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A PROTECTION SHIELD AGAINST ELECTROMAGNETIC FIELDS OF TRANSFORMER SUBSTATIONS IN RAIL TRANSPORT

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ABSTRACT

This paper presents characteristics of electromagnetic fields that arise from the generation and affect railroad workers. Besides, radiofrequency electromagnetic fields, there is human exposure to electromagnetic fields that are being generated by utility frequency power transformers. The high voltages and high currents of the transformer substations are sources of strong electromagnetic fields on railroad. For this reason, the analysis has been conducted on protective properties of a new shield design and suggested a design of a multilayer electromagnetic shield to protect the workers and automatic equipment for the railroad industry from exposure to utility frequency fields.

Disciplinary: Transportation & Infrastructure Management, Electromagnetic Engineering.

1. INTRODUCTION

Electrical installations of transformer substations (TS), including traction ones are a powerful source of electromagnetic fields (EMFs), as they change voltage from one level to another at a sufficiently high-current load.

Today, in fact, a source of biological hazard is three-phase sources of the utility frequency (UF) 50 Hz that produces electromagnetic induction (for example [1, 2]). It is a common fact that a hygienic evaluation of the electromagnetic field of utility frequency (50 Hz) is done separately, according to the electric field strength (E) in kV/m and the magnetic field strength (H) in A/m (or magnetic field induction (B) in μT).

A load irregularity over time and its nature leads to the current harmonics and voltage harmonics

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in the chains, which are the sources of electromagnetic influence on the workers and the automatic equipment for the railroad industry in a wide frequency range from 0 Hz to units of kilohertz, including the utility frequency 50 Hz.

Figure 1 shows a spectrum of the electric field (EF) intensity in a transformer substation room, and Figure 2 shows the change in the EF intensity over time [3].

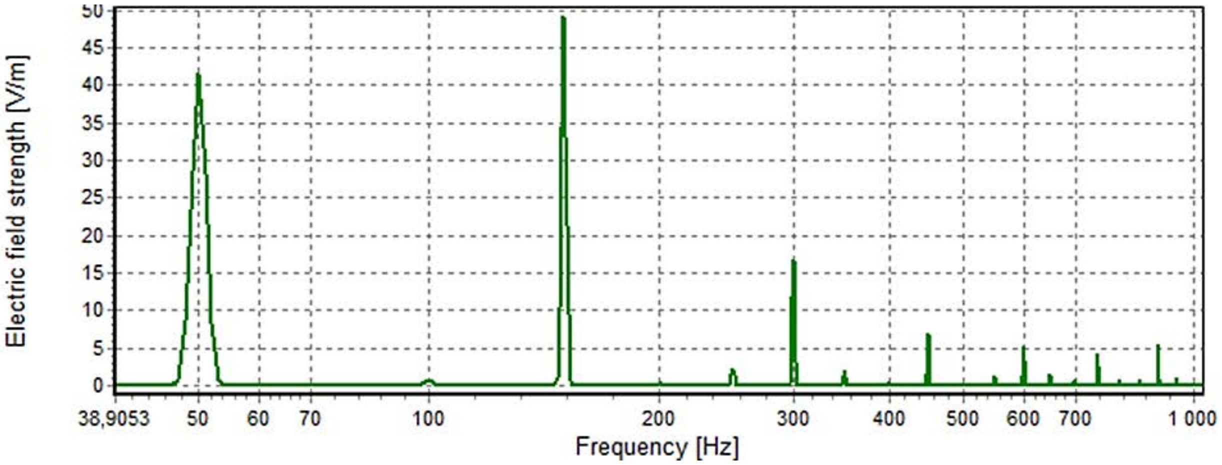

Figure 1: The spectrum of the EF intensity in the transformer substation room.

Figure 1: The change in the EF intensity over time.

As noted above, here arises a problem with the shielding of power transformers at the transformer substations. In addition, the multilayer shields are the most effective shielding for that [4-6].

2. RESEARCH METHOD

Generally, the shielding attenuation coefficient of radiofrequency electromagnetic fields for the electromagnetic fields of utility frequency is defined as [7]:

$$A_E = 20\log\frac{E_0}{E_A} \qquad (1),$$

$$A_H = 20\log\frac{H_0}{H_A} \qquad (2),$$

where

A_E is the shielding coefficient (attenuation) for the electric component of the electromagnetic field, dB

A_H is the shielding coefficient (attenuation) for the magnetic component of the electromagnetic field, dB,

E_0 is the electric intensity of the electromagnetic field at the measurement point when the shield is absent, V/m,

E_A is the electric intensity of the electromagnetic field at the measurement point when the shield is present, V/m

H_0 is the magnetic intensity of the electromagnetic field at the measurement point when the shield is absent, A/m;

H_A is the electric intensity of the electromagnetic field at the measurement point when the shield is present, A/m.

