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Heating of Short Segments of Flat Bus Bars at the Passage of Continuous Currents

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The obtained investigation results indicate that at calculating current carrying capacity of short bus bar segments it is necessary to take axial heat flow into account. The axial heat flow effect shows by temperature changes at the rated duty and in particular by a non-uniformity of temperature increment distribution over the whole bus bar length.

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Introduction

Temperature increments that occur in bus conductors, contacts and other apparatus elements under the load current influence make one of the most important criteria at the evaluation of the apparatus operation. It follows from the negative effect of elevated temperature on durability and correct operation of the device elements. Regarding the variety of heat transfer forms and a complex geometry of real technological systems the phenomenon of bus bar heating is a complex problem that is possible to solve only in simple model systems. Because of the simplifying assumptions results of that analytical solution often are of no practical significance for a quantitative analysis of heat exchange phenomena in real bus systems.

I. Heat balance at convective heat dissipation

Calculations concerning heat phenomena in electrical devices and apparatus are based on a heat balance. A full form of the heat balance equation can be written for two domains: time and location. However, the form of those relations can be adequately simplified depending on the considered specific conditions.

Heat balance of a conductor with Joule effect and convective heat dissipation per length unit through the external surface of an infinitely long conductor taken into account can be described by the Newton's law in the following form: [1]:

$$\Delta P dt = cmd\vartheta + hs(\vartheta_{gr} - \vartheta_o) dt \quad (1)$$

where: ΔP – power losses occurring in the considered object s [W/m]; t – time; c - specific heat [W/kg deg]; m – mass of the considered body; ϑ_o – ambient

temperature; ϑ_{gr} – temperature of the heated body; h – heat exchange coefficient [W/m²deg]; s – surface of heat emission from a body of the ϑ_{gr} temperature to its environment of the ϑ_o temperature

In steady state conditions when $d\vartheta/dt = 0$ the equation (1) can be written as follows:

$$\begin{aligned} I^2 R &= hs(\vartheta_{max} - \vartheta_o) \Rightarrow \\ \Rightarrow I &= \sqrt{\frac{hs}{R_g}} \cdot \sqrt{\vartheta_{max} - \vartheta_o} \end{aligned} \quad (2)$$

The dependence makes it possible to determine temperature increments for electric conductors only when boundary conditions are neglected i.e. at the assumption that the conductor is infinitely long [2-6].

II. Temperature increment distribution over a short segment of a bus bar with a junction

Usually, at performing heat calculations for electric conductors their infinite length is assumed, which means that one of the heat balance components, namely - longitudinal heat transfer by conduction is neglected. Such an assumption also eliminates the dependence of heat equations on the location and they can be solved only for the time domain. Hence, at determining fixed temperatures for short bus bars one cannot neglect the effect of boundary conditions on the temperature increment value.

In our investigation a flat copper bus bar of the 20x5 mm cross-section and 0,5 m length has been tested. Power leads have been connected to the tested conductor so that the contact surface would exceed the bus bar cross-sectional area. That way the connection has had no greater effect on the bus temperature growth at the

