with the utility who owned the substation. Extensive measurements were made of the field magnitude in and around the substation and more particularly in the reading room. Fields up to 5 microtesla were measured, which is far higher than recommended values. Further analysis showed that although the substation contributed to the total measured field pattern, a significant part was due to stray currents. Analysis of the main components in the substation were made (analytical calculations and 3-dimensional simulations combined with measurements). Due to the analysis executed and the demonstration of acceptable levels of fields from the modified substation, significant cost reductions were possible as authorities dropped their initial requirement of removing the station from the premises.

BACKGROUND

Since about two decades [1] the possible health effects of power frequency magnetic fields (50/60 Hz) are under debate but still remains an unresolved issue. These fields correspond to the lowest end of the non-ionizing part of the electromagnetic spectrum, in the range of extremely low frequencies. Hence, from the energy point of view it is hardly believable that they could cause any harm to human tissue. Nevertheless some epidemiological studies [2] show a correlation between certain cancer forms and domestic or work exposure to magnetic fields. It follows that the influence -if any- of these fields on human tissue might be rather subtle and therefore difficult to detect. This means that it could take a rather long time until we know for certain what the mechanism and the actual effects of these fields are. Until then, it is advisable to exercise a policy of *prudent avoidance* [3] and, in the specific case of public buildings, to study and try to reduce these fields. The Swedish building board recommends that new governmental buildings have magnetic fields below 0.2 T at stationary working positions [4]. An additional reason for the increasing awareness of these fields is the interference they can cause on video display units. This is evident in the form of screen jittering at field values over 0.6 T [5]. In the beginning of 1997, Chalmers University of Technology started a project to study 50 Hz magnetic fields and more specifically fields originating from substations and related sources.

Studied region

The Gothenburg city library (Göteborgs stadsbibliotek) is located in the center of Gothenburg and is surrounded by other public and urban buildings. About 190 persons work in this building [6], and around 3,000 visit it per day. The electricity supply to the library and neighboring buildings is a secondary 10/0.4 kV substation (two 800 kVA, three-phase transformers), see figure 1. It is situated in the cellar of the library building; the ceiling of the substation room is 3.5 m over the floor level.

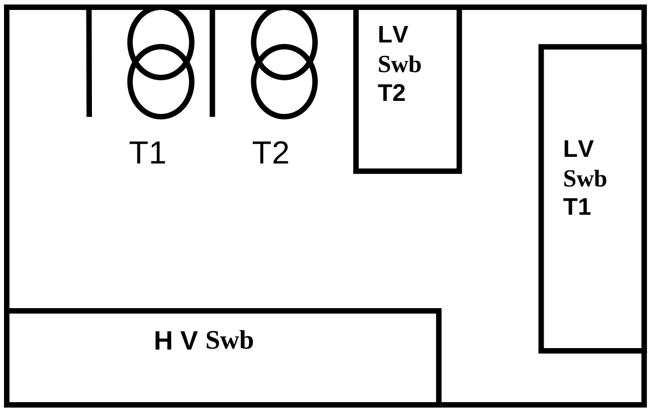

Figure 1. Secondary substation located in the cellar of the municipal library. There are two transformers T1 and T2, and high voltage (HV) and low voltage (LV) switchboards (Swb).

FIELDS AT THE LIBRARY AND THEIR SOURCES

A preliminary survey of the magnetic fields in the library indicated high values at floor level above the substation, indicating that these fields could originate from the substation components. Before the initiation of this study, relocation of the substation was under consideration. Since the majority of the substation components were about 25 years old a renovation was also planned.

Measurements

In cooperation with the personnel of the utility that owns the substation (Göteborg Energi) measurements were made covering an extended region (newspapers and magazines reading room) at the floor above the location of the substation. This was done at the floor level. A square (1-meter side) grid was constructed. The data were collected with the instrument EnviroMentor ML-1, a magnetic field logger [7].

Experimental results

The data (at the floor level) were plotted in a contour map. From this plot the presence of high magnetic fields (figure 2) is evident. Furthermore can be observed:

(i) magnetic fields values of around 1-4 T were registered on the part of the floor that is just above the high-voltage part (HV Swb) of the substation; similar values were registered over one of the low-voltage parts (LV Swb, T1).

(ii) values up to 6 T were registered at the reading room (under which there were no substation parts) following a diagonal path along the floor of this room.

