Raina TZENEVA

Technical University of Sofia

Investigation of High Power Bolted Busbar Connectors with Longitudinal Slots

***Abstract**. In this paper high power bolted busbar connectors which pads and busbars are sectioned by cutting one or two longitudinal slots in order to increase the real contact area and to improve the reliability of their performance are investigated. Applying the method of finite elements models of contact pressure, contact penetration, electric current density and Joule heat are obtained. It has been estimated that the new cases lead to a raise in contact pressure P and contact penetration μ in the interface between the busbar and the pad.*

***Streszczenie.** W artykule przedstawiono wyniki badań śrubowego łącznika szyn na wysoką moc. W celu wyznaczenia gęstości prądu i ciepła Joule'a przeprowadzono badania nacisku oraz wnikania styku, przy wykorzystaniu metody elementów skończonych. (**Badania śrubowych łączników szyn na wysoką moc z podłużnymi złączami**)*

Keywords: bolted busbar connectors, contact penetration, contact pressure, current density distribution, longitudinal slots.
Słowa kluczowe: Śrubowe łączniki szyn, wnikanie styku, nacisk styku, rozkład gęstości prądu, styki wzdłużne.

Introduction

Bolting is a generally accepted way of making reliable joints in copper and aluminium busbars connections. The joints produced in such a way are compact and efficient. However, these joints have a rather uneven contact pressure compared to clamped plates joints.

The variety of factors that influence the connector behaviour as well as a thorough analysis of the degradation mechanisms of power connections are given in [4] and [5].

Among the multitude of mentioned factors, there are two very important that affect the reliability of a power joint. The first one is the design of the connection and the material from which it is fabricated and the second one is the environmental influence to the joint.

Theoretical Background

It is well known that actual contact surfaces are not flat and when contact is made between two metals localized metallic contacts appear. As the contact force increases the number and the area of these small metal-to-metal contact spots will increase. These spots, termed α-spots, are small cold welds insuring the only conducting paths for the transfer of the electrical current [3].

The real contact area also termed conducting area is a fraction of the apparent contact area, determined by the dimensions of the contact parts and is generally smaller than 1%.

The above mentioned considerations show that a sufficiently large contact area is an important prerequisite for good connector behaviour. As Boychenko and Dzektser [7] have shown, changing the connection design can equally be effective in increasing the contact area or cutting slots in the busbar, as illustrated in Fig.1. Thus, the actual surface area of a joint can be increased by 1.5 to 1.7 times of that without slots. The contact resistance of joint configuration with slots (b) is 30-40% lower than that of (a) and is mechanically and electrically more stable when subjected to current cycling test [1], [2].

The advantages of sectioning the busbar, as proposed by M. Braunovic [2], are attributed to a uniform contact pressure distribution under the bolt, which leads to a larger contact area.

Classic high voltage 700 kV power connectors are used for connections of stranded conductors and for connecting a variety of power equipment at the sub-station site. These connectors have two parts: keeper and current-carrying part comprised of a grooved section and flat end (pad, tongue).

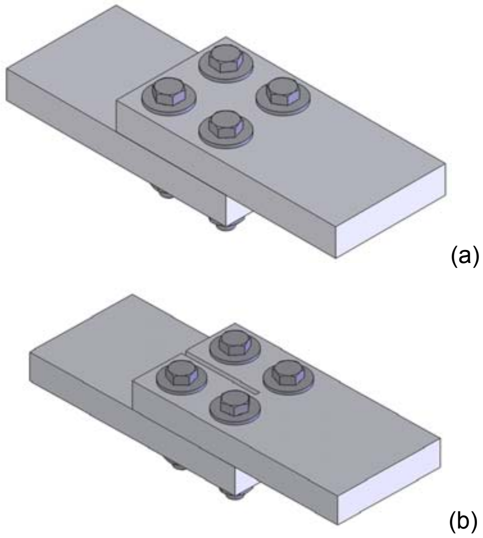

Fig.1. Overlapping busbar joint (a) non-slotted; (b) single slotted

Either high-strength aluminium (7075 grade) or steel bolts are applied for securing the conductor in the groves. Keeper and current-carrying part, for the old design, are made of solid block cast or wrought aluminium, while for the new design the keeper is sectioned with one or two slots.