Quite often, we can calculate quantitative characteristics for the protection properties of electromagnetic shields. In some cases, calculation methods give more reliable results, especially in relation to ultra-low frequency ranges that may have significant measurement errors. In addition, we need to consider conductivity of component materials for complex shielding systems as well as modern composite materials.

Power attenuation of the electromagnetic wave K_e is defined as

$$K_e = \frac{(n+1)+\chi^z}{4n}\exp\left(\frac{z\cdot\chi\cdot\omega\cdot x}{c}\right) \qquad (3),$$

where

n is refraction coefficient of the material,

χ is the coefficient that determines the wave attenuation rate,

ω is the cyclic radiation frequency,

x is the sample thickness,

z is the coefficient the corrects attenuation when there is the protection shield consisting of two materials.

$$z = \frac{\sigma_1}{\sigma_2} \qquad (4),$$

where

σ_1 is the material conductivity 1,

σ_2 is the material conductivity 2.

$z = 1$ if we use only one material.

If the wave attenuates, the reflection coefficient K_e is given as

$$K_e = \frac{(n-1)^2 + \chi^z}{(n+1)^2 + \chi^z} \qquad (5),$$

The magnitude of the extinction coefficient χ and the magnitude of refraction coefficient of the material n are determined in relation

$$\chi = \sqrt{\frac{\varepsilon' - \sqrt{\varepsilon'^2 + \varepsilon''^2}}{2}} \qquad (6),$$

$$n = \sqrt{\frac{\varepsilon' + \sqrt{\varepsilon'^2 + \varepsilon''^2}}{2}} \qquad (7),$$

where

ε' is the real part of the complex dielectric constant

ε'' is the imaginary part of the complex dielectric constant

$$\omega = \varepsilon + i({}^{4\sigma}/_{\omega}) \qquad (8),$$

where

σ is the electrical conductivity of the material

ω is the cyclic radiation frequency

To determine the frequency and amplitude dependence of the shielding coefficients for various materials in laboratory conditions requires special equipment such as wideband voltage generators and time-consuming work. The most acceptable way is to determine the spectrum of the shielding field before and after the shield and to obtain changes in the field amplitudes at the frequency with the necessary step of its change (frequency).

3. RESULT AND DISCUSSION

Next, we have examined the design of the multilayer electromagnetic shield (MES) for built in and built on transformer substations. The shielding principles were developed, tested, and confirmed by measurements. They are being used to protect the human and the equipment against exposure to the electromagnetic fields induced by the equipment of transformer substations at the high-current load (up to 3500 A) [8].

Such MESs were tested out on the influence of long-duration electromagnetic pulses (EMPs) with a front rise-time up to 7 ns. The MES attenuates the level of acoustic noise produced by power transformers within the range of 8 to 12 dB. The reviewed MES converts and suppresses the electromagnetic fields of the utility frequency compared to single layer shields that are still being in practice. The MES design provides acceptable stabilization for the background level of the magnetic field in the protected rooms when the induction intensity increases as the transformer is overloaded. Sheets of the electromagnetic shield that are covered with protection coating and transition frequency decrease in the metal sheets through the dew point as a result of its heating by the magnetic field decrease a velocity of electrochemical and biological corrosion processes. That way an expected operational life of the MES is at least 25 years [8].

The basic design of the MES (Fig. 3) consists of three shielding layers. The first and third layers were made from the sheets of isotropic electrical steel with a 1 mm thickness. There is a double layer lattice placed between the sheets and made from a metal rectangular pipe 80 × 40 mm (with 2 mm wall thickness). Besides, there cells that play the role of a waveguide below cut-off. The lattice cells suppress the vertical components of the magnetic field that have passed from the 1st layer of magnetic fields. Thus, “the lattice, the 3rd layer of the MES” is in space and works as the waveguide mechanism. It is expected that the lattice weakens only a component of the linearly polarized magnetic field. The third layer should suppress this magnetic field to an intended safe level in the protected premises.

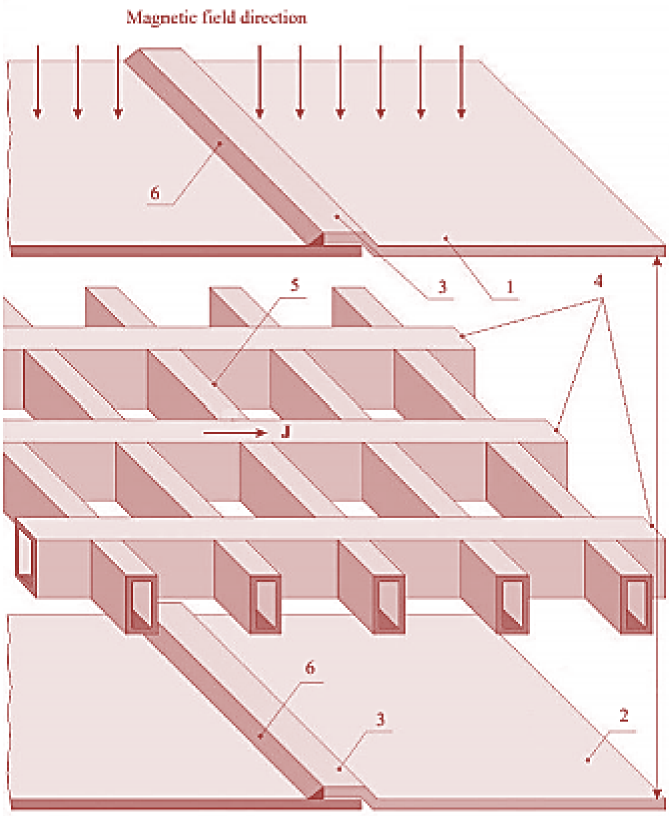

Figure 3: The design of the multilayer electromagnetic shield: 1 and 2 - steel sheets, 3 - an example of an overlap side and end joints of steel sheets during their installation, 4 - bar guide pipes (and tie bars between them), 5 - gap between sheets, 6 - continuous welded seam.

Gap between sheets - thickness of the bar guide pipe 4 (50-100 mm).

The ferromagnetic metal of electrical steel sheets and the lattice pipes absorb the energy of the shielded magnetic field, heat the shield elements, and increase the MES shielding efficiency. Namely, it is a result of swirling effect, hysteresis loop and magnetization reversal process. The magnetization reversal energy losses are proportional to the area of the hysteresis loop and the magnetic field of the metal shield elements.

Shielding effectiveness depends on shape of the shields. Considering the shielding effectiveness level of an internal source, let us compare widely used shields that have regular shapes without gaps, such as a cube, a cylinder, and a sphere. Let us say the effectiveness of shield that has the shape of cube (rectangle) set to 1, then the shielding effectiveness of shield that has the shape of cylinder will be more than twice as high as the shield with the rectangle shape. Even more, if the shield has the shape of sphere (ball), then its shielding effectiveness will be 3 times higher than the rectangular shield can provide.

The shielding efficiency of the two-layer shield with the gap that was made from the steel sheets is almost four times higher than the efficiency of the two-layer shield without the gap, and it is four times less in metal mass at the same efficiency value.

Figure 4 shows the experimental characteristic that has intended for the optimal choice of the gap d at the proposed MES depending on the size of the first layer D.

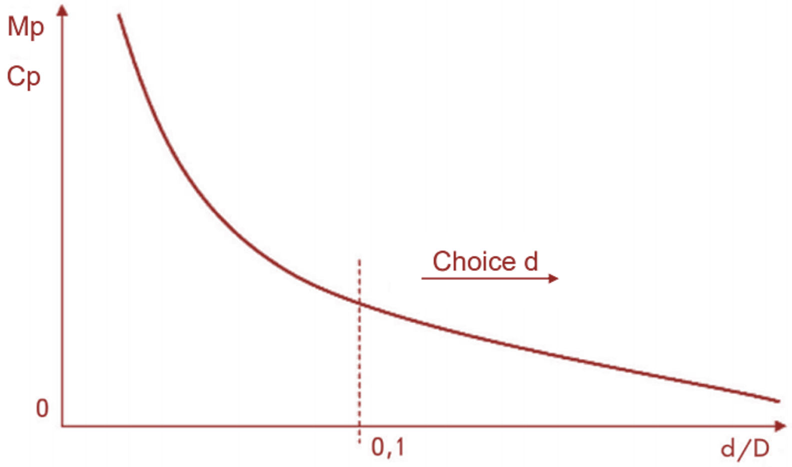

Figure 4: Dependence of the mutual inductance Mp (H /m^2) and the capacity Cp (F/m^2) from the ratio of the gap size d to the length of the current flowing along the straight part D of the shield layers 1 and 2 (d/D).

Figure 5 shows how to mount a shield on (inside view). Outside there are a layer of metal and the bar guide pipes 4 (as in Figure 3). The internal shield is not installed.

Figure 5, there is not any shield in a picture as it should be mounted before the transformer will be installed. There is no train in the picture as well. The transformer substations to supply power for consumers and railroads are not installed near the rails, they usually installed in places that are the most suitable for the consumers.   The railroad system requires shield walls because there are the high voltages and currents as well as a very high interference level.


Figure 5: Mounting the multilayer shield.

4. CONCLUSION

A need for the TS shielding is caused by growing problems of increasing their power, negative effects on human and equipment created by the magnetic field induction, rapid development of the railroad infrastructure and the protection of equipment from external factors.

The proposed design of the multilayer electromagnetic shield to protect human and equipment from exposure to the electromagnetic fields of utility frequency at power transformer substations is more effective than the known options. This is supported by the measurements.

Here are presented a new approach to convert the rotating magnetic fields of utility frequency at the power transformers into the linearly polarized fields and the methods for their effective suppression using the example of the three-layer MES - “sheet-lattice-sheet”.

5. DATA AND MATERIAL AVAILABILITY

Information regarding this study is available by contacting the corresponding author.

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