Magnetic field survey in indoor MV/LV transformer substations

The TransCat –project
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TransCat; Categorization of indoor MV/LV transformer substations according to magnetic field exposure

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1 Background

Electromagnetic fields are an inseparable part of electricity distribution. Indoor Medium Voltage/Low Voltage substations may be located near the general population, which means that the magnetic field they cause may increase the exposure of nearby people significantly. Because the voltages used in electricity distribution do not cause a significant exposure to electric fields, and because the electric field is greatly absorbed by the substation walls, this guide concentrates solely on magnetic fields. The aim of this guide is to give information to electricity distribution companies on management of magnetic fields in substations. Two points of view will be considered; the distribution company’s own awareness obligation, and customer contact.

In Finland, Ministry of Social Affairs and Health has given recommended maximum values for current density and magnetic flux density in its decree 294/2002 to control exposure to non-ionising radiation. These recommended maximum values are presented in Table 1. They have been set based on known acute effects of magnetic fields. They do not take stand on long-term effects, of which there is no scientifically proven data. The recommended maximum value for current density inside human body should be primarily followed. In practice, the measurable magnitude is the magnetic flux density outside human body. The recommended maximum values in Table 1 are applied in targets where the population spends a significant amount of time. For non-significant times of stay the values are applied as fivefold.

Table 1: Recommended maximum values for current density and magnetic flux density in significant time of population exposure.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Current density (head and body) (mA/m²)</th>
<th>Magnetic flux density (µT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- 1 Hz</td>
<td>8</td>
<td>40000</td>
</tr>
<tr>
<td>1 - 4 Hz</td>
<td>8/f</td>
<td>40000/f²</td>
</tr>
<tr>
<td>4 - 8 Hz</td>
<td>2</td>
<td>4000/f²</td>
</tr>
<tr>
<td>8 - 25 Hz</td>
<td>2</td>
<td>5000/f</td>
</tr>
<tr>
<td>0.025 - 0.8 kHz</td>
<td>2</td>
<td>5000/f</td>
</tr>
<tr>
<td>0.8 - 1 kHz</td>
<td>2</td>
<td>6.25</td>
</tr>
<tr>
<td>1 - 3 kHz</td>
<td>f/500</td>
<td>6.25</td>
</tr>
</tbody>
</table>

Using Table 1 it can be calculated that at 50 Hz frequency, the recommended maximum value for magnetic flux density is 100 µT in significant time of population exposure and 500 µT in non-significant time. The decree also presents how occurring harmonics in the current can be taken into account by summing up the magnetic flux densities at different frequencies. RMS-meters for magnetic flux density may be used in charting the substations, in which case the different frequencies are not distinguished. In these cases the harmonic coefficient is typically between 1.5-3, so the effect of harmonics can be roughly estimated by dividing the 50 Hz recommended maximum value by the approximate 50 Hz cumulative harmonic coefficient. Magnetic field meters are also available which directly measure the magnetic flux density in its decree 294/2002 to control exposure of nearby people significantly. Because the voltages used in electricity distribution do not cause a non-significant time. The decree also presents the recommended maximum value for magnetic flux density in significant time of population exposure.

2 Awareness obligation

The electricity distribution company should be aware of the environmental effects of its operations, and thus also of the magnetic fields caused by its own substations. Chapter 2 of this guide describes procedures to categorize and chart magnetic fields in substations. The guide does not take stand on post-charting procedures, which are affected by technical and economical factors and company-specific courses of action.

2.1 Categorizing substations

The purpose of categorizing substations is to choose the substations to which the chartings should be directed. Categorization is meant to be done as work. The usability of the distribution company’s computer systems may naturally set limits to how much of the work can be done without visiting the substations. Similarly, the reliability of information recorded to the systems is company-specific. Substations can be categorized in two steps: first by location and then by the design of the low-voltage connection.

2.1.1 Categorization by location

Substation locations can be categorized according to whether the population exposure time in its vicinity can be considered significant. Significant exposure time means for example living, going to school or day-care in the exposure area. Working can generally be considered as significant exposure time, but the decree 294/2002 by Ministry of Social Affairs and Health does not apply to workers.

