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Electromagnetic fields from underground cable lines: FEM calculations and measurements

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***Abstract*—The paper describes and analyze the electromagnetic fields from underground cable lines. Characteristics will be given of the cable and considered shields. Also, presents calculations of fields with help of FEM 4.2 for semi round and rectangular magnetic shield. Practical measurements will be given and made comparison between two types of magnetic shields.**

Keywords—electromagnetic radiation; low frequency; magnetic schields; measuring

I. Introduction

In urban areas, most often due to rationality, economy, safety and appearance of the terrain, cable lines are laid in the country. When installing them, it must be taken into account that with the flow of current through the cables, electromagnetic fields are created. The same happens with the installation of installation cables in individual dwellings, collective buildings, centers, wherever a person stays indoors.

Magnetic fields, which are created as a consequence of low frequencies, have certain harmful effects on humans, so, when laying underground installations and cables, it is necessary to install appropriate protection, which aims to reduce these impacts [1].

When choosing the material from which the protection will be made, special attention must be paid to its magnetic characteristics, more precisely the material should have high conductivity and high magnetic permeability.

II. Charasteristics of Rear Cable and Magnetic Shield

The analysis in this case is made for an underground three-phase cable line with a voltage level of 25 kV. The line consists of three conductors for each phase, with an even load and a flow current of 100A. The conductors are placed at a depth of about one meter underground, with a distance between the longitudinal axes of 10 cm.

Above the conductors themselves, a suitable magnetic shield is placed at about 20 cm, which can have a rectangular or semicircular shape, in order to reduce the impact of the electromagnetic field. The shield should have good magnetic properties, and most often these are ferromagnets that have a high value of magnetic permeability μ_r. In this case it is about refined iron with 99.95% purity and $\mu_r = 500$.

In the calculations and constant frequency of 50 Hz characteristic for our networks, the skin effect must be taken into account, which is important when choosing the material for making the shield.

III. Analysis for Underground Cable with FEM 4.2

In order to analyze the effects of the magnetic fields from the cable lines, area of a circle with a certain diameter of 3.5 meters is taken, in order to see the different influences at different heights, and in the center of the circle are placed conductors.

Fig. 1 shows this situation.

The field reduction factor (RF%) is given by (1) :

$$RF_{\%} = 100 \cdot \frac{B_0 - B}{B_0} \tag{1}$$

Where:

B_0 [μT] - Magnetic induction at any point in space when no magnetic shield is placed

B [μT] - Magnetic induction at the same point in space when a magnetic shield is placed

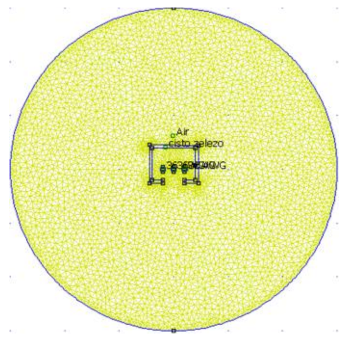

Fig. 1. Geometry and grid for simulations with FEM4.2 [5]

Mathematical simulations are performed using the FEM 4.2 software package. Accordingly, three analyzes are performed, one meter high from the cable, that is on the ground itself, then one meter high from the ground and two meters high from the ground.

IV. RESULTS OF FEM'S CALCULATIONS FOR SEMI-ROUND AND RECTANGULAR MAGNETIC SHIELD

A. *Semicircular magnetic shield*

For the analysis of the magnetic shields are given values of the shield thickness of 2 mm and magnetic permeability of μ_r = 15000.

Three simulations were made with different lengths of the shield arms, at 0 mm, 100 mm and 200 mm, as well as without a shield.

TABLE I. RESULTS OF SIMULATION OF SEMI-ROUND SHIELD

	B (µT)	**PF (%)**
On the ground (1m above the conductors) *B_o = 0.459 (µT)*		
Without shield	0,459	0
With arms 0 mm	0,191	58,3878
With arms 100 mm	0,186	59,47712
With arms 200 mm	0,182	60,34858
2m above the conductors *B_o = 0.233 (µT)*		
Without shield	0,233	0
With arms 0 mm	0,13	44,20601
With arms 100 mm	0,1269	45,53648
With arms 200 mm	0,123	47,2103
3m above the conductors *B_o = 0.156 (µT)*		
Without shield	0,156	0
With arms 0 mm	0,0921	40,96154
With arms 100 mm	0,0895	42,62821
With arms 200 mm	0,0845	45,83333

