Magnetic field around flat high-current gas-isolated three-phase enclosed busducts

Tomasz Szczegielniak*, Dariusz Kusiak**, Zygmunt Piątek*

* Czestochowa University of Technology, Faculty of Environmental Engineering and Biotechnology
** Czestochowa University of Technology, Faculty of Electrical Engineering

Abstract **Using the analytical method, based on Laplace's and Helmholtz's equations for the electromagnetic field, the distribution of the magnetic field around flat high-current gas-isolated three-phase enclosed busducts is determined, with regard to skin and proximity effects.**

Keywords **Electromagnetic field, gas-insulated transmission line (GIL), high power transmission.**

I. INTRODUCTION

Each single-phase unit of the flat high-current gas-isolated busduct (GIL), shown in Fig. 1, consists of a grounded aluminum enclosure tube containing a concentric tubular aluminum alloy conductor arranged in a coaxial configuration [1].

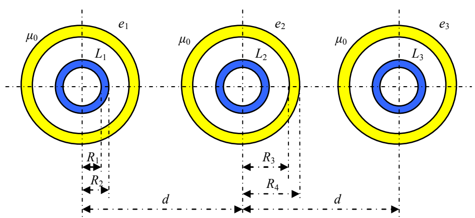

Fig. 1. Flat three-phase high current busduct

The nominal current values in GILs are high meaning that a precise knowledge of magnetic field values outside the aluminium enclosing tubes is necessary due to EMC considerations.

There are several papers dealing with the numerical solution of magnetic field in GILs [2], [3]. In this paper analytic formulae are proposed.

II. MAGNETIC FIELD IN A SYSTEM OF TWO PARALLEL TUBULAR CONDUCTORS

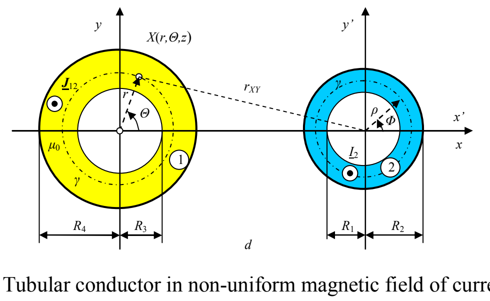

Fig. 2. Tubular conductor in non-uniform magnetic field of current $\underline{I}_1$

In the external area of the 1st conductor (Fig. 2) the resultant magnetic field

$$\underline{\boldsymbol{H}}^{ext} = \underline{\boldsymbol{H}}^{w} + \underline{\boldsymbol{H}}^{rr} \tag{1}$$

where $\underline{\boldsymbol{H}}^{w}$ is the harmonic electromagnetic field forced by the current $\underline{I}_2$ and $\underline{\boldsymbol{H}}^{rr}$ is the reverse reaction magnetic field due to eddy currents induced in the 1st conductor by the same current.

The electric field strength accompanying the magnetic field $\underline{\boldsymbol{H}}^{rr}(r,\Theta)$ fulfills the scalar Laplace's equation

$$\nabla^2 \underline{E}^{rr}(r,\Theta) = 0 \tag{2}$$

In the 1st conductor ($R_3 \le r \le R_4$) eddy current density fulfills the scalar Helmholtz's equation

$$\nabla^2 \underline{J}_{12}(r,\Theta) = \underline{\Gamma}\,\underline{J}_{12}(r,\Theta) \tag{3}$$

where $\underline{\Gamma}$ is the complex propagation constant of the 1st conductor. Inside the considered conductor, i.e. for $0 \le r \le R_3$, the electric field $\underline{E}^{\text{int}}(r,\Theta)$ has one component fulfilling the scalar Laplace's equation the kind of (2).

After solving the above set of equations with appropriate boundary conditions, we have [4] the magnetic field outside the 1st conductor as follows

$$\underline{\boldsymbol{H}}_{12}^{ext}(r,\Theta) = \mathbf{1}_r \underline{H}_{12r}^{ext}(r,\Theta) + \mathbf{1}_\Theta \underline{H}_{12\Theta}^{ext}(r,\Theta) \tag{4}$$

where its components are

$$\underline{H}_{12r}^{ext}(r,\Theta) = -\frac{\underline{I}_2}{2\pi r}\sum_{n=1}^{\infty}\left[\left(\frac{r}{d}\right)^n - K\right]\sin n\Theta \tag{4a}$$

$$\underline{H}_{12\Theta}^{ext}(r,\Theta) = -\frac{\underline{I}_2}{2\pi r}\sum_{n=1}^{\infty}\left[\left(\frac{r}{d}\right)^n + K\right]\cos n\Theta \tag{4b}$$

with

$$K = \frac{1}{\underline{\Gamma} R_3}\left(\frac{R_4}{r}\right)^n\left(\frac{R_4}{d}\right)^n \frac{\underline{s}_{cn}}{\underline{d}_{cn}} \tag{4c}$$

The functions s_{cn} and d_{cn} are expressed by modified Bessel's functions and are given in [4].

