ANALYSIS OF MAGNETIC FIELD EFFECTS OF UNDERGROUND POWER CABLES ON HUMAN HEALTH

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ABSTRACT

Transmission and distribution lines of electrical energy are generally used to plant far from residential areas. But today, due to the growing population, the cities considerably expanded and electrical network have to lie within the living spaces. Especially, uses of medium voltage underground cables for distribution systems become widespread in such areas. The voltage levels of these cables are not too high and the electric field caused by the voltage is fairly shielded by the cable's screen. However, by the reason of flowing load current through the cable's conductor, low frequency magnetic fields occur around the cable. It is known that this magnetic field strength becomes greater with increasing current. Basically, shielding of low frequency magnetic fields is quite harder than shielding the electric fields. In case of being exposed to this kind of magnetic fields by people may lead to crucial health problems. Therefore, some limit values are introduced by the "International Commission On Non-Ionizing Radiation Protection" (ICNIRP) and "The Institute of Electrical and Electronics Engineers" (IEEE). For this reason, it has importance of measuring magnetic fields caused by high voltage cables (HVC) in urban areas and the required shielding measures should be taken if needed. In this study, magnetic field strengths at different points above a 12/20 kV, 150 mm^2 (Al), single core HVC are measured for different current values. According to the results obtained, even at low currents, the magnetic field strength values could exceed the limiting values for certain distances.

Keywords: Magnetic Field, Underground Power Cable, Human Health

1. INTRODUCTION

Electrical energy is one of the most important sources in our age. The need for electrical energy is rapidly growing with developing technology and increasing population. Generated energy is supplied for the end users through transmission and distribution lines to meet this energy demand. Resulting from expanding of residential areas and increasing energy demand, especially distribution lines penetrate in living spaces [1]. While energy is distributed with overhead lines in the beginning, today underground power cables are being used especially for human safety and clear visual pollution. These cables are widely used for supplying distribution transformers in thickly populated places [2,3].

Underground power cables used in distribution systems cause electric field because of being operated at medium voltage. All underground power cables, which operate at medium voltage, consist a screen layer made of copper or lead [4]. This screen is grounded in practice and can shield almost all electric field arise from conductor. However, this screen layer cannot totally shield low frequency magnetic fields arise from load current. Current carrying capacity of underground power cables, which generally used in residential areas, is quite high. Therefore, magnetic field exposure risk occurs for humans.

In literature, there several studies about the effects of magnetic field exposure on human health [5-8]. Thus, analysis of magnetic fields arise from underground power cables has an importance. Limiting magnetic field values for different frequencies are introduced by ICNIRP [9].

In this study, magnetic field measurements of an underground power cable are carried out for different currents at certain distances. The results obtained are analyzed by using ICNIRP standard. In the following section, for magnetic field calculation for, fundamental formulas of a current carrying conductor are given and limit values by ICNIRP are presented. In the third section, measurement setup and results are presented. Consideration of results and suggestions are given in the last section.

2. BASIC THEORY

In power systems, magnetic fields occur around the conductors which carry currents. When the current increases, the magnetic field is also strengthen proportionally. Magnetic field induced a voltage in conductors and dielectric materials placed within the field [10]. This induced voltage cause to flow current in object which harms the livings. Limiting values are defined to keep human health in safe. It is important to consider these values while designing a system which consist current carrying conductors.

At a specified distance, magnetic field value of a current carrying conductor can be calculated by Bio-Savart equation given in Eq. (1).

$$H = \frac{I}{2 \cdot \pi \cdot r} \text{[A/m]} \tag{1}$$

where,

H = Magnetic Field Strength [A/m]
I = Current [A]
r = Distance [m]

As it is known that magnetic field strength (H) is a vectorial magnitude. So, a current carrying conductor at point K causes to occur both horizontal and vertical magnetic field component. With vectorial sum of these components, resultant magnetic field (H) at point P is acquired as shown in Fig. 1 [10].

