Heating of Three-Phase Shielded Supply at Short Circuit

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Abstract **Supplying conductors of high-powered electrical devices are highly stressed mechanically and thermally, in particular at short circuits. Mechanical stress on these conductors can significantly be reduced using wires shielded with steel jackets. On the other hand, the presence of shielding reduces the possibility of transfer of heat from the conductor and, moreover, further losses by eddy currents induced in the shielding jackets are generated. The paper describes a method for calculation of heating of such a shielded conductor.**

Keywords **shielded three-phase line, three-phase short circuit, heating of three-phase line.**

I. INTRODUCTION

Straight cable conductors X, Y, Z are isolated and placed in the shielding steel jackets, see Fig. 1. The conductors carry short-circuit currents. The aim of the paper is to investigate the volumetric Joule losses in the wires and shielding jackets and propose an algorithm for calculation of their heating.

Since the fault is a short phenomenon, the process of heating is assumed adiabatic. This assumption leads to higher temperatures than those actually occurring in the system. As information about heating serves for evaluating heat stress of the insulation system, the method provides safer values.

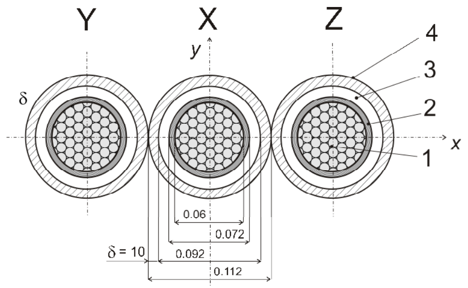

Fig. 1. Arrangement of the shielded conductors: **1**-Copper core of the cable, **2**-Insulation, **3**-Setting blocks, **4**-Shielding jackets

II. MATHEMATICAL MODEL

The task is solved as a weakly coupled problem. The influence of skin effect in the supplying cables is neglected. **Magnetic field** in the system is expressed by the magnetic vector potential $\boldsymbol{A} = \mathbf{z}_0 \cdot A_z(x,y,t)$ [1]. The basic equation reads

$$\frac{\partial}{\partial x}\frac{1}{\mu}\frac{\partial A_z}{\partial x}+\frac{\partial}{\partial y}\frac{1}{\mu}\frac{\partial A_z}{\partial y}-\gamma\frac{\partial A_z}{\partial t}=-\mu_0 J_{z,i} \qquad (1)$$

The volumetric Joule losses per unit length of the conductors carrying fault currents $i_i(t)$ are

$$w_{\mathrm{c}}(t)=\frac{R_i\, i_i^2}{S_i\, l}, \qquad i = \mathrm{X,Y,Z}, \qquad (2)$$

where R_i is the resistance of the i-th conductor of length l and diameter d_i.

The volumetric Joule losses in shielding jackets per unit length are

$$w_{\mathrm{s}i}=\frac{J_{z,i}^2}{\gamma_{\mathrm{Fe}}}, \qquad (3)$$

where

$$J_{z,i}=\gamma_{\mathrm{Fe}}\frac{\partial A_{z,i}}{\partial t} \qquad (4)$$

The time evolution of the volumetric Joule losses in the i-th shielding jacket is

$$w_{\mathrm{s},i,\mathrm{avrg}}(t)=\frac{1}{V_i}\int_{V_i} w_{\mathrm{s},i}\left(x,y,t\right)\mathrm{d}V_i \qquad (5)$$

where V_i is the volume of the i-th jacket.

Nonstationary temperature fields (*approximation*) in the cable conductors X, Y, Z, of length l, is given by the balance between the internal energy of the conductors) and energy transported by the heat sources. The *adiabatic heating of wire* X (for example) is described by the relation

$$\int_0^t w_{\mathrm{c,X}}(t)\,\mathrm{d}t=\rho\, c\, T(t) \qquad (6)$$

(see (2)). For numerical computation, (6) is discretized as follows

$$\sum_0^N w_{\mathrm{O,X},i}\ \Delta t_j=\rho c\sum_{j=0}^N \Delta T_j \quad => \quad \Delta T_j=\frac{1}{\rho\, c}w_{\mathrm{c,X},j}\ \Delta t_j, \qquad (7)$$

where ΔT_j is the increase of temperature of the conductor in the j-th step of length Δt_j. The total temperature rise ΔT of the conductor for N intervals Δt_j is

$$\Delta T=\sum_{j=0}^N \mathrm{d}T_j \qquad (8)$$

Similarly we can obtain the temperature rise of the shielding jackets produced by the specific Joule losses w_{si} (3).

III. EXAMPLE

The arrangement and dimensions of the cable conductors are depicted in Fig. 1. The time evolutions of the short-circuit currents are known.

<u>Conductors X, Y, Z:</u> copper, $\mu_r = 1$, $\gamma_{\mathrm{Cu}} = 5.7\cdot 10^7$ S/m, ρ = 8966 kg/m^3, c = 383 J/(kg·K).

<u>Shielding jacket</u>: steel, $\gamma_{\mathrm{Fe}} = 5.0\cdot 10^6$ S/m, ρ = 7840 kg/m^3, c = 465 J/(kg·K).

IV. CONCLUSION

During the first three periods of the short-circuit currents the temperature of the conductor X grows by ΔT = 0.123 ^{0}C while the temperature of the shielding jacket grows only by ΔT = 0.0021 ^{0}C, see Figs. 2 and 3. This is probably due to the very short time of the short circuit and lower conductivity of the steel jacket with respect to the copper conductor.

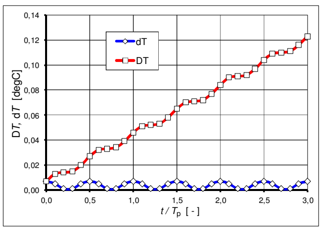

Fig. 2. Conductor wire X warming

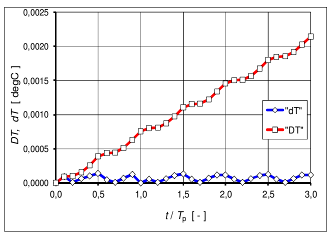

Fig. 3. Conductor wire X warming

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

[1] Mayer D., Ulrych B.: Numerical approach for computation of electromagnetic shielding. Journ. El. Eng., Vol. 64 (2013), No. 4, pp. 256-260.