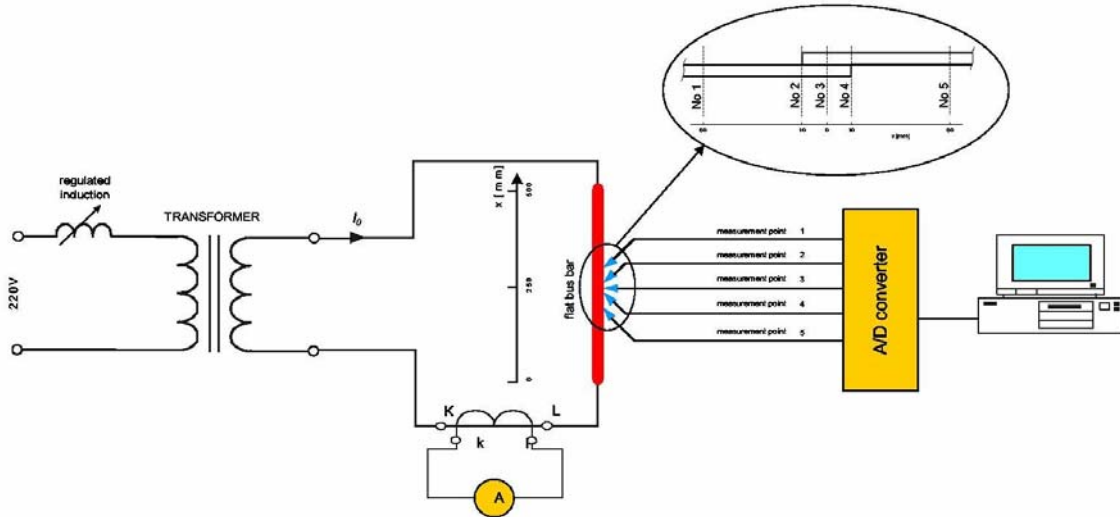


Fig. 1. A circuit to measure temperature increment values for bus bars

terminals. Also, by the application of power leads whose current-carrying capacity has exceeded the bus bar capacity by several times a heat flow in the direction to the feeders has been obtained apart from convective heat abstraction through the bus bar. The flow can be noticed at extreme sections of a curve of temperature increment distribution over the tested bus bar segments. Temperature increments have been measured in a geometric centre of the tested bus bar and symmetrically at the junction edges as well as at the distance of 5 cm away of the edges. (Fig. 1). The measurements and temperature recording have been performed by a multi-channel recorder. Results of the temperature increment measurements for individual points on the tested bus bar are presented in Tables 1 and 2 as well as in Figs 2 and 3.

Table 1.

Temperature increments measured at individual points of a flat copper bus conductor (20x5mm) with a junction ($I_{zn} = 242A$) – for the heating duration of 2.5 minutes.

I [A]	$\Delta\theta_1$ [K]	$\Delta\theta_2$ [K]	$\Delta\theta_3$ [K]	$\Delta\theta_4$ [K]	$\Delta\theta_5$ [K]
I_{zn}	3,134	3,392	2,093	3,644	3,071
$1,5 I_{zn}$	10,959	11,147	7,645	11,401	11,015
$2 I_{zn}$	19,929	20,369	11,104	20,603	20,647
$2,5 I_{zn}$	24,782	24,780	15,909	24,882	24,647
$3 I_{zn}$	25,891	26,371	16,698	26,324	26,003

Based on the temperature increment values obtained in the performed tests a certain regularity of their distribution over the conductor length can be noted. The regularity consists in that for a bus bar without any junction maximal temperature increment values occur in the geometric centre of the tested conductor segment while minimal ones – towards its ends. On the other hand, when a bus bar with a junction is applied maximal temperature increment values occur at the ends of the tested conductor segment and the minimal ones – in its geometric centre.

Table 2.

Temperature increments measured at individual points of a flat copper bus bar (20x5mm) without any junction ($I_{zn} = 242A$) – for the heating duration of 2,5 minutes.

I [A]	$\Delta\theta_1$ [K]	$\Delta\theta_2$ [K]	$\Delta\theta_3$ [K]
I_{zn}	4,601	5,743	4,119
$1,5 I_{zn}$	9,484	10,604	9,181
$2 I_{zn}$	19,401	20,673	19,799
$2,5 I_{zn}$	28,410	29,685	28,740
$3 I_{zn}$	33,424	34,867	33,877

It can be concluded that temperature distribution over bus conductors differs from the distribution in areas where bar junctions are located. Joule energy gets the most emitted at the junction edges, which makes the temperature there the highest (Fig. 2). Additionally, both in the bus bar circuits with a junction and without it an axial flow in the direction to the power leads can be noticed (Figs 2 and 3).

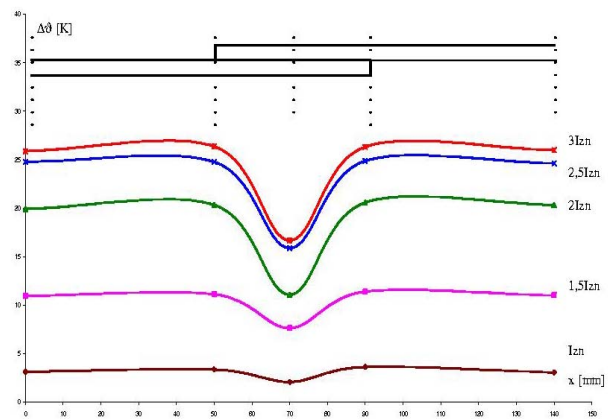


Fig. 2. Temperature increment distribution for selected load currents of a flat copper bus bar of the 20x5 mm cross-section, with a fixed junction, after an elapse of 2,5 minutes.

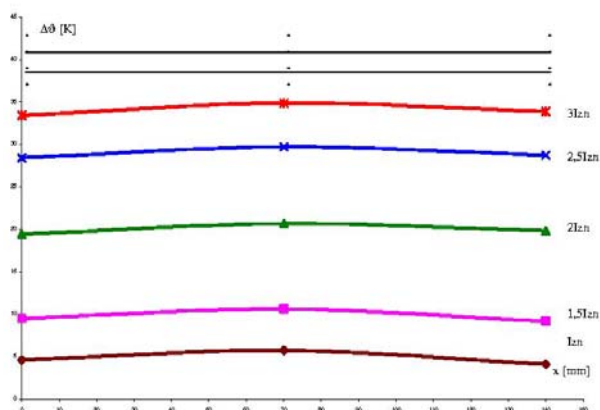


Fig. 3. Temperature increment distribution for selected load currents of a flat copper bus bar of the 20x5 mm cross-section, without any junction, after an elapse of 2,5 minutes.

With an assumed occurrence of resistance losses and convective heat transfer in a conductor curves of fixed temperature increments over the whole bus bar length determined in an experimental way and by analytical calculations should be the same. However, an analysis of the above mentioned curves for individual points of the tested bus bar with a junction indicates that the maximal values of fixed temperature increments occur at the junction edges and the minimal ones - in its geometric centre (Fig.4). The fact is related to the increased Joule effect at spots where contact pressure force in the junction is the smallest i.e. at its edges. Differences in the

fixed temperature increment values at the junction edge (Fig.4a) and at a measurement point located closer to the feeding terminal of the tested bus bar segment (Fig. 4b) can also be noticed. The mentioned regularity that shows at the passage of successive multiples of the rated current indicates the occurrence of axial heat flow from the tested conductor to the power leads. An analysis of heating curves obtained experimentally and by analytical calculations shows that axial flow influences temperature values determined over the bus bar segment from the junction edge to the electric feeding terminals.

Conclusions

The obtained investigation results indicate that at calculating current carrying capacity of short bus bar segments it is necessary to take axial heat flow into account. The fact is related to the elimination of additional heat sources, which could result from differences in current carrying capacity of the tested bus conductor and of the power lead. A comparison of the two presented bus systems shows that a junction on a bus bar causes a decrease of temperature increments over its area intensified by an occurrence the axial flow phenomenon.

The axial heat flow effect shows by temperature changes at the rated duty and in particular by a non-uniformity of temperature increment distribution over the whole bus bar length.

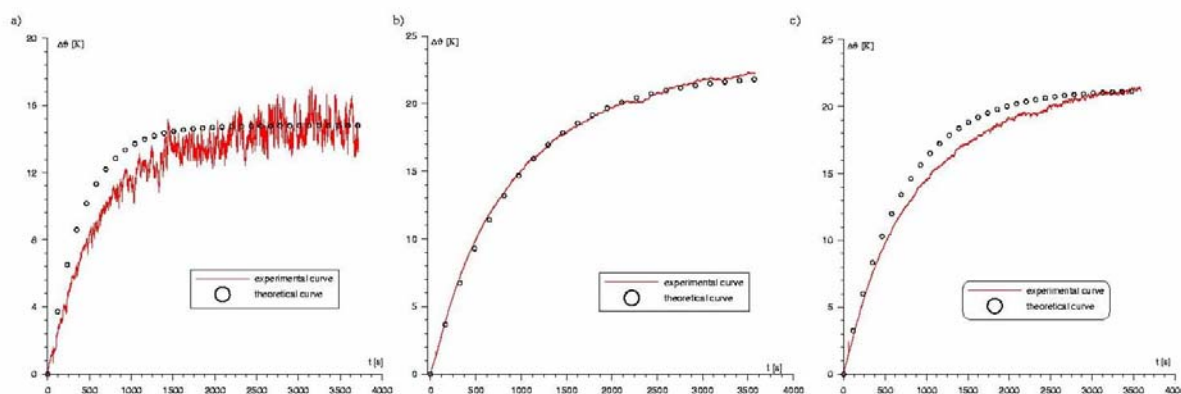


Fig. 4. Curves of temperature increments determined at the passage of rated current for a flat copper bus bar of the 20,5x5mm cross-section obtained by experiments and by theoretical calculations a) for the junction geometric centre, b) for the junction edge, c) for a spot located 5 cm away from the junction edge.

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Нагрівання коротких сегментів плоских контактних з'єднань при проходженні безперервних струмів

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та відділ електричних пристроїв і інформаційних технологій*

Температурні прирости, які відбуваються в плоских контактних з'єднаннях і інших апаратних елементах під дією струмових навантажень, є одним із найголовніших критеріїв при оцінці апаратної дії. Це витікає з негативного ефекту зростання температури при тривалій дії елементів пристроїв. Щодо різноманітності форм передач тепла і складної геометрії технологічних систем, явище нагрівання, – складна проблема, яку можливо вирішити тільки в простих системах. Із-за спрощень і припущень результат цього аналітичного рішення часто немає ніякого практичного значення для кількісного аналізу явищ теплообміну в реальних плоских контактних з'єднаннях.