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Power Frequency Withstand Voltage Type Testing and FEM Analysis of the Medium-Voltage Switchgear Busbar Compartment

Marko Zubčić, Maja Krčum
Marine electrical engineering and IT department
Faculty of Maritime Studies, University of Split
Split, Croatia
mzubcic@pfst.hr, mkrcum@pfst.hr

Abstract — **This paper presents the „new“ busbar geometry for the existing Medium-Voltage switchgear feeder. The investigated feeder is BVK-A-17,5 manufactured by KONČAR-Electrical Equipment Inc. This feeder uses supporting epoxy resin insulators to support its busbar geometry. In this paper the busbar geometry without supporting insulators is proposed. When dealing with new design of the product the type testing is inevitable. Type test of interest in this paper is "Short-duration power frequency withstand voltage test". The prototype consisting of two feeders is built, and type tested in the company facilities. New busbar geometry successfully passed the type test. This paper also presents FEM analysis of the type test and compares 3D and 2D model simulation results with the outcome of the real-life test.**

Key words - busbar geometry; medium-voltage switchgear; type test; FEM analysis;

I. INTRODUCTION

Air insulated medium voltage metal-enclosed switchgear is indispensable part of power distribution system. Typically, it is consisted of several compartments: low-voltage compartment, busbar compartment, circuit breaker compartment, cable compartment. More detailed construction is shown in Fig. 1. There are many manufacturers of medium-voltage (MV) switchgear. Each of them has it own variations but concept regarding division on compartments is the same. MV switchgear is subjected to type testing. Type tests are conducted according to referent standards like ANSI or IEC. Basic differences between mentioned standards can be found in [1]. These tests verify the design of the manufacturer regarding mechanical construction, dielectrics/insulation, heating, safety. The standard to which this paper refers is *IEC 62271-200: AC metal-enclosed switchgear and control gear for rated voltages above 1 kV and up to and including 52 kV*. This standard is in conjunction with *IEC 62271-1*. There are several type tests: dielectric test, radio interference voltage test, measurement of the resistance of the circuit, temperature-rise test, etc. Description of the tests can be found in [2]. The test of interest in this paper is "Short-duration power frequency withstand voltage test".

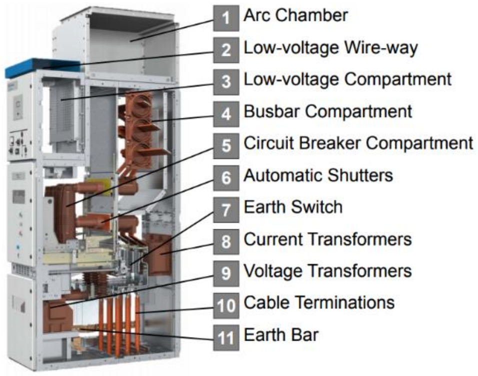

Figure 1. Construction parts of MV switchgear

The object of the test is the newly proposed busbar system/compartment for BVK-A-17.5 MV switchgear. BVK-A-17.5 is a product of KONČAR-Electrical Equipment Inc. [3]. Different manufacturers have different busbar geometry. Fig. 2 show three different types of busbar compartments. Busbar compartment of BVK-A-17.5 is shown in Fig. 3b from which it can be seen that this busbar geometry uses epoxy insulators to support the busbars. This design has been verified through type testing. Some of the other manufacturers have managed to design their busbar compartments without supporting insulators. From cost analysis point of view this provides savings. Newly proposed design regarding BVK-A-17.5 busbar geometry is one without supporting insulators.