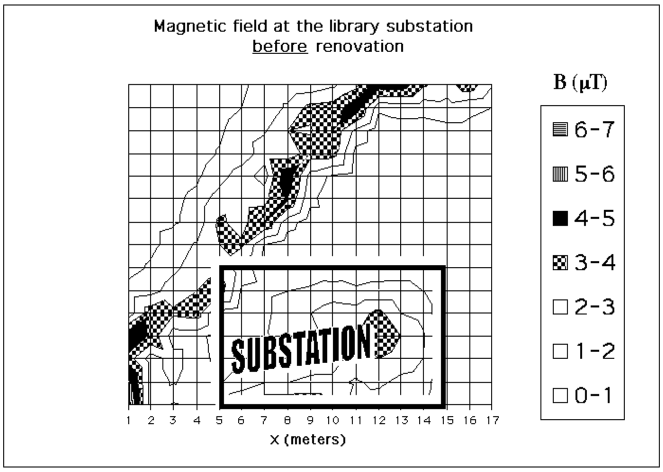

Figure 2. Magnetic field at the reading room of the Gothenburg city library, one floor above the substation.

Interpretation

Fields produced by some of the substation components can explain observation (i). The field values over the low-voltage part (LV Swb, T1) are due to the field originating at the bus bars situated inside the switchboard [8]. Cables passing near the ceiling of the substation produced the fields over the high voltage part (HV Swb). This was verified by additional measurements of the fields outside the building in areas adjacent to that side of the substation [8]. The observation (ii) demanded another explanation and required further study.

A stray current (current that escapes from an intended electric circuit) was suggested as the most probable cause of the field values described in (ii). To determine its location and its value, it was assumed that the stray current followed a straight path (as it is suggested from the contour plot). In addition, we considered the cables carrying this current to be located in a non-ferromagnetic and non-conductive region. Knowing the distribution of the magnetic field at the floor (which also gives the gradient of the field), it was possible to calculate where this current (I) was located and what its value was. For this, a straightforward calculation using Biot-Savart formula was sufficient [8]. The predictions were:

> The current had to be located at about 0,5-0,75 m under the floor of the reading room.
> The value of the current should be about 10-15 A.

The predictions were correct. The cables that were producing the main values of the magnetic field in the reading room were found; they were located between the floor of the reading room and at the ceiling of the cellar (figure 3). The cables were connected to a switchboard and running diagonally, at the predicted locations. The value of this current (around 12 A) was in agreement with the estimations. Measurements of the field at other locations (e.g. at 1m over the floor of the reading room and on other floors of the library) showed the penetration of the magnetic field, due to stray currents, in other areas of the building.

Figure 3. Stray currents were responsible for the penetration of the field in an extended area.

Time variation of the field

A magnetic field logger was installed at the reception desk in the reading room. It was situated 10 cm over the floor. The purpose was to detect 24-hours variations on the magnetic field. It was observed that the average magnetic field during the day increases about 2 T with respect to the night values (figure 4).

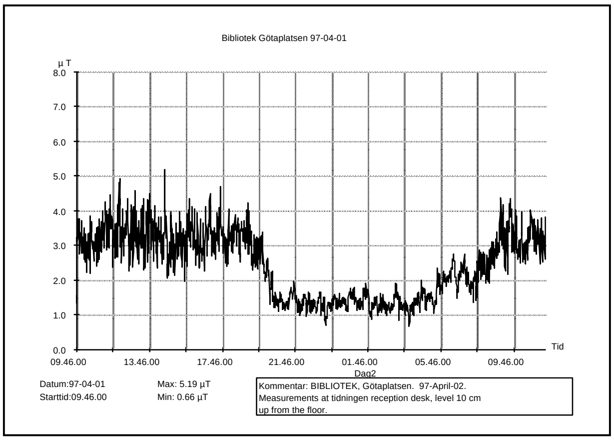

Figure 4. Time variation of the fields (24-hours), at a specific location, in the reading room.

A short-time variability (order of seconds and minutes) was also observed showing a correlation with the currents of various loads at the library [8].

EXPERIMENTS WITH THE SUBSTATION COMPONENTS

After evaluating of the results for the magnetic fields in the library it was decided to renovate the substation, discarding the option of removing it. This was caused by the strong possibility of reducing the fields (by modification of the components) in the area directly over the substation. The elimination of stray currents was not the direct responsibility of the utility, but rather of the owners of the building; this initiated another project that is based on “magnetic field reducer” [9].