Numerous observations proved that contact resistance between the current-carrying part and conductor is unstable that often leads to unacceptable overheating of the joint as a whole. It results from the inability of a relatively large and rigid keeper to maintain a good uniform contact between the conductor and current-carrying part of a connector. Slotting the keeper was an acceptable solution to the problem and significantly improved both mechanical and electrical stabilities of a joint. It can be explained with a more uniform stress distribution between the keeper and conductor that leads to a larger contact area at the conductor-connector electrical interface. The results of contact resistance measurements clearly outline that the electrical and mechanical integrities of bolted high-power connectors can be significantly improved by slotting, i.e. cutting longitudinal slots into the current carrying parts (pads). The observed improvement was associated with a more uniform stress distribution mentioned above.

Modelling Bolted Busbar Connection with Longitudinal Slots

In this paper an attempt to discuss how introducing longitudinal slots in high power bolted busbar connectors changes the contact pressure and contact penetration in the interface between the pad and their influence on the true contact area and therefore on the contact resistance. Additionally current conduction analysis is used to analyze the electric field distribution changes.

The investigated connectors in this work are of new design, that is with sectioned keeper part, whose current-carrying pads have four and six –bolt holes. The pads are modified by cutting slots 4 mm wide and 72mm long as seen in Fig.2. Bolt hole diameter is 13.2mm for the 12.7mm bolt diameters.

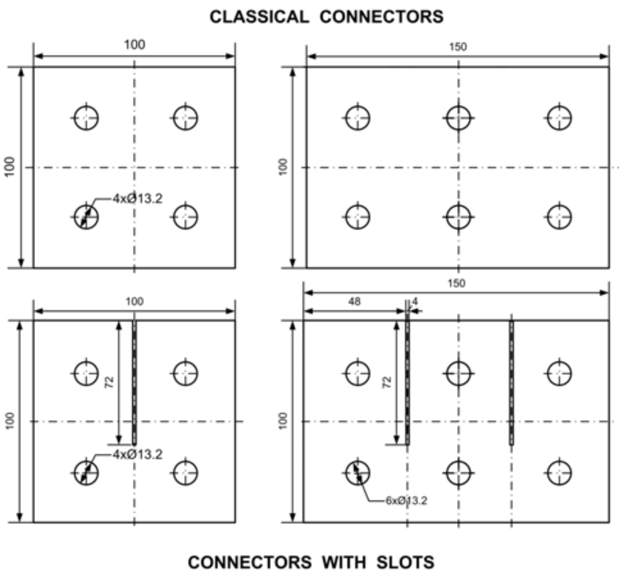

Fig.2. Drawings of the connector current-carrying pads without and with slots

All dimensions in the figure are in mm. The thickness of the connector's pads is 25mm and is made of aluminium. The busbars were made of the same grade aluminium. The behavior of these connectors is compared with the same connectors, having no slots in their pads.

The mechanical changes, associated with the contact penetration depth and the contact pressure, in the contact area between two busbars in a bolted busbar connection are studied by the help of the finite elements simulation tool ANSYS Workbench. If a higher contact penetration increases α-spots both in numbers and dimensions, which in turn expand the true contact area and decreases contact resistance, then a new design could be introduced for this connection. Typical bolted busbar connector with two longitudinal slots is shown in Fig.3.

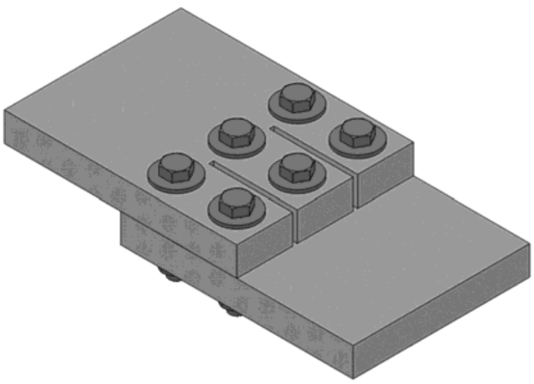

Fig.3. Slotted assembly with 2 slots

The investigated assembly consists of:

Alluminium busbars (Young's modulus E = $0.7.10^{11}$Pa, Poisson's ratio μ = 0.35, width 100mm and 150mm, height 25mm, length 160mm, busbars' overlap 100mm with 4 holes of Ø13.2mm and 150mm with 6 holes of 13.2mm;

Fasteners: bolts – Hex Finished Bolt_Al–HFBOLT 0.5-20-3-1.25-N, steel E = 2.10^{11}Pa, μ = 0.3; nuts – Heavy Hex Nut_Al–HHNUT 0.5000-13-D-N, steel E = 2.10^{11}Pa, μ = 0.3; washers –Flat Washer Type A Wide_Al- FW 0.5, steel E = 2.10^{11}Pa, μ = 0.3. Tension in each bolt F = 12559N.