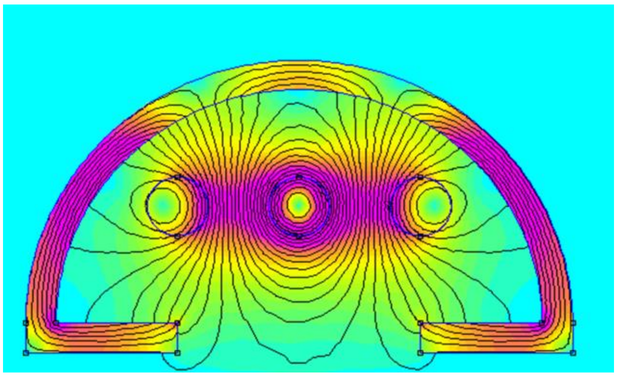

Fig. 2. Display of magnetic force lines with FEM 4.2 for conducter with semiround shield with arm 200mm [5]

Table 1 show the average values of the reduction factor and the magnetic induction vector (B) calculated one meter above the conductors (on the ground), two meters from the conductors and three meters from the conductors, for the three simulations for different values of the arms of the magnetic shield.

The obtained results show that for double reduction of the magnetic field, the arms of the semicircular shield need to be at least 100 mm.

The greatest protection is obtained with a semicircular magnetic shield with arms of 200 mm, and its display with FEM 4.2 is given on Fig. 2.

B. *Rectangular magnetic shield*

The same procedure was applied in the analysis of a rectangular magnetic shield. Table 2 shows the average values of the reduction factor and the magnetic induction vector (B) calculated one meter above the conductors, (on the ground), two meters from the conductors and three meters from the conductors, for the three simulations for different values of the arms of the magnetic shield.

The results obtained from the mathematical analysis for a rectangular magnetic shield placed above the conductors, show better protection than the previous case.

Compared to a semicircular magnetic shield, in this case, for arms with a length of 100 mm, a magnetic field with a reduced factor of 70% can be obtained.

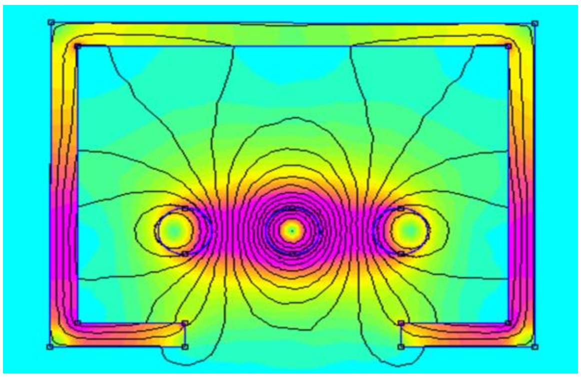

Fig. 3. Display of magnetic force lines with FEM 4.2 for conducter with restangular shield with arm 200mm [5]

TABLE II. RESULTS OF SIMULATION OF RESTANGULAR SHIELD

	B (μT)	PF (%)
On the ground (1m above the conductors) B_o = 0.459 (μT)		
Without shield	0,459	0
With arms 0 mm	0,138	69,93464
With arms 100 mm	0,134	70,8061
With arms 200 mm	0,12	73,85621
2m above the conductors B_o = 0.233 (μT)		
Without shield	0,233	0
With arms 0 mm	0,117	49,78541
With arms 100 mm	0,114	51,07296
With arms 200 mm	0,102	56,22318
3m above the conductors B_o = 0.156 (μT)		
Without shield	0,156	0
With arms 0 mm	0,0839	46,21795
With arms 100 mm	0,0819	47,5
With arms 200 mm	0,07	55,12821

The greatest protection is obtained with a rectangular magnetic shield with 200 mm arms, and its display with FEM 4.2 is given in Fig. 3.

The calculations should also take into account the possible losses due to the installation of the magnetic shield. The material from which the shield is made has good electrical conductivity, so due to that internal (whirlwind) currents will flow which will heat the shield, and due to the hysteresis cycle there are losses that will be converted into heat. The losses in soft ferromagnets that have a lower hysteresis area will be smaller.

V. CONCLUSION

In the case of underground cable lines, using a suitable magnetic shield can reduce the magnetic field by up to 80%, if the shield has a correct geometric design and if it is made of good ferromagnetic material. A thicker shield offers greater protection from the magnetic field. The effectiveness of the shield is also greater with the length of the arms and the increase of the angle. The losses from the hysteresis and the whirlwind currents also depend on the material of the shield. For soft ferromagnetic materials the losses due to hysteresis are smaller due to the smaller surface area of the hysteresis cycle, and for hard ferromagnetic materials with a wide hysteresis cycle the losses will be higher.

From the performed simulations it can be concluded that in terms of the shape of the magnetic shield, the rectangular shield provides better protection.

Regarding the size of the shield arms, the best protection is obtained with 200 mm arms.

At 2 m from the ground, тhe field is reduced by 56.2% in the rectangular shield, and in the circular 47.2%, which is 10% more.

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