Analysis of the influence of some factors on the contact resistance of bolted busbar connections

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Abstract. The paper presents an experimental setup and a method for determining the contact resistance between busbars at a given contact force. Experiments have been conducted by means of an experimental setup, developed for the purpose of studying the influence of the contact force on the contact resistance between busbars with cross-sectional area of 60x6 mm. The study has been performed for two types of bolted connections, complying with DIN 43673, which have been studied for both copper and aluminum busbars.

1. Introduction
A typical functional element in low voltage switchboards are the busbar systems, characterized by their complex configurations and relationships. This results in a significant number of contact connections in these systems. The presence of contact connections is a prerequisite for increase in the resistance, as well as for overheating of the electrical equipment. It is known [1], [2] that the contact resistance depends on complex physical processes, big part of which random in character, and therefore its analytic calculation is related to big inaccuracies. Papers [3] and [4] propose formulas, in which the influence of micro and macro geometry and contact surface hardness have been taken into account and expressed by means of empirical coefficients. The range of change of these coefficients is quite big, which additionally leads to insufficient accuracy of the obtained results. Besides, the proposed formulas do not reflect any specific constructive peculiarities of the contact surfaces. The analysis of planar contact connections, taking into account geometric and physical characteristics of the contact surfaces, proposed in [5], [6] and [7], is of great interest. The method, proposed here, is used for analysis of planar contact connections with specific construction, which is not possible by the methods, given in [1], [2], [3] and [4]. Despite the progress in theoretical research, however, the experimental studies of contact resistance are still valid at this stage.

This paper presents a study of the influence of the contact force, the material of the busbars and the construction of the contact connection between the busbars on the contact resistance, realized by means of a specially developed experimental setup.
2. Description of the method of studying and the experimental setup
A comparative method was chosen for studying the contact resistance between the busbars. It consists in comparing the resistance in sections of the busbar without and with a contact connection, as shown in Fig. 1. The sections have the same length. Under this condition:

\[ R_{12} = R_0 \quad (1) \]
\[ R_{23} = R_0 + R_K \quad (2) \]
\[ R_K = R_{23} - R_{12} \quad (3) \]

where:
- \( R_0 \) - resistance between the points 1 and 2, measured in ohms;
- \( R_K \) - contact resistance;
- \( R_{23} \) - resistance in the section between the points 2 and 3.

The resistance can be defined by the voltage drops and the current through the busbar:

\[ R_K = \frac{U_{23} - U_{12}}{I} \quad (4) \]

where:
- \( U_{12} \) - voltage drop in the section between the points 1 and 2;
- \( U_{23} \) - voltage drop in the section between the points 2 and 3.

**Figure 1.** Location of the points 1, 2 and 3 for determining the contact resistance by the comparative method.

The experimental setup is presented in Fig. 2. The testing current is set by means of both an autotransformer and a load transformer. Voltmeters with high input resistance are used to measure the voltage drops in the sections mentioned above.
Figure 2. Electric circuit of the experimental setup: Qs – circuit breaker; AT – autotransformer; LT – load transformer; A – ammeter; V₁, V₂ – voltmeters.

The contact force is set by means of a screw drive. Fig. 3 presents the device for measuring the force. It is done by measuring the pressure of the hydraulic fluid. The construction of the hydraulic system is shown in Fig. 3. When the piston is loaded by means of a given force, the force is converted into pressure on the liquid, from which the value of the force is defined. The compressive force for the developed system can be determined by the following formula:

\[ F[kg] = p.S = k.p \]  \hspace{1cm} (5)

where:

\( k \) – constant of the measuring device;
\( p \) – pressure.

Figure 3. Device for setting the contact force: 1 - cylinder; 2 – hydraulic oil; 3 - piston; 4 - busbars; 5 - manometer.
Fig. 4 presents a picture of the experimental setup for studying the contact resistance.

![Experimental Setup](image)

**Figure 4.** Appearance of the experimental setup.

3. **Construction of the studied contact connections**

Two types of contact connections between busbars without additional treatment of the contact surfaces were the object of the presented study (as shown in Fig. 5 and Fig. 6).

![Contact Connections](image)

**Figure 5.** Contact connection between busbars (60x6) mm in accordance with [8].

**Figure 6.** Contact connection between busbars (60x6) mm in accordance with [8].

All tests for measuring the contact resistance were conducted for the following cases:
- contact connection type 1 as in Fig. 5;
- contact connection type 2 as in Fig. 6.

The contact connections were studied for both copper and aluminum busbars, measuring (60x6) mm.
4. **Experimental results**

By means of the experimental setup, described above, studies of the dependence between the contact resistance and the contact force, the construction of the contact connection and the material of the contact connection were realized. Four samples were produced for each type of a contact connection. Twelve independent experiments for measuring the contact resistance were conducted for each sample.

4.1. **Influence of the contact force on the contact resistance**

Fig. 7-10 illustrate the change in the contact resistance depending on the contact force for both copper and aluminum busbars for the two types of contact connections (type 1 and 2).

![Figure 7](image1.png)

**Figure 7.** Experimental data and a curve, describing the dependence of the contact resistance on the contact force for type 1 bolted connection between copper busbars (60x6) mm.

![Figure 8](image2.png)

**Figure 8.** Experimental data and a curve, describing the dependence of the contact resistance on the contact force for type 2 bolted connection between copper busbars (60x6) mm.

![Figure 9](image3.png)

**Figure 9.** Experimental data and a curve, describing the dependence of the contact resistance on the contact force for type 1 bolted connection between aluminum busbars (60x6) mm.

![Figure 10](image4.png)

**Figure 10.** Experimental data and a curve, describing the dependence of the contact resistance on the contact force for type 2 bolted connection between aluminum busbars (60x6) mm.

4.2. **Influence of the contact connection construction on the contact resistance**

Fig. 11 and Fig. 12 draw a comparison between the contact resistance for type 1 and type 2 construction for copper and aluminum busbars.
5. Conclusion
The following conclusions can be drawn up based on the obtained results:
- When considering contact connections between copper busbars, the average values of the contact resistance for contact force of over 5 kN are practically the same for both types (type 1 and type 2) of contact connections. When the contact force is below 5 kN, the average value of the contact resistance for type 1 increases by 20%, compared to the value for type 2.
- In case of bolted connections between aluminum busbars the average value of the contact resistance for type 2 is less than the one for type 1. This difference is quite significant at a minimum value of the contact force (about three times) and it decreases at a maximum force (about 30%).
- The dissipation of the contact resistance values for type 2 connections at a low force is significantly less than it is for type 1.

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