III. MAGNETIC FIELD IN A THREE-PHASE FLAT GIL WITH ISOLATED ENCLOSURES

Outside the screen L_1 the total magnetic field

$$\underline{\boldsymbol{H}}_{1}^{ext}(r,\Theta) = \underline{\boldsymbol{H}}_{11}^{ext}(r) + \underline{\boldsymbol{H}}_{12}^{ext}(r,\Theta) + \underline{\boldsymbol{H}}_{13}^{ext}(r,\Theta) \tag{5}$$

where

$$\underline{\boldsymbol{H}}_{11}^{ext}(r) = \mathbf{1}_\Theta \underline{H}_{11\Theta}^{ext}(r) = \mathbf{1}_\Theta \frac{\underline{I}_1}{2\pi r} \tag{5a}$$

and $\underline{\boldsymbol{H}}_{12}^{ext}(r,\Theta)$ is given by (4). The field $\underline{\boldsymbol{H}}_{13}^{ext}(r,\Theta)$ is given by (4) after replacing d in (4) with $2d$ and $\underline{I}_2$ with $\underline{I}_3$.

In the same way we determine the magnetic field outside the phase L_2 and L_3 – Fig. 3. The phase currents are assumed to be symmetrical.

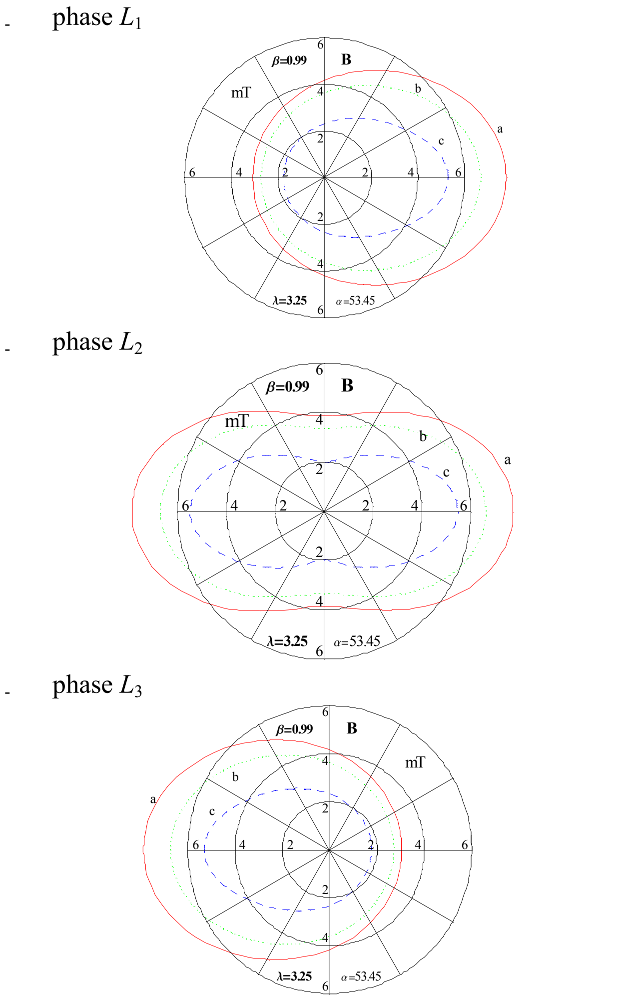

Fig. 3. Distribution of the magnetic flux density outside three-phase flat GIL ELPE-36/15 with isolated enclosures; R_4 = 0.645 m; a – $r = R_4$; b - $r = R_4$+0.1; c – $r = R_4$+0.5; I_N=15 kA

IV. Magnetic Field in a Three-Phase Flat GIL with Bonded Enclosures

In order to reduce considerably the magnetic field outside the GIL its enclosures are bonded with each other. In this case induced reverse enclosure currents appear. These current flowing through enclosures have almost the same values as the corresponding currents in the phase conductors but generally they are in the revers of the original phase currents. The negative superposition of phase current and induced reverse current in the enclosure results in a small magnetic field. The reverse currents are calculated by solving equivalent circuit consisting of self impedances of phase conductors and enclosures as well as mutual impedances between them [5].