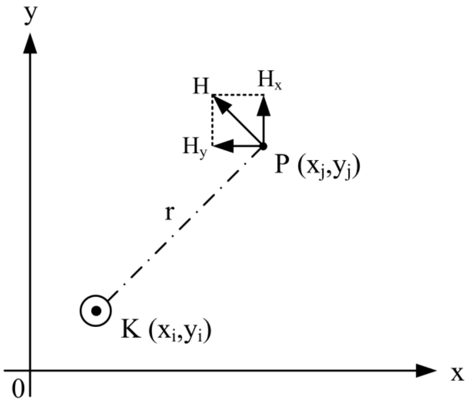

Figure 1 Magnetic field strength of a conductor (K) at point P

According to the Figure 1, horizontal and vertical components of magnetic field strength (H) at point P can be calculated with formulas given in Eq. (2) and (3) respectively.

$$H_x = \frac{I}{2 \cdot \pi} \cdot \frac{y_j - y_i}{r^2} \tag{2}$$

$$H_y = \frac{I}{2 \cdot \pi} \cdot \frac{x_j - x_i}{r^2} \tag{3}$$

Here, x_i and y_i are the coordinates of point K and x_j and y_j are the coordinates of point P. r is the distance from the current source defined as,

$$r = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \tag{4}$$

To calculate resultant magnetic field strength, horizontal and vertical components are vectorially added. If there are n conductors in a system, resultant magnetic field strength can be calculated with the Eq. (5).

$$H = \sqrt{\left(\sum_{i=1}^{n} H_{xi}\right)^2 + \left(\sum_{i=1}^{n} H_{yi}\right)^2} \tag{5}$$

Magnetic flux density (MFD) can be calculated by multiplying the magnetic field strength (H) and magnetic permeability of vacuum or air ($\mu_0 = 4 \cdot \pi \cdot 10^{-7}$ [H/m]) as given in Eq. (6).

$$B = \mu_0 \cdot H \tag{6}$$

In Eq. (6), B is the magnetic flux density or magnetic induction in Wb/m^2 or Tesla.

Several studies have been published about the effects of magnetic field on human health. Magnetic field exposure levels depend on many factors such as distance from the magnetic field source, exposure duration, strength and frequency of the magnetic field. Therefore, limit values for magnetic fields at different frequencies are specified by the ICNIRP [9]. These values are given in Table 1 for occupational and general public exposure.

Table 1 Reference levels for occupational exposure to time varying magnetic fields (unperturbed rms values).

Exposure	Frequency Range	Magnetic Field Strength H (A/m)	Magnetic Flux Density B (T)
Occupational	1 Hz – 8 Hz	1.63 x $10^5/f^2$	$0.2/f^2$
	8 Hz – 25 Hz	2 x $10^4/f$	2.5 x $10^{-2}/f$
	25 Hz – 300 Hz	8 x 10^2	1 x 10^{-3}
	300 Hz – 3 kHz	2.4 x $10^5/f$	$0.3/f$
	3 kHz – 10 Mhz	80	1 x 10^{-4}
General Public	1 Hz – 8 Hz	3.2 x $10^4/f^2$	4 x $10^{-2}/f^2$
	8 Hz – 25 Hz	4 x $10^3/f$	5 x $10^{-3}/f$
	25 Hz – 50 Hz	1.6 x 10^2	2 x 10^{-4}
	50 Hz – 400 Hz	1.6 x 10^2	2 x 10^{-4}
	400 Hz – 3 kHz	6.4 x $10^4/f$	8 x $10^{-2}/f$
	3 kHz – 10 MHz	21	2.7 x 10^{-5}

In this study, 50 Hz power system frequency is considered. Measured MFD values at this frequency should be under 1 mT for general public exposure and 0.2 mT for occupational exposure.

3. EXPERIMENTAL SETUP AND RESULTS

In the measurement, 12/20 kV, 150 mm^2, single core high voltage underground cable is used. The technical specifications of the cable sample are given in Table 2 [11].

Table 2 Technical specifications of the cable sample

Parameter	Value
VDE Code	NA2XSY
Nominal voltage (kV)	12 / 20
Nominal cross-section (Al/Cu Tape) (mm^2)	1x150/16
Conductor DC resistance (at 20°C) (ohm/km)	0.198
Operating inductance (mH/km)	0.63
Operating capacitance (μF/km)	0.25
Current carrying capacity (in air) (A)	425
Cable length (m)	12
Overall diameter (mm)	33.5

The cross-sectional area of the sample cable is given in Fig. 2. The underground power cable consists of a few layers. The conductor is the main part which transfers energy. The main insulation material of the cable is cross linked polyethylene (XLPE). There are semi-conductor layers around the copper conductor and insulation. Semi-conductor layer is used for smoothing the field distortion caused by stranded structure of conductor and roughness of the sheath. The role of the screen is shielding of electric and magnetic fields. For this reason, lead is generally used as screen material for cables which have high current carrying capacity. The outer sheath is made of PVC and it protects cable from environmental effects.

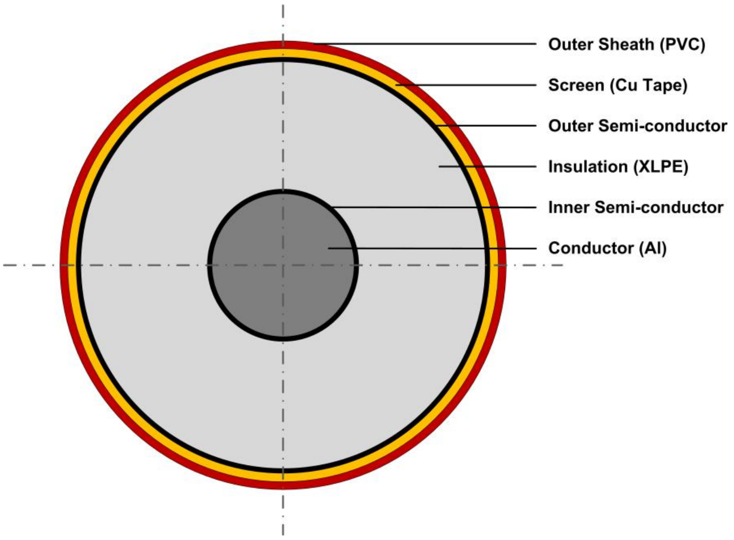

Figure 2 Cross-sectional area of underground power cable

The measurement setup given in Fig. 3 is arranged for flowing current through the cable conductor. The conductor of the cable is connected to the secondary windings of a 220V/5V and 5 kVA high current transformer. This transformer is supplied with a 220V/0-220V, 5 kVA variac. So the desired current value is obtained by varying the secondary winding voltage of the variac. A 1000 A clamp meter with ±1.5% sensitivity is used to measure the cable current. Additionally, the screen of the cable is grounded as in practice.

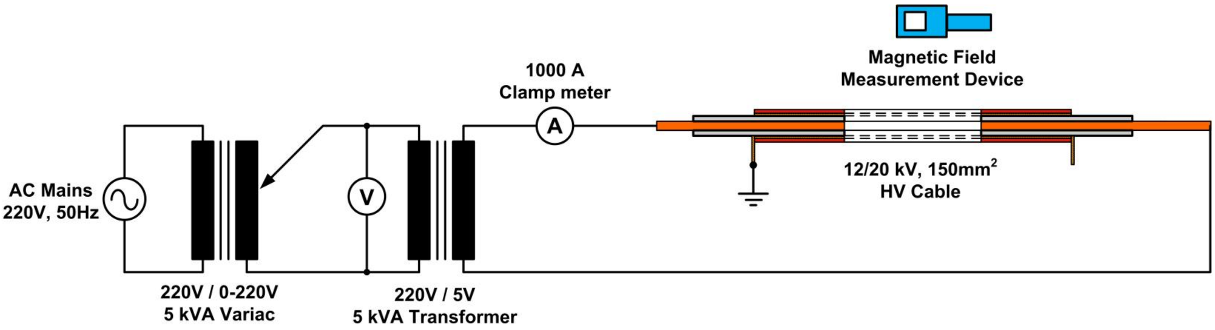

Figure 3 The experimental setup

In the measurement, a magnetic field measurement device Spectran NF-5035 is used. The measurements are realized for certain distances (5, 10, 20, 40, 60, 80 and 100 cm) above the upper side of cable. The minimum load current for measurement is specified as 50 A. The measurements are carried out up to 450 A with 50 A steps. The results obtained are given in Table 3.

Table 3 Measured magnetic flux density values

Distance From Upper Side (cm)	Magnetic Flux Density [µT]								
	50 A	100 A	150 A	200 A	250 A	300 A	350 A	400 A	450 A
5	135.5	**262.5**	**371.3**	**471.6**	**559.1**	**693.7**	**794.2**	**914**	**1010**
10	70.27	142.5	**210.9**	**267**	**333.6**	**384.4**	**449.9**	**504.2**	**567.2**
20	39.65	75.05	113.8	149.8	182	**215.4**	**247.7**	**283**	**312.9**
40	18.98	40.81	60.37	78.37	97	113.9	131.2	151.2	170.3
60	16.54	23.45	40.6	50.51	65.9	75.08	87.94	102	112.8
80	14.79	19.55	27.31	36.59	46.97	54.67	63.56	75.46	83.29
100	12.04	19.05	21.1	27.81	33.5	42	50.72	56.27	63.89

As seen in Table 1, MFD is increasing with the increased current. Also, it reaches the highest values for all current levels when it gets closer to the cable surface. The highest MFD is obtained as 1010 µT for 450A current and 5 cm distance. The weakest MFD value is acquired as 12.04 µT for 50 A current and 100 cm distance. Additionally in Table 1, some values, which exceed the limit values in ICNIRP for general public exposure, are given in bold. Especially for the currents from 300 A up to 450 A and 20–30 cm distance, it is clearly seen that the measured MFD values are unsafe for general public.