Substations are divided into two categories by location: PP (Permanent Presence) and NPP (Non-Permanent Presence). PP -category includes for example substations near apartments or classrooms. NPP -category includes for example substations in the vicinity of garages or garbage sheds.

When categorizing, it must be taken into account that even if the substation is located in an apartment building, all the spaces surrounding it may be storages, stairways, heat distribution rooms or similar spaces in which the exposure time is non-significant. Determining the nature of the surrounding spaces from building blueprints may be difficult, in which case the only possible way to determine them is in connection to maintenance checks or other visits to the substation, or at the actual charting. NPP -location category substations do not require further actions concerning public exposure to magnetic fields. PP -location category substations are further categorized by structure.

2.1.2 Categorization by structure

Categorization by structure is based on the design of the low-voltage connection. The strongest current in the substation typically flows in the low-voltage connection and is often located closest to the above or neighbouring space. In some cases some other substation components like transformer connectors and lead-throughs may be more significant for the surrounding area than the low-voltage connection. Table 2 shows the substation categorization by structure, estimated magnetic field intensity and estimated need for further actions.

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Table 2: Categorization by structure.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Magnetic field intensity (µT)</th>
<th>Estimated need for further actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>10</td>
<td>Strongest current in low-voltage connection.</td>
</tr>
<tr>
<td>U2</td>
<td>5</td>
<td>Medium current in low-voltage connection.</td>
</tr>
<tr>
<td>NP</td>
<td>1</td>
<td>Low current in low-voltage connection.</td>
</tr>
</tbody>
</table>

Based on Table 2, the magnetic field chartings are directed to structure categories U1 and U2. Only in some special cases the chartings required by the awareness obligation should be done in substations belonging to other structure categories. It should also be noted that technical and economical factors may in some cases make magnetic field-reducing actions advisable without charting.
2.2 Charting substations

The purpose of charting substations is to choose the substations that need further magnetic field reducing actions. Chartings can be done by the company itself or be bought. It is important that the persons doing the charting are acquainted with the task and understand what the goal of the charting is and how the measurements need to be done. Especially if several teams are doing the chartings, initiation is very important in order to get comparable results. The team should include at least two members because the work is done inside the operational facilities of the electricity network.

2.2.1 Basic data

To collect substation data before the charting is necessary for example for determining the charting time-point. Other background information concerning the substation should also be collected beforehand, because information in the data systems can be checked in the substation at the same time.

Substation address and route to the substations must be clear in order to locate it. Knowing the substation age and the last modernisation time-point help in optimising the procedures. Substation floor plan or equipment drawing is needed to mark the measurement results. Using the substation load graph, the best possible time-point is chosen for the measurements. Especially in residential areas this leads to measurements taking place in the evening. Nominal power and practical maximum current of the substation are necessary data when interpreting the results.

2.2.2 Charting

The charting includes following procedures: measurement of low-voltage connection load current; measurement of instantaneous magnetic flux density RMS-values in the vicinity of low-voltage connection and, when necessary, other components; and observation of substation room and surrounding spaces. Carrying out the charting may proceed for example in the following order:

1) The spaces surrounding the substation are identified in as great detail as possible. If it can reliably be assumed that people are not expected to spend a significant amount of time in any of the neighbouring spaces, the charting needs not be carried on further.

2) The floor plan or equipment drawing is checked to be accurate and corrected if necessary. The location of the neutral conductor is marked on the drawing. The nominal power of the substation is checked.

3) The distance between the ceiling and low-voltage connection is measured. The thickness of the ceiling is measured or estimated. The phase distance (the distance of the centres of adjacent phase conductors) of the low-voltage connection is measured. In case the low-voltage connection is symmetrised, the symmetrisation method is written down.

4) The load current of the substation at the time of charting is determined. The current can be checked from the switchgear meters if they are regarded sufficiently reliable. Another option is to measure the load current using for example a clamp-on meter.

5) Measuring the magnetic field density is primarily done from below the low-voltage connection. The measuring distance should be equal to the sum of ceiling thickness and the distance of the connection from the ceiling. The measurement point is where the magnetic flux density is lowest at that distance and it can be found below the middle phase conductor by moving the magnetic field meter parallel to the low-voltage connection. In most cases this point can be found near the centre of the low-voltage connection, because the effect of other components in the substation is usually lowest at this point. The mag-
magnetic field at this point indicates best the magnetic field at floor surface in the above space.

