Magnetic field measurements and calculations with 20 kV underground power cables

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Abstract

Magnetic fields from power systems have been studied extensively due to possible health risks. Another reason is disturbances caused by magnetic fields. Power cables are generally used in central areas, but they have not been studied as much as other field sources. In this study the aim was to measure and calculate with different commercial calculation programs the magnetic field from 20 kV underground power cables. The programs used here calculate magnetic field with the Finite Element Method (2D-FEM) and an analytical method. The analytical method is accurate in simple cases. When there are induced earth currents in the soil, the analytical method may produce a small difference. The magnetic field was also measured, and these results were used to analyze the accuracy of calculations. The sensitivity and suitability of the methods were studied by comparing the results to other calculation results and measurements.

During the magnetic field measurements, the load currents were obtained from the control room. The cables were located with the charts of the distribution network owner. The effect of different soil types on magnetic fields was also studied.

The highest value of all measurements was 1.5 µT at ground level. The calculated results of both programs were close to each other. The difference between measured values and calculated results seems to come from the installation depth. The soil did not have a significant effect on the results.

1 Introduction

Magnetic fields from power systems have been studied much because of possible
health risks. There are new ICNIRP guidelines for limiting exposure to time-varying electric and magnetic fields [1]. Another reason for measurements is the European EMC standard [2, 3], which sets immunity levels for magnetic fields. Power cables are generally used in central areas, and people may frequently be exposed to their magnetic fields. However, power cables have not been studied as much as other lines.

Magnetic fields from electric power systems have been studied at the Tampere University of Technology for many years. The aim of this study was to measure and calculate the magnetic field from 20 kV underground power cables. The effect of different soil types on magnetic fields was also studied.

2 Methods

The magnetic fields of 20 kV power cables (n=3) were measured in the Tampere city center. Analytical and finite element method (FEM) were used in calculations when not considering soil. The effect of different soil types was studied by considering their conductivity in FEM calculation.

2.1 Measurement method

The meter used here was Radians Innova ML-1 (accuracy ± 10%, three-axial, range 0.01 ... 100 μT and pass band 30 ... 2 000 Hz). The meter is three axial, hence it gives the resultant of the field in the measurement point. The magnetic field was measured at 3 heights, 0.0, 0.5, and 1.0 m up to 5 meters from the cable with 0.5 m intervals in both directions. In total, there were 63 measurement points. Figure 1 presents the measurement points of the cable.

![Figure 1: Measurement points above an underground cable.](image)

The cables were located with the charts of the distribution network owner. The exact place was detected with the magnetic field meter, as the field is highest just above the cable. Because the depth cannot be measured, it was assumed to be a 0.7 m. It is the installing practice in Finland.

When one side had been measured, the measurement of the other side was started from the center. The center point was measured twice, so there were 66 measurements per each cable. The load current was obtained from the control room.

2.2 Analytical calculation method
The magnetic field produced by a single electric conductor can be determined accurately with the law of Biot and Savart.

\[
B_s (r) = \frac{\mu_0}{4\pi} \int \frac{J(r') \times (r - r')}{||r - r'||^3} dv'
\]

where \( r \) is viewing point, \( r' \) is point with source current density, \( J \) is current density and \( v' \) is volume with source current density. Each conductor can be calculated separately, and the total field is summed as vectors.

2.3 FEM calculation method

FEM analysis is based on Maxwell's equations, from which an analysis eqn (2) is formulated. In the eqn (2) the primary variables are magnetic potentials (vector potential, \( A \)), which implement the differential forms of Maxwell's equations. This yields eqn (2) in a homogeneous area.

\[
\nabla \times \frac{1}{\mu} \nabla \times A = -\sigma \left( \frac{\partial A}{\partial t} + \nabla U \right) \cdot \vec{J}_s
\]

where \( \sigma \) is electrical conductivity, \( \partial t \) is differential time and \( \nabla U \) is gradient of electric scalar potential. In two-dimensional calculations the electric scalar potential is zero.

3 Cable modeling

In this study the magnetic field was calculated with analytical Resicalc 1.1 program and with numerical FEM, MagNet 5.2.3 program.

3.1 Cable modeling with analytical program

In the calculations of the commercial Resicalc only load currents can be accounted for, not earth return currents. Cable distances and the cable configuration are specified graphically or fed with the computer. The cable is supposed to be infinitely thick. In the model, calculation areas have to be defined. Results are brought out as an areal contour or map plots in calculation area. Statistical values of the magnetic flux density: the minimum, the maximum and standard deviation, are also available from the calculation area.

3.2 Cable modeling with FEM program

In numerical MagNet program both the load and earth return currents were considered. The geometry of the cable and the environment are preprocessed. The conductors in the cable, soil and air above the cable are first defined as
homogeneous areas with their material conditions. The load currents are set in areas. The boundary conditions are set in boundaries of the calculation area. All areas are discretized into elements. Then the program calculates the field. Results can be seen as an areal contour or vector plots. Result lists are also available.

4 Results

The magnetic field of 20 kV cables was studied above three example cables in Tampere city area.

4.1 Measurement results

Figure 2 presents the measurement results of example 1. The load current was 78 A. Negative distances are south from the cable, positive distances are to north. There was a road above the cable. The road was grift and since 3.5 m north from the cable asphalt. The ground is glacial drift, with resistivity between 1 000 ... 10 000 Ωm.

![Figure 2: Magnetic field as a function of the distance in example 1.](image)

The higher results are from ground level and lower results from 1 m height. The highest measured value is 1.5 μT.

In example 2 there were three cables in the same cable channel. One 20 kV cable (current 59 A) and two 0.4 kV cables (sum current 73 A). Figure 3 presents the measurement results of the example. Negative distances are west from the cable, positive distances are to east.
The differences between two center point measurements at ground level are caused by the variations of the current. The highest measured value is $0.9 \mu T$.

In example 3 there was a 20 kV cable (current 158 A). Figure 4 presents the measurement results. Negative distances are south from the cable, positive distances are to north.

Up to -3 m to south the heavy traffic precluded the measurements, because the
measurement points were in the road. The highest measured value is 1.2 μT.

4.2 Calculation results

The magnetic field was calculated with the analytical Resicalc 1.0 program and with numerical FEM, MagNet 5.2.3 program. Resicalc calculation results are presented in figures 5 ... 7.

Figure 5: Magnetic field calculation results with Resicalc in example 1.

Figure 6: Magnetic field calculation results with Resicalc in example 2.
Figure 7: Magnetic field calculation results with Resicalc in example 3.

Resicalc results are symmetrical in positive and negative values because the analytical method does not consider the uncertainties of the ground. The difference between the measured and calculated magnetic field in example 3 is quite high, as can be seen when comparing figures 4 and 7, but the form of the figures is the same.

Magnet calculation results are presented in figures 8 ... 10. The FEM program can consider the soil material. In example 1 the soil material is drift, and in example 2 it is sand with resistivity 2 300 Ωm, and in example 3 it is mull with resistivity 50 Ωm.

Figure 8: Magnetic field calculation results with Magnet in example 1.
Calculation results differ from the measured ones only in example 3. The difference is 2.0 μT. Because the difference is about the same with both methods, it can be supposed that the difference is caused only by the cable depth.

From figures 5 ... 10 it can be seen that the calculation results are practically equal. Figure 11 presents the difference of the results more clearly in example 1.
The difference is very small, only a few nano teslas. That means that the calculation method does not cause the differences between the calculations and the measurements.

4.3 Calculation results with various soil types

The surrounding soil effect on the magnetic fields was studied with FEM. The soil material was varied, and the results were analysed. Calculated soil materials were sea water (resistivity $\rho$ 1 $\Omega$m) and concrete ($\rho$ is 100 000 $\Omega$m). Calculated relative differences between the magnetic field in the case of sea water and dry concrete (from the concrete case value) for the cable in example 1 are presented in figure 12.
The difference is very small, only a few per milles. That means that the soil material does not cause any differences between the calculation methods.

5 Discussion

In measurements of magnetic fields from underground cables the highest magnetic field 5 μT was obtained for cable 1 (current 78 A). The measured magnetic field of cable 3 was lower, although the current was over double. Because same kind of cables were concerned, we can suppose that the measurement distance deviates remarkably from the cable 1 or the installation depth of the cable was different. In example case 2 two 0.4 kV cables beside the 20 kV underground cable seem to effect so, that the field attenuates slower when moving the center line.

While making magnetic field measurements of underground cables it was noticed clearly that even small changes in the measurement height effect measurement results considerably. The alternation detectable in results on different sides of the cable may be due to alternation of load current of the cable during measurements. These factors may cause errors in measurement results, so for this reason one must always pay special attention to the realization of measurements.

Calculated and measured results are, except cable 3, further away from the center line of the cable very close to each other. Instead, close to the cable there occurred some differences in calculation, that were at maximum about 0.4 μT. These errors were due to the fact that there was no specific information about installation depths of cables. Another possible reason for differences was alternations of load current during measurements.

6 Conclusion

The highest value of all measurements was 1.5 μT for cable 1 at ground level. The calculated value at the same point was 1.6 μT with both methods. The highest measured and calculated results were for cable 2; 0.9 μT and 1.2 μT, and for cable 3; 1.2 μT and 3.4 μT. The calculated results of the programs were close to each other, and the soil did not have a significant effect on the results.

Based on calculation, the installation depth seems to have major effect on magnetic fields. Therefore, the measured values can also vary a lot depending on the cable depth. That may be one reason for significant differences between the measured and calculated values with cable 3. The surrounding soil does not have an effect on the magnetic fields.

References
1. ICNIRP, Guidelines for Limiting Exposure to Time-varying Electric, Magnetic, and Electromagnetic Fields (Up to 300 GHz), Health Physics, Vol. 74, no. 4, pp 494-522, 1998.