Models are studied for contact pressure P (Pa) and penetration µ (m) within the busbars electrical interface.

The aspect of model meshing is distinguished as a key phase for proper analysis of the problem. This is because on the one hand it is an established certainty that the reason for the good quality of physical space triangulation is closely related to the consistent mapping between parametric and physical space.

On the other hand a properly meshed model will present a fairly close-to-reality detailed picture of stress distributions which is a hard task for analytical solution and is usually an averaged value. It is evident from Fig.4 and Fig.5, for the uneven allocation of penetration, that the 2 investigated designs bring even more complexities.

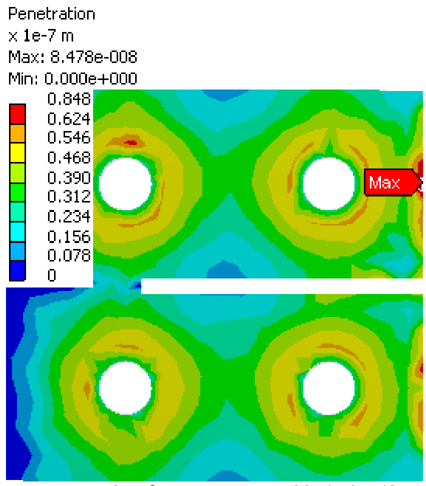

Fig.4. Contact penetration for connector with 1 slot (2 sectors)

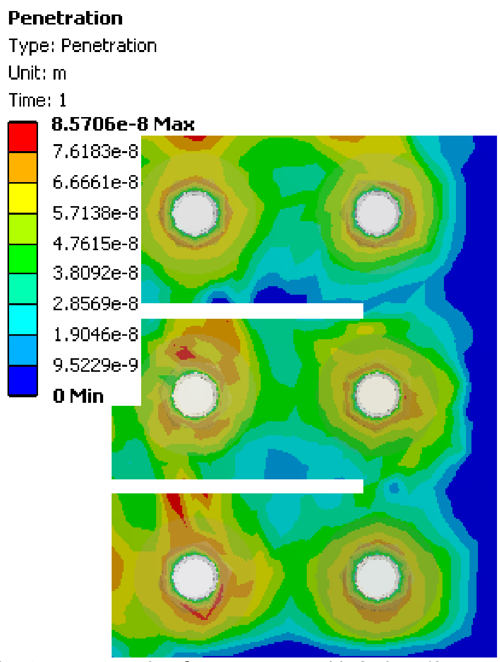

Fig.5. Contact penetration for connector with 2 slots (3 sectors)

In the solving process the meshed models incorporate the following elements: 10-Node Quadratic Tetrahedron, 20-Node Quadratic Hexahedron and 20-Node Quadratic Wedge. Contacts are meshed with Quadratic Quadrilateral (or Triangular) Contact and Target elements.

Contact penetration for connector with 1slot (2 sectors) is shown in Fig.4. Fig.5 presents the same characteristic for connector with 2 slots (3 sectors).

Table 1 shows the comparison between the max values of the contact pressure P_{max} and contact penetration μ_{max} for the connectors with and without slots.

Table 1. Comparison of P_{max} and μ_{max} for connectors with and without slots

Param	no slots	1 slot	no slots	2 slots
Pmax (Pa)	1.046e7	1.266e7	9.511e6	1.061e7
%	100	121.03	100	111.57
μmax (m)	7.025e-8	8.478e-8	7.405e-8	8.571e-8
%	100	120.68	100	115.75

Electric Field Distribution

Current conduction analysis is used to analyze a variety of conductive systems. Generally, the quantities of interest in a current conduction analysis are voltages, current densities, electric power losses (Joule heat).

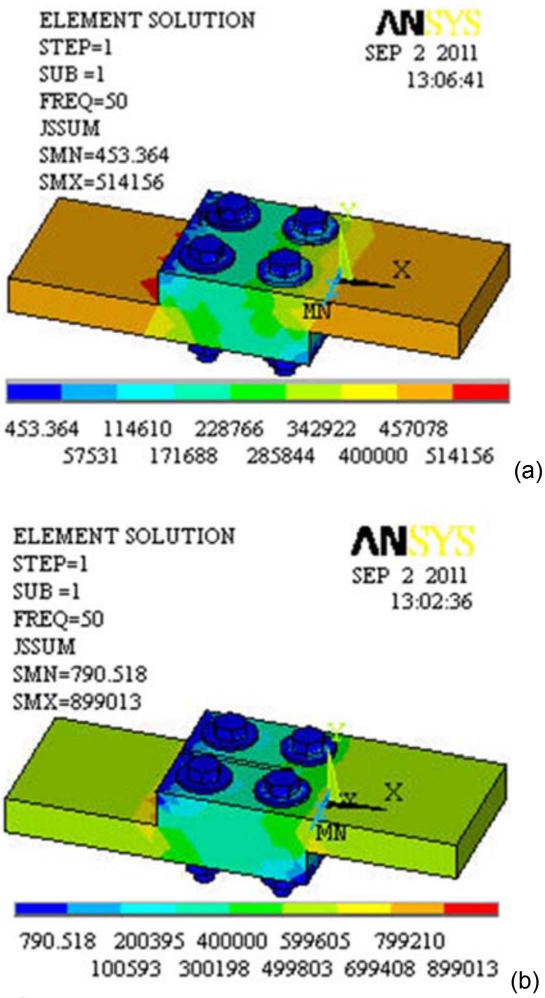

Fig.6. Current density distribution in the bolted busbar assembly without –a) and with 1 slot –b)

Several computer models smooth the research progress of the current density and Joule heat distribution changes that take place within the bolted busbar connection, due to the introduced longitudinal slots (sectors). The FEA package ANSYS is employed in the analysis of the electric field and the Joule heat distributions. The model is meshed with the SOLID 232 element - a 3-D, 10-node, tetrahedral current-based electric element. The element has one degree of freedom, voltage, at each node and is based on the electric scalar potential formulation. It is applicable to the low frequency time-harmonic quasistatic electric field analyses.

The current density distribution in the bolted busbar assembly without –a) and with 1 slot –b) is shown in Fig 6.

Another very important characteristic is the heat generated by the current flow. Joule heat distribution in the connector without –a) and with 1 slot –b) is illustrated in Fig.7.

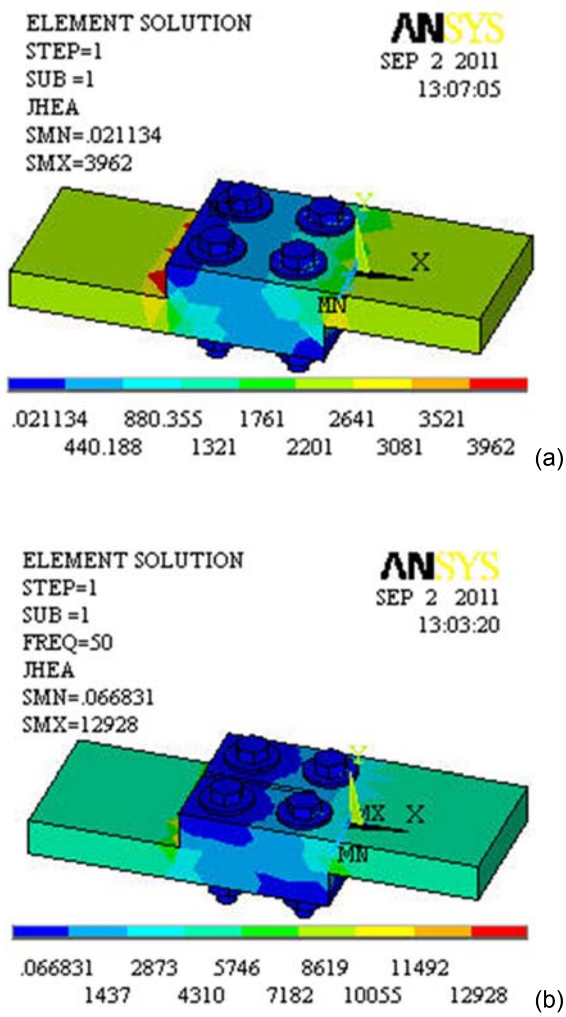

Fig.7. Joule heat distribution in the connector without –a) and with 1 slot –b)

Fig.8 shows the current density distribution in the bolted busbar assembly with 2 slots. The distribution of the Joule heat, generated by the current flow in the connector with 2 slots is illustrated in Fig.9.