In case measuring from below the LV connection is not possible, the measurement is done from the side of the connection or from above it. If possible, the measurement is done from the opposite side in relation to the neutral conductor. This situation may occur when measuring other structure classes than U1, U2 or U3, or if the low-voltage connection is so short that the transformer and switchgear strongly affect the point below the low-voltage connection. These measurements cannot directly be used to estimate the magnetic field caused in the above space. The measurement results can be extrapolated to apply to the above space by a calculation method, if the horizontal and vertical distances of the closest conductor to the magnetic field measurement point have been measured as well as the phase distance of low-voltage connection and the distance of the low-voltage connection to the above floor surface. In addition, the magnetic field measurement should be done from at least a 20 cm distance from the closest low-voltage connection conductor in order to extrapolate the results as accurately as possible.

6) The substation room is photographed. General pictures of the room should be taken showing the location of the equipment in relation to each other. In addition, detailed pictures of for example symmetrisation or other specific solutions can be taken.

Safety at work must be taken into account during the charting. The magnetic flux density meter should be attached to for example an insulating rod, so that the workers do not have to get too close to live components. Safety at work also needs to be considered during measuring the phase distance of low-voltage connection and the distance of the low-voltage connection to the above ceiling. When measuring the current the measurer must be qualified for the task.

2.2.3 Reporting on the charting

Substation categorization data and basic data are collected in the charting record. The time-point of the charting and the persons performing it also need to be written down, as well as the meter used in measuring the magnetic flux density. All photographs are attached to the record.

Measuring points are marked on the substation floor plan. The measuring points should be tied to a solid structure in the substation, so that the measurement can be repeated at the same spots. Measurement results can be marked either straight on the substation floor plan or the measuring points numbered and the results marked separately in numerical order.

3 Chartings based on customer contact

The need for charting originating from customer contact basically causes the same procedures as described in chapter 2. In case the substation categorization has already been done, some targets may allow direct estimation of how likely the recommended maximum values are to be exceeded. It should be noted that interference to electrical equipment may be caused by much weaker magnetic fields than the recommended maximum values for population exposure. If the customer requests for magnetic field measurement, it is recommendable to perform the measurement inside the customer premises, because the measurements done inside the substation room are even at their best only estimations of the actual situation in the above or neighbouring space. The load current at the measurement time-point has to be determined also when measuring inside the customer premises. For reference purposes, the magnetic field strength should also be measured from inside the substation room, so that the customer’s electric equipment do not affect on the result. The measurements inside customer premises are, however, always primary. It is recommendable to report the measurement results in writing also to the customer.

4 Interpreting the measurement results

The magnetic flux density measurement results are connected to the load current at measurement time-point. The measurement results can be scaled to for example the practical maximum current or nominal current of the substation. Scaling to practical maximum current gives the worst possible situation corresponding the contemporary loads. Scaling to nominal current gives the worst possible situation in cases when the substation is not overloaded. The proportion of magnetic flux density harmonics usually diminishes when the load increases. For this reason, scaling the recommended maximum value always by for example harmonic coefficient 3 may result in a more sombre estimation of the magnetic field strength than the reality is.

Measurements done inside the substation room do not give direct indication on magnetic fields in the neighbouring spaces. Naturally, if the recommended maximum value for population exposure is not exceeded inside the substation at ceiling or wall surface, it is not exceeded in the surrounding area either as caused by the substation. For the point of view of population exposure, it is however more relevant to reliably estimate the magnetic field caused to the neighbouring space. In case the ceiling or wall thickness have been estimated during the charting, and the measurements are done from a distance matching it, the scaled measurement result can be considered a good estimation of the magnetic field in the neighbouring space. In case the measurements have been done from for example the side of the LV connection, and the connection has been implemented using busbars or cables, magnetic field graphs developed by Tampere University of Technology can be used to extrapolate the results.

Further information

European Council. Recommendation (1999/519/EC) on the limitation of the general public to electromagnetic fields (0 Hz to 300 GHz). 1999

International Commission on Non-Ionizing Radiation Protection. ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). 1998

ICNIRP. Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines. 2003


Participating companies: