Shielding and Mitigations of the Magnetic Fields Generated by the Underground Power Cables

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Abstract— In urban areas, especially in city centres, underground power cable usage in power distribution lines has been increasing dramatically. In this study, shielding the source and shielding the underground power cable raceway are investigated. In order to mitigate the magnetic field caused by underground power cables, two different shield topologies, the flat plate and the reverse-U shape shielding screens, are examined theoretically and practically on currently used cable raceways. The most appropriate shielding type is investigated.

1. INTRODUCTION

In recent years, increasing energy demand results in more loading in power transmission lines and correspondingly more magnetic field occurrence around transmission lines. These excessive magnetic fields can cause harmful effects on human health. These fields can also lead to deteriorating effects on the sensitive electronic equipment due to the electromagnetic interference. Therefore, investigation of the magnetic field that occurs around the underground cable lines used in the energy distribution network has become an important research topic. There are number of design options that would mitigate the magnetic field. However, magnetic field management can be basically classified into two main categories; which are shielding the subject and shielding the source. High voltage power line magnetic fields can occur at the top of the underground cable channels in city centers, playgrounds near the substations, on sidewalks, at business centers and many other vital areas which have energy demands. According to the studies, although the harmful effects of electromagnetic fields over human health are not totally confirmed, the results are sufficient to make the people worry, and hence, some of the countries have published safety standards for electromagnetic fields [1–4]. Measurement results are evaluated according to the limits of international standards or national standards according to the limit values which are considered as not to be damaging to the human health [5, 6].

In this study, the magnetic field levels on the underground power cable channels were measured and the behaviors to reduce the magnetic field of the different shielding materials were evaluated. The results are evaluated in the light of safety limits and recent studies maintained in this regard, and the optimal screen type for cable channels have investigated.

2. THE THEORY OF SHIELDING AND SHIELDING MATERIALS

Electric field shielding effectiveness (SE_E) and the magnetic field shielding effectiveness (SE_M) of a plate shield are obtained by the following equations.

$$SE_E = 20\log_{10}\left|\frac{\hat{E}^{inc}}{\hat{E}^{tran}}\right|, \text{ (dB)} \tag{1}$$

$$SE_M = 20\log_{10}\left|\frac{\hat{H}^{inc}}{\hat{H}^{tran}}\right|, \text{ (dB)} \tag{2}$$

where, $\hat{E}$ is the electric field intensity (V/m), $\hat{H}$ is the magnetic field intensity (A/m), *inc* is the incident wave, *tran* is the transmitted wave, and SE is the function of frequency. In shielding, the attenuation of electromagnetic waves from the air/conductive surface and with regard to the interaction enters the screen conductor takes place in three stages. These are: Reflection Losses (R_{dB}), Absorption Losses (A_{dB}) and Multiple Reflections (M_{dB}). The priority phase of the shielding is a reflection. To reflect wave with shielding, shielding is required to have load carriers (electrons and holes) which interact to each other. As a result, the shielding must be electrically conductive.

The Shielding Effectiveness of (dB) is denoted by the following expression:

$$SE_{dB} = R_{\text{dB}} + A_{\text{dB}} + M_{\text{dB}} \tag{3}$$

$$SE_{\text{dB}} \approx \underbrace{20\log_{10}\left|\frac{\eta_0}{4\eta}\right|}_{R_{\text{dB}}} + \underbrace{20\log_{10} e^{t/\delta}}_{A_{\text{dB}}} + \underbrace{20\log_{10}\left|1-e^{-2t/\delta}e^{-j2t/\delta}\right|}_{M_{\text{dB}}} \tag{4}$$

E/H ratio varies depending on the characteristics of the source in the near field region. If the source has high current and low voltage character, the magnetic field is dominant in the near field region and the ratio of $E/H < 377\,\Omega$. Whenever getting farther from this region, H *decreases by* $1/r^3$ and E *decreases by* $1/r^2$ *ratio*. On the other hand, if the source has high voltage and low current character, the electric field is dominant in the near field region and the ratio of $E/H > 377\,\Omega$. Whenever getting farther from this region, H *decreases by* $1/r^2$ and E *decreases by* $1/r^3$ *ratio*. In the near field, the wave impedances of E and H fields are expressed as;

$$\eta_E = \frac{\eta_0\lambda_0}{2\pi r} \gg \eta_0 \quad \text{and} \quad \eta_H = \frac{\eta_0 2\pi r}{\lambda_0} \ll \eta_0 \tag{5}$$

The electrical properties of some materials used in shielding are given in Table 1. The effect of the thickness of the shielding material versus shielding effectiveness is shown in Figure 1.

Table 1: Electrical properties of some shielding materials.

Material	**Resistivity (ρ) (Ωm)**	**Conductivity (σ) (Siemens/m)**	**Magnetic Permeability (μ_r)**	**Skin Depth (m)**		
				Frequency 50 Hz	**Frequency 60 Hz**	**Frequency 100 Hz**
Aluminum	2.82×10^{-8}	3.5×10^{7}	1	0.012	0.01	0.008
Copper	1.68×10^{-8}	5.58×10^{7}	1	0.0092	0.0084	0.0065
Iron	9.58×10^{-8}	1.04×10^{7}	500	0.0031	0.0028	0.0022
Steel	1.61×10^{-7}	6.21×10^{6}	100	0.0029	0.0026	0.0020

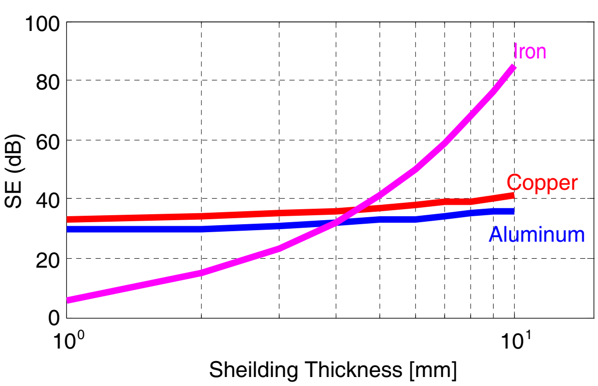

Figure 1: Shielding effectiveness versus material thickness for iron, copper and aluminum materials.

Figure 2: Measurement in the high voltage channel with reversed U galvanized shielding.

3. MAGNETIC FIELD MITIGATIONS OF UNDERGROUND POWER CABLES

In this study, 2 mm thick galvanized flat sheet, 2 mm thick flat iron plate, and 2 mm thick reversed U-shaped galvanized sheet (see Fig. 2) is used in the cable channels measurements as an electromagnetic field shielding material. Three-axis Hioki FT3470 brand magnetic field measurement device was used in the magnetic field measurements. This device is capable of RMS measurements in the range of 2 micro Tesla–2 mT, 0.5 mG–20 Gauss, 0.040 A/m–1592 A/m within 250 ms time periods with ±3.5% accuracy in the X, Y, Z-axis. Frequency range is from 10 Hz to 400 kHz.

The cable channel included HV cables has 80 cm depth and 66 cm width. There are 3 piece of $1 \times 240/25\,\text{mm}^2$ cross sectional XLPE cable for R, S, T phases. Line voltage of the plant is

31.5 kV. During the measurement, the load was recorded as 400 kW ($pf = 0.97$) and the current was observed as approximately 7.55 A. Shielding material thickness of 2 mm flat iron sheet and 2 mm reversed U galvanized sheet was used for the electromagnetic field measurements in the HV cable channel. For each shielding material, measurements were taken with 20 cm intervals from the vertical plane of the cable channel through the central axis of the ground level and the values were recorded. The measurement results are shown in Table 2.

Table 2: Magnetic field measurements in the HV cable channel.

HEIGHT	**Usage of Uncovered Channel (μT)**	**Usage of Reversed U Type Galvanized Sheet (μT)**	**Usage of 2 mm thick Flat Iron Plate (μT)**
0 cm	0.462	0.387	0.263
20 cm	0.385	0.332	0.227
40 cm	0.282	0.248	0.181
60 cm	0.181	0.164	0.129
80 cm	0.157	0.145	0.117
100 cm	0.134	0.125	0.11

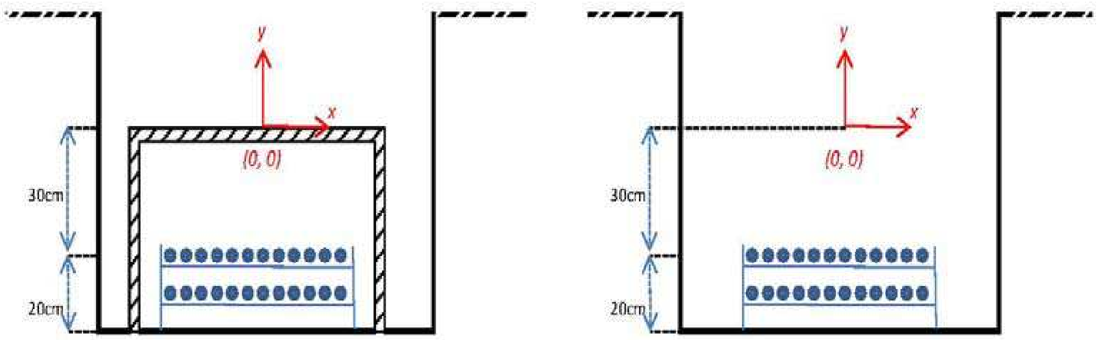

Figure 3: Representation of LV cable channel.

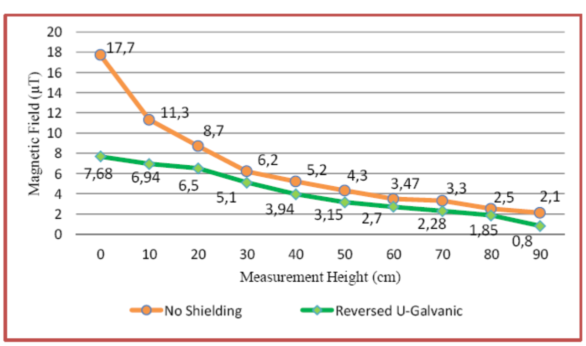

Figure 4: Comparison of LV measurement results.

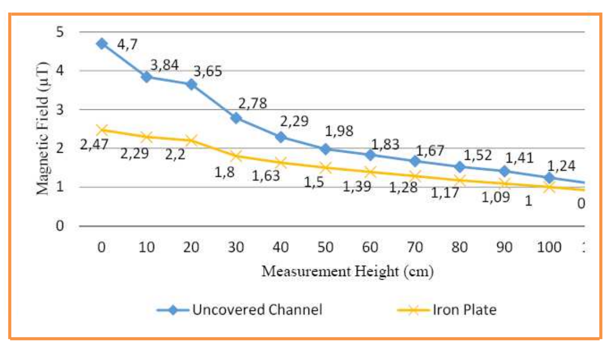

Figure 5: Shielding effect of iron sheet in the LV cable channel.

While the cable channel is uncovered and the top of the channel is covered with galvanized and iron sheets, the measurements of the magnetic field were carried out. Since multiple cable arrangement has been used, the current value was not measured separately for each cable channel. The LV output of the facility has been installed as balanced and approximately 38 kW load existed in each phase during the measurements.

For each shielding material, measurements were acquired at the central axis of the cable channel from ground level through 10 cm intervals at a vertical plane and the values were recorded. While the change of the shielding effectiveness of reversed-U galvanized in the LV power channel is shown in Fig. 4, the shielding effectiveness of the iron plate is shown in Fig. 5.

It is concluded that, better shielding efficiency is achieved when closed shields are used. On the other hand, in case of the flat plate shield usage, the efficiency depends on the electrical properties and the thickness of the material.

4. CONCLUSION

When measurements and the research findings which are obtained with established mechanisms with different shielding materials in the LV and HV cable channels are analyzed, the results denoted that "the shielding materials used and the distance between the source of the electromagnetic wave and the shielding material directly affects the shielding effectiveness". The measurement results made with different shielding materials showed that when the iron plate is used as the magnetic field shielding material, the highest shielding effectiveness is reached. U-typed screen displays are more effective than plain plate shaped. Accepted magnetic field limits should be revised, and in the light of recent research, regulations all over the world should be updated by reducing the general trend under the 0.3–0.4 μT level. While facilities and power transmission lines are being designed, the magnetic field calculation of the cable channels and their panels should be carried out. The analysis of power losses that occur in the screen materials for the lines to be screened, it is recommended as a further study subjects that can be done in this field.

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