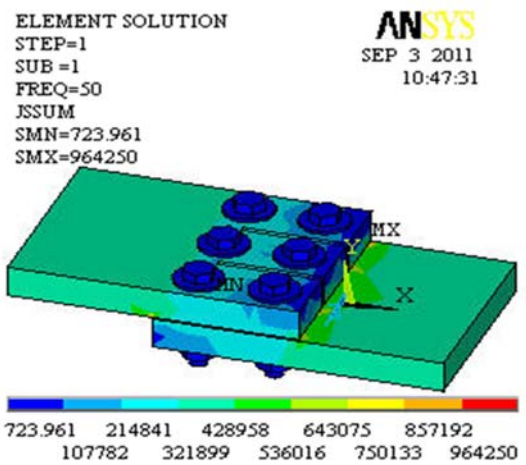

Fig.8. Current density distribution in the bolted busbar assembly with 2 slots

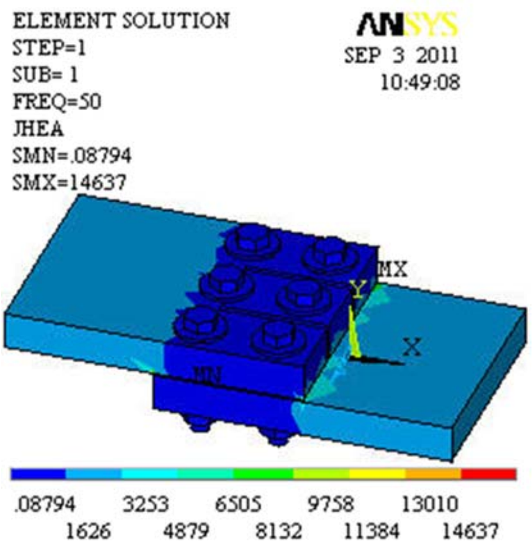

Fig.9. Joule heat distribution in the connector with 2 slots

An assessment of the max values of the current density j_{max} and Joule heat J_{max} for the connectors with and without slots is given in Table 2.

Table 2. Comparison of j_{max} and J_{max} for connectors with and without slots

Param	no slots	1 slot	no slots	2 slots
j_{max} (A/m^2)	514156	899013	959010	964250
%	100	174.85	100	100.5
J_{max} (J)	3962	12928	14339	14637
%	100	326.3	100	102.08

Discussion and Conclusion

As summarized in Table 1 the new design of high power bolted busbar connectors, introducing one or two longitudinal slots 4 mm wide and 72mm long leads to rise in max contact pressure of 21% for the connector with one slot and 11.6% for the two slotted connector. The max contact penetration increases with 20.7% for the connector with two sectors and 15.7% for this one with three sectors. Therefore, the true area of metal to metal contact is maximized within the electrical interface and that leads to reduced contact resistance and more efficient performance of the connectors of new design.

The generalized data in Table 2 show that the new connection design with one slot exhibits a significant increase in the max current density (74.8%) and Joule heat (more than three times), but it is concentrated in very small zones around the slots and edges. The max current density and the max Joule heat generated does not change with introducing longitudinal slots for the connector with three sectors therefore its thermal behaviour is perfect.

The idea of introducing slots in high power bolted busbar connections is additionally developed in 3 new designs, where the slots are a part of the bolt holes: slotted bolt holes - design S, slotted bolt holes, ending with small holes – design SH and groups of small holes around the bolt holes – design G. In all of these cases the rise of contact pressure and contact penetration is about 50% and the experimentally proved reduction of contact resistance is significant [6].

REFERENCES

[1] M. Braunovic, Effect of Connection Design on the Contact Resistance of High Power Overlapping Bolted Joints, *IEEE Transactions on Components, Packaging and Manufacturing Technology* 25(4), (2002), 642-650.
[2] M. Braunovich, Effect of Connection Design on the Performance of Service Entrance Power Connectors, *IEEE Transactions on Components, Packaging and Manufacturing Technology* 27 (1), (2004), 72-78.
[3] M. Braunovich et al., Fundamentals of Electrical Contacts, CRS Press, NY, 2006
[4] P. Slade, M. Dekker, Electrical Contacts, Boston, 1999.
[5] R. S. Timsit, The Technology of High Power Connections: A Review, *20-th International Conference on Electrical Contacts*, Zurich, Switzerland, 2002, p. 526.
[6] R. Tzeneva et al., New Connection Design of High Power Bolted Busbar Connections, *1, WSEAS International Multiconference CSCC* (Circuits, Systems, Communications, Computers), Crete Island, Greece, 2007, pp. 227-232
[7] V. I. Boychenko, N. N. Dzektser, Busbar Connections (in Russian), Energia, 1978.

***Author**: assoc. prof. dr. Raina Tzeneva, Technical University Sofia, 8, Kliment Ohridski St, Sofia-1000, Bulgaria; Tel. +359 2 965 2614, Fax: +359 2 962 41 96, e-mail: tzeneva@tu-sofia.bg*