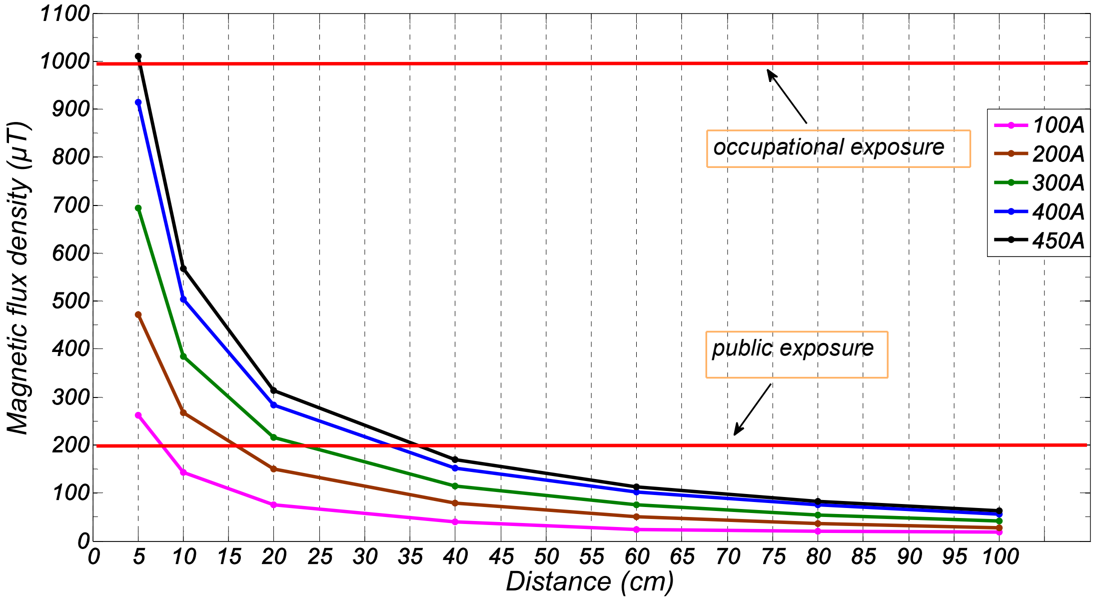

Figure 4 The relation between distance and magnetic flux density

The relation between the distance and MFD for all current levels is given in Fig. 4. It seen from the Fig. 4 that, MFD is exponentially increasing with decreasing distance from the source for all current levels. Additionally, the difference between MFDs obtained for certain current levels show difference according to the distances. When it gets closer to the cable such as 5 cm distance, the difference is quite high for different current levels. In contrast with this change, the difference is quite small when it goes far from the cable.

4. CONCLUSION

In this study, magnetic field measurements of a 12/20 kV, 1x150/16 mm^2 underground power cable is realized for particular current and measurement distances. The results showed that magnetic field is increasing with the increased current and decreased distance. Especially for 450 A current, the MFD value exceed the limit value for general public at 35 cm distance.

In addition, underground power cables are commonly installed 80 cm below the ground surface. So approximate distance value, that the people can be exposed to magnetic field, is over 80 cm distances from the cable. Therefore, the MFD values obtained in this study seem safe for human health. However in practice, there are at least three cables in the cable route for three phase systems. In this situation, each magnetic field strength value is vectorially added together as in Eq. (5). Thus, the magnitude of MFD can be reach to considerable high values which can be unsafe for human health. Additionally, there underground cables whose sectional area and so the current carrying capacity is higher from the one in this study. So, the cables which have high current carrying capacities are bigger threads for human health.

Consequently, magnetic field strength caused by an underground power cable can be at dangerous levels for human health. To get over this problem, magnetic field measurements around the underground power cables should be done carefully. In the case of existing high magnetic field values, the whole cable system could be shielded by a ferromagnetic material or the cable route could be further from the ground. Thus, generated magnetic field can be decreased down to required limit values.

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