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.

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 \( \mathbf{A} = A_0 \mathbf{A}(x, y, t) \) [1]. The basic equation reads

\[
\frac{\partial}{\partial x} A_1 + \frac{\partial}{\partial y} A_1 \mu_0 \frac{\partial}{\partial t} A_1 = -\gamma_0 J_{z,1} \quad (1)
\]

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

\[
w_{c,i}(t) = \frac{R_i i_i^2}{S_i l} , \quad i = X, Y, Z \quad (2)
\]

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

\[
w_{s,j} = \frac{J_{c,j}^2}{\gamma_{Fe}} , \quad (3)
\]

where

\[
J_{c,j} = \gamma_{Fe} \frac{\partial A_{c,j}}{\partial t} \quad (4)
\]

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

\[
w_{s,i,\text{avg}}(t) = \frac{1}{V_i} \int_{V_i} w_{s,i}(x, y, t) \, dV_i
\]

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

\[
\int_0^t w_{c,X}(t) \, dt = \rho c T(t) \quad (6)
\]

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

\[
\sum_{j=0}^{N} w_{0,j} \Delta T_j = \rho c \sum_{j=0}^{N} \Delta T_j \quad \Rightarrow \quad \Delta T_j = \frac{1}{\rho c} w_{c,X,j} \Delta T_j, \quad (7)
\]

where \( \Delta T_j \) is the increase of temperature of the conductor in the \( j \)-th step of length \( \Delta l \). The total temperature rise \( \Delta T \) of the conductor for \( N \) intervals \( \Delta T \) is

\[
\Delta T = \sum_{j=0}^{N} \Delta T_j \quad (8)
\]

Similarly we can obtain the temperature rise of the shielding jackets produced by the specific Joule losses \( w_s \).

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.

Conductors X, Y, Z: copper, \( \mu_r = 1 \), \( \gamma_s = 5.7 \cdot 10^7 \text{ S/m} \), \( \rho = 8966 \text{ kg/m}^3 \), \( c = 383 \text{ J/(kg·K)} \).

Shielding jacket: steel, \( \gamma_s = 5.0 \cdot 10^6 \text{ S/m} \), \( \rho = 7840 \text{ kg/m}^3 \), \( c = 465 \text{ J/(kg·K)} \).

IV. CONCLUSION

During the first three periods of the short-circuit currents the temperature of the conductor X grows by \( \Delta T = 0.123 \text{ °C} \) while the temperature of the shielding jacket grows only by \( \Delta T = 0.0021 \text{ °C} \), 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. 1. Arrangement of the shielded conductors: 1-Copper core of the cable, 2-Insulation, 3-Setting blocks, 4-Shielding jackets

Fig. 2. Conductor wire X warming

Fig. 3. Conductor wire X warming

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VI. REFERENCES