In the case of the GIL ELPE-36/1, $\lambda = d/R_4$, $\beta = R_3/R_4$, $\alpha = R_4\sqrt{\omega\mu\gamma/2}$ and with the phase currents $\underline{I}_1 = I_N \mathrm{Exp}\left[\mathrm{j}\,0^0\right]$, $\underline{I}_2 = I_N \mathrm{Exp}\left[-\mathrm{j}120^0\right]$, $\underline{I}_3 = I_N \mathrm{Exp}\left[\mathrm{j}120^0\right]$, after determing all impedances, we calculated the reverse enclsure currents as follows: $\underline{I}_{e1} = 16873\,\mathrm{Exp}\left[-\mathrm{j}174.67^0\right]$, $\underline{I}_{e2} = 19038\,\mathrm{Exp}\left[\mathrm{j}\,62.31^0\right]$ and $\underline{I}_{e3} = 17237\,\mathrm{Exp}\left[-\mathrm{j}\,62.52^0\right]$.

In this case the formula (4) is used replacing in it the current $\underline{I}_2$ with the sum $\underline{I}_2 + \underline{I}_{e2}$ and then the magnetic field is shown in Fig.4.

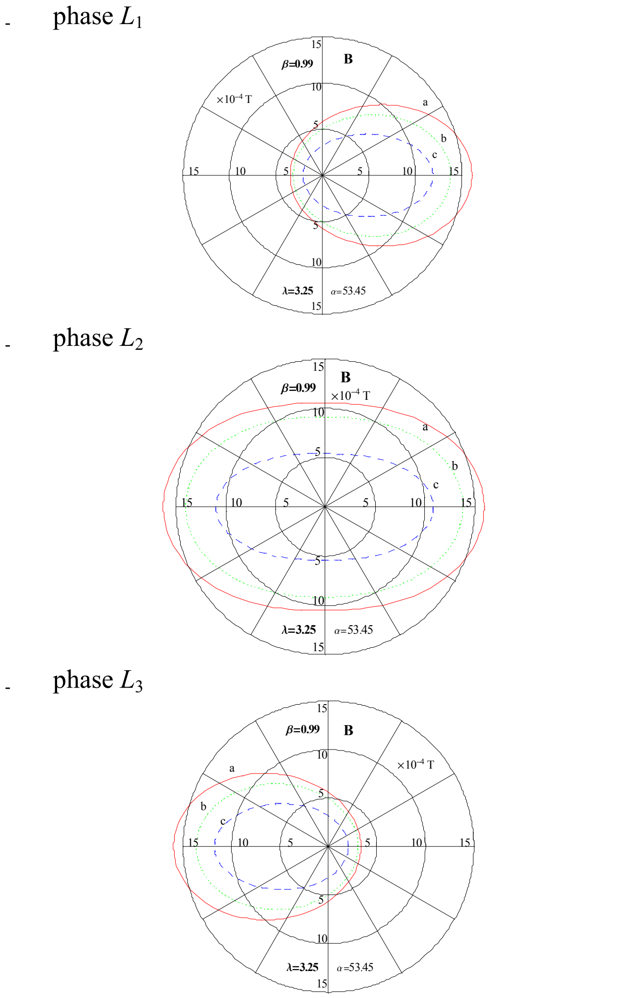

Fig. 4. Distribution of the magnetic flux density outside three-phase flat GIL ELPE-36/15 with bonded enclosures; R_4 = 0.645 m; a – $r = R_4$; b - $r = R_4$+0.1; c – $r = R_4$+0.5; I_N=15 kA

V. Conclusion

Taking into account the so-called reverse reaction of eddy current induced in enclosures of GIL allows (together with application of the Laplace and Helmholtz equations) to calculate the magnetic field around it in the form of analytical formulas expressed by Bessel functions. In this case they refer to tubular enclosures with any electrical and geometrical parameters, including the thickness of their walls.

VI. References

[1] Koch, H.: "Gas-Insulated Transmission Lines (GIL)", John Wiley & Sons, Ltd., Chichester. 2012.

[2] Benato, R., Di Mario C., Koch H.: "High-Capability Applications of Long Gas-Insulated Lines in Structuress", IEE Trans. On Power Delivery. 2007, Vol. 22, No. 1, January, pp. 619-626.

[3] Sarajcev, P.: "Numerical Analysis of the Magnetic Field of High-Current Busducts and GIL System', Energies, ISSN 1996-1073, 2011, pp. 2196-2211.

[4] Piatek, Z.: "Method of Calculating Total Eddy Currents Induced in Screens of a Symmetrical Three-Phase Single-Pole Gas-Insulated Transmission Line", Acta Technica CSAV 53, 2008, pp. 103-120.

[5] Piątek, Z.: "Impedances of tubular high current busducts", Series Progress in High-Voltage technique, Vol. 28, Polish Academy of Sciences, Pol. Cz., Czestochowa 2008.