The modification of the various parts of the substation (transformers, bus bars, switchboard, and cable-arrangement) implied the choice of low field emission components. For this purpose several experiments were performed evaluating the 50 Hz magnetic field emission of various parts. These measurements were done at an experimental facility of the utility; the background field of this location was 0.02-0.03 microtesla.

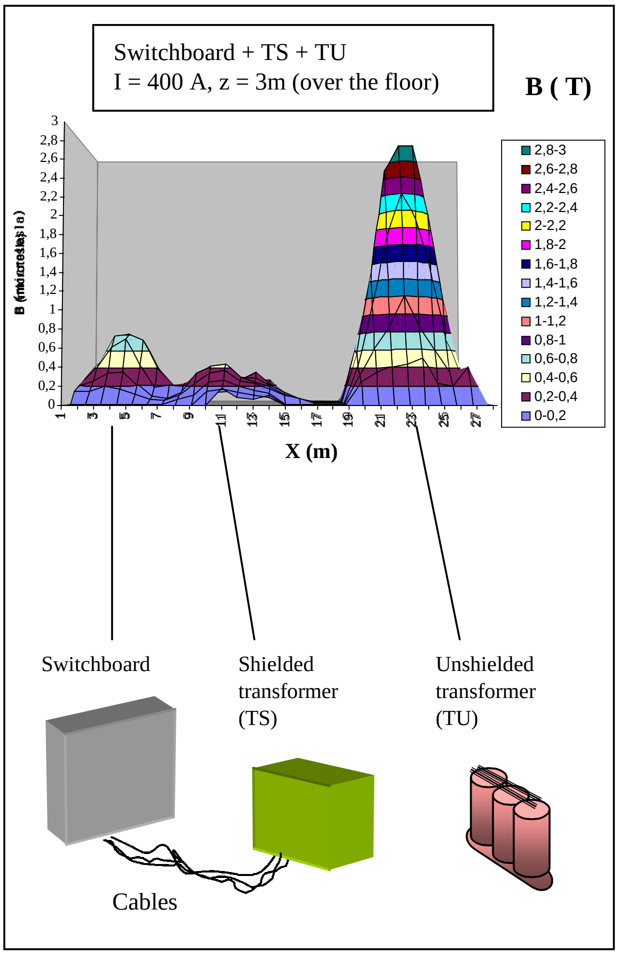

Figure 5. Comparison of magnetic field emissions from various substation components.

The field from a shielded (5mm-aluminum cover) transformer (TS), was compared with one having similar characteristics but being unshielded (TU). Both were three-phase, 800 kVA, and were from two different manufacturers. As a realistic arrangement, a connection to a switchboard (containing 2m-bus bars, made of Al covered by Cu) was added. The cables were arranged in bundles of different phases, in order to yield the lowest field emission The measured magnetic field at the height 3m above the floor of the facility, from the switchboard, with optimal cable arrangement, and transformers TS and TU, is shown in figure 5.

The magnetic field from shielded transformer was mitigated by a factor of 6-7. Therefore the aluminum-encapsulated type of transformer was chosen for the new substation.

The switchboard and its cover (2mm plain steel) were also studied. A finite element method (FEM) simulation of the bus bars, without cover, was made (fig 6). It gave a maximum value of 4.7 T, at the height 3m over the floor. Measurements at the same distance, for the covered switchboard, yielded a maximum of 0.7 T. Thus, this type of switchboard enclosure yields a low field emission, and it represented a good option for the substation modifications.

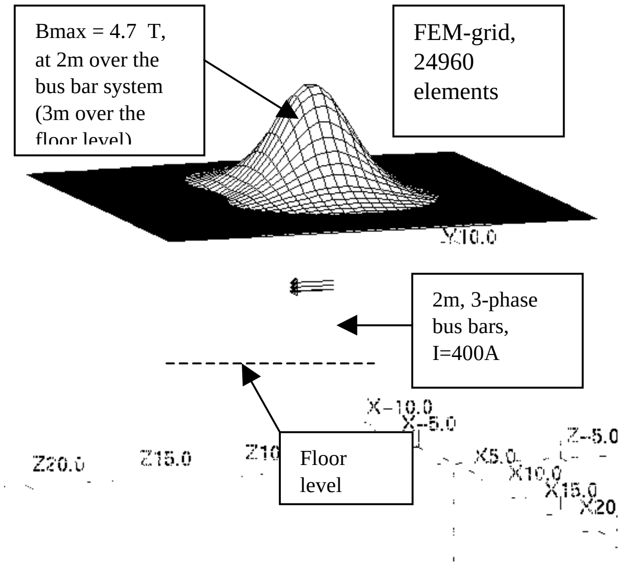

Figure 6. Magnetic field over a 3- phase bus bar system

THE MODIFIED SUBSTATION

Based on the result of the experiments and calculations, various modifications were made, not only by installing new substation components, but also altering their geometrical disposition in the room of the substation. A shielding of Aluminum (5mm-thick plate) was also added. A plate was welded it to the ceiling and other to the back part or the low voltage switchboards. Figure 7 shows the new disposition of the components at the substation.

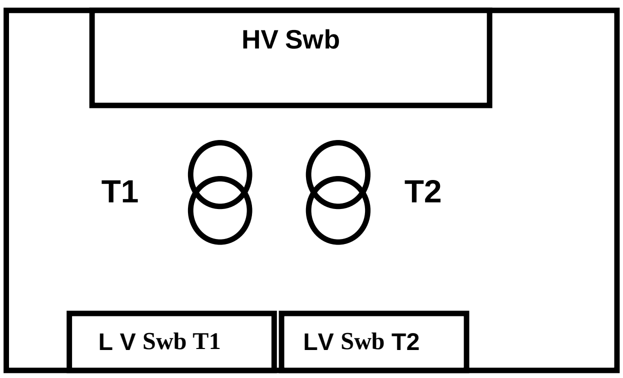

Figure 7. New substation at the cellar of the library. The two transformers are shielded; the cables in and out from the transformers go under the floor level; a 5mm welded aluminum shield lined the ceiling and the back of the low-voltage switchboards of the substation.

After the modification a series of measurements were performed in the reading room. To show more clearly the effect of the modifications made, the devices under installation to reduce the fields from stray currents were temporarily disconnected. The average value on the floor level was around 0.5 T and the maximum value (in a very small region) was 1.1 T (figure 8). Thus the reduction factor achieved was about 4 to 5.

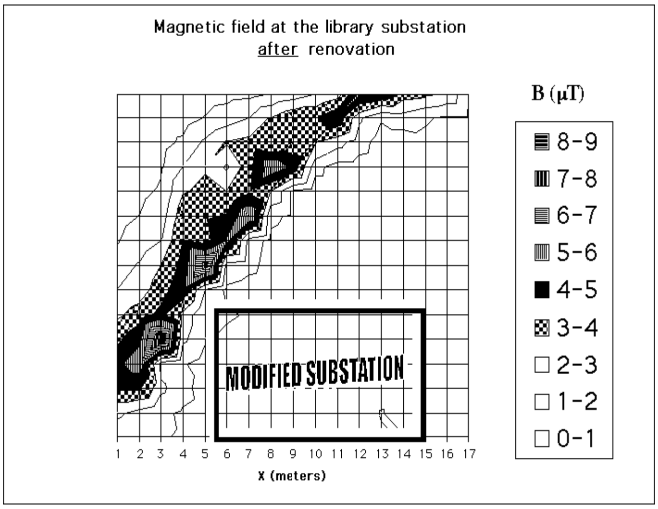

Figure 8. Field values at the reading room over the new substation. The average value inside the rectangle is about 0.5 microtesla.

CONCLUSIONS

Based on measurements, the mapping of the data in a contour plot, and doing simple theoretical calculations, stray currents were determined to be the main source of the magnetic fields at the Gothenburg city library. These currents were responsible for the field penetration in other regions of the library.

The substation also contributed to some of the high values at the floor over the substation. Since this was a concern to the utility, a decision was taken to modify the substation components in order to reduce the fields. The substation was rebuilt using the results of a series of experiments and calculations in order to determine low-emission components.

The modified substation shows an average field of 0.5 microtesla on the floor above, which represents a rather good mitigation of the fields. The decision of modifying the substation, compared to the option of relocating it, produced significant cost reductions to the utility.

Stray currents are not possible to shield. But there are other options to reduce them: a change to a 5-conductor system, or installation of magnetic field reducers. The first option is costly. Consequently the second is being implemented, which is the subject of an ongoing project.

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