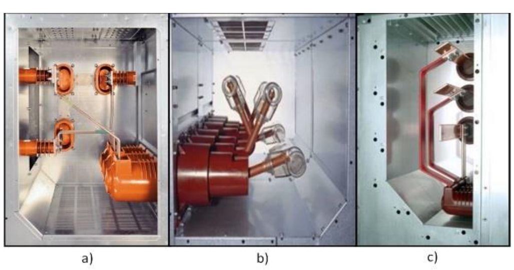

Figure 2. Busbar compartments of different manufacturers: a) Phu Giant Electric b) ABB c) Multi-Link SDN BHD

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a) b)

Figure 3. MV switchgear BVK-A-17.5: a) One incoming and two outgoing feeders b) busbar compartment

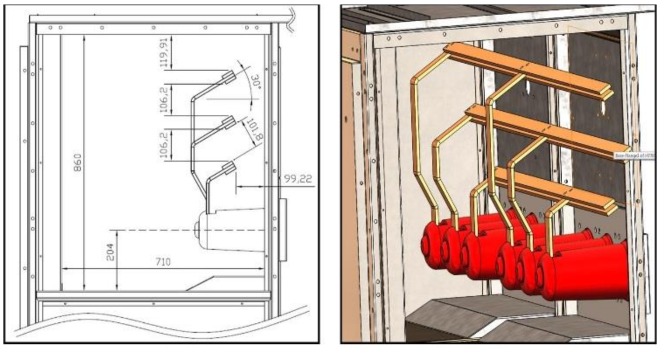
The true verification of proposed geometry would be through type testing in independent laboratories. Testing and certification can be costly and time consuming especially if switchgear does not pass the tests. Every manufacturer that has the testing equipment will preform pretesting in his own facilities. KONČAR – Electrical Equipment Inc. has in its possession the AC dielectric test set with maximum test voltage of 100 kV [4].

In this paper the results of the “Short-duration power frequency withstand voltage test” on the newly proposed busbar geometry are presented.

Every manufacturer i.e. the company tends to reduce time to market (TTM). One of the tools which is used to achieve this is finite element method (FEM). With FEM analysis manufacturers can understand the physics of their product. They can predict possible problems that can arise during type testing, problems that are for example in the domain of coupled-physics. In this paper the FEM analysis of the busbar compartment under test is conducted. The results are present and compared to the outcome of the real-life test.

II. CONSTRUCTION

The new proposed busbar geometry is shown in Fig. 4a. It is system without epoxy supporting insulators. Busbars are supported only with bolted joints inside epoxy resin contact box insulators. There are two busbars per phase horizontally and one busbar per phase vertically. All busbar are rounded edge busbars with cross-section dimension of 40x10 mm. To create more realistic scenario two switchgear units or two feeders are made. One is considered to be last feeder and the other second last. Last feeder must be enclosed with metal sheet. This makes him more interesting for electric field analysis then e.g. some middle switchgear feeder. The system is designed for rated insulated voltage of 17.5 kV. The rated lightning impulse withstand voltage was chosen to be 75 kV. For this voltage level minimum clearance phase-to-earth and phase-to-phase is 120 mm [5]. As it can be seen from Fig. 4a these minimum clearances are not obeyed and for this reason the busbars are insulated with heat-shrinkable insulation tubing [6]. The overall construction design was made in SolidWorks. The 3D prototype design of the busbar is shown in Fig. 4b. Because 3D drawing is for construction purposes only the busbars are drawn without insulation tubing.



a) b)

Figure 4. Newly proposed system - busbar system without supporting insulators: a) busbar geometry/dimensions b) 3D model drawn in SolidWorks

The differences between SolidWorks model and 3D FEM model which will be shown later in the text are observed in overall construction. For FEM analysis purposes, only the busbar compartment is modeled. For manufacturing purposes, the busbar compartment and lower construction which holds the busbar compartment at the right height from the ground is modeled in SolidWorks.

III. TESTING

Because only the busbar system is the object of study the testing procedure for “Short-duration power frequency withstand voltage test” is simplified. There is no switching apparatus inside of the feeders so there is no possibility to conduct the test for all cases stated by the referent standard. According to standard [7] the test voltage for 17.5 kV is 38 kV. The test is conducted in the following way: test voltage is applied to phase L1. All other phases along with the whole construction (frame) are connected to earth. The test voltage is maintained for 1 minute. Same procedure is applied to phases L2 and L3. The busbar system shell be considered to have passed the test if no disruptive discharge occurs [2]. Table 1 shows all test conditions. On Fig. 5 the testing of the prototype is shown.

TABLE I. TEST CONDITIONS

Test condition	**Test voltage 38 kV applied to**	**Earth connected to frame and:**	**Duration**
1	L1	L2, L3	1 min
2	L2	L1, L3	
3	L3	L1, L2	

Figure 5. Short-duration power frequency withstand voltage test of the prototype

Because the altitude of the facility in which the prototype was tested is under 1000 m the altitude correction factor was not required. The standard reference atmospheric condition for which standardized withstand voltages apply, are [7]:

a) temperature: $t_0 = 20$ °C

b) pressure: $b_0 = 101.3$ kPa

c) absolute humidity: $h_0 = 11$ g/m^3

At the time of the test, the following atmospheric conditions were measured: t = 21 °C, b = 101.9 kPa, RH = 44 %. The absolute humidity was calculated according to [8]. The value of absolute humidity was 8.06 g/m^3. According to [9] the air density correction factor and humidity correction factor were calculated. By multiplying these factors the atmospheric correction factor of $K_t = 0.966$ was obtained. The test voltage was then corrected to the value of 36.74 kV.

The corrected value was not applied. The test voltage which was applied was 38 kV. During testing no disruptive discharge had occurred.

IV. FEM MODEL

The idea behind the FEM simulation is to calculate static electric field, find the maximum value of the electric field and compare it to dielectric strength of the air and busbar insulation. In the real-life test the frame of the switchgear along with two phases (e.g., L1 and L2) is grounded while voltage of 38 kVrms is applied to the third phase. In FEM simulation the potential $\varphi_0 = 0$ V is prescribed to the frame and two phases. The potential $\varphi_{max} = 38\sqrt{2}$ kV is prescribed to the third phases. For FEM simulation COMSOL Multiphysics software was used. COMSOL consists of many modules, each of them representing one branch of physics. For this investigation the AC/DC module was used [10]. With this module static and low-frequency electromagnetics can be simulated. The 3D model was built in the COMSOL graphical interface. The model consists of two busbar compartments with insulated busbars. Finite element type used in this investigation is the tetrahedral element. The default COMSOL mesh generator was used which has predefined groups of element size: *Normal, Fine, Finer, Extra fine, Extremely fine*. In this investigation *Extra fine* setting was used. *Extremely fine* setting resulted in "Out of memory in meshing processing" massage. The 3D model along with the prototype is shown on Fig. 6. On Fig. 6 the lowest busbar is phase L1 and the middle one is the phase L2. The model itself is located in the air. Fig. 7 shows the 3D model in the air domain.

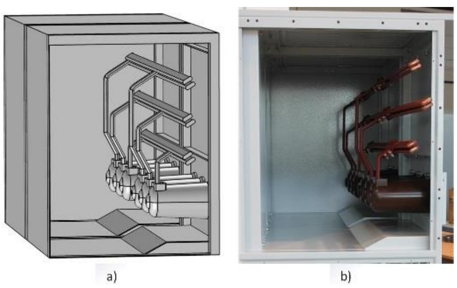


Figure 6. Busbar compartment: a) 3D model in COMSOL b) built prototype

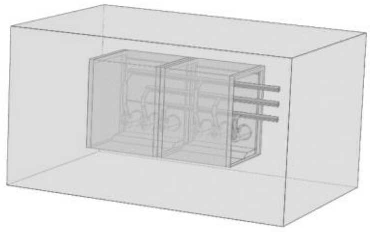


Figure 7. Busbar compartment model in air domain

V. FEM RESULTS

The technical data of the busbar insulation does not give the value of dielectric constant. The manufacturer of the used insulation tubing declares the equivalence of his product to the product of other manufacturer. According to technical data of [11], the value of the dielectric constant $\varepsilon_r = 3$ is taken. Once the electrostatic field is calculated the function "Max/Min Volume" is applied. The function is giving the maximum and minimum value of the electric field amplitude and its coordinates. For better perception of the results, some coordinates of the model are shown on Fig. 8.

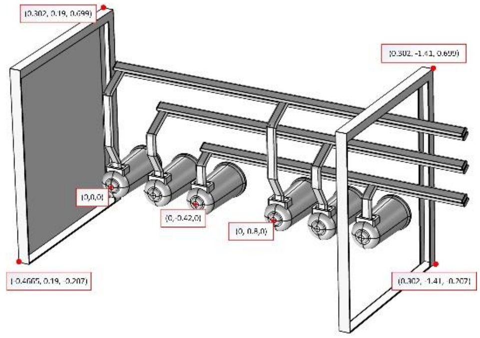


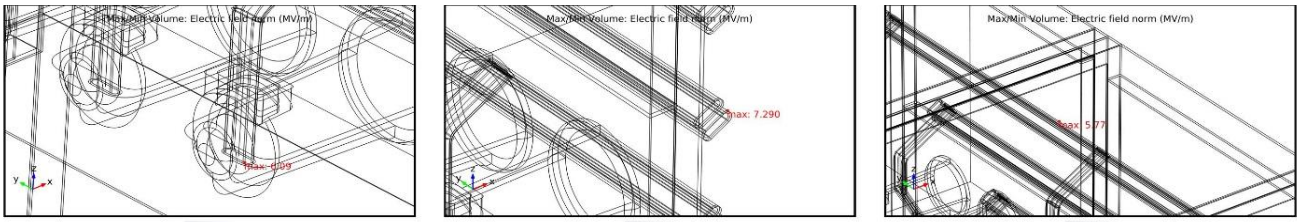
Figure 8. Coordinates of the model for better perception of the results

The results which are obtained with "Max/Min Volume" function in COMOSL are presented in Table 2. These results are obtained for *Extra fine* mesh element size setting. Investigation started with *Normal* size setting. It was observed that with denser mesh the values of E_{MAX} decrease. For available computer performances the most dense mesh setting used was *Extra fine* element size.

TABLE II. FEM RESULTS – MAX. VALUE OF ELECTRIC FIELD AMPLITUDE

φ_{max} applied to:	φ_0 applied to frame and:	E_{MAX} (MV/m)	Coordinates		
			x	*y*	*z*
L1	L2, L3	6.09	0.045	-0.435	-0.02
L2	L1, L3	7.28	0.150	-1.643	0.362
L3	L1, L2	5.76	0.136	-0.642	0.537

Comparing results from Table 2 with dielectric strength of the air which is 3 MV/m leads to conclusion that disruptive discharges can be expected at given coordinates during testing of the prototype. The dielectric strength of the busbar insulation is declared to be ≥ 16 kV/mm. No dielectric breakdown of the insulation is expected. The location of the critical points is shown on Fig. 9.



a) b) c)

Figure 9. Location of the critical points from the Table 2: a) Phase L1 – inside of the epoxy resin contact-box insulator, on the bottom of the busbar b) Phase L2 – outside of the metal enclosure on the surface of the insulator c) Phase L3 – on the surface of the insulator near the upper part of the frame

Before conducting FEM analysis the critical points were expected in the location where busbars are the closest to the frame. It is interesting to see the electric field distribution along with potential contours in the cross-section where the phases are closes to the frame. The location where all busbars are closest to the frame is at the junction of two feeders or busbar compartments. In this investigation that plane is *y* = -0.61 m. Fig. 10 shows the electric field distribution, potential contorus and the maximum vale of electric field amplitude for the phase L3. Fig. 11 and Fig. 12 show the same data for the phase L2 and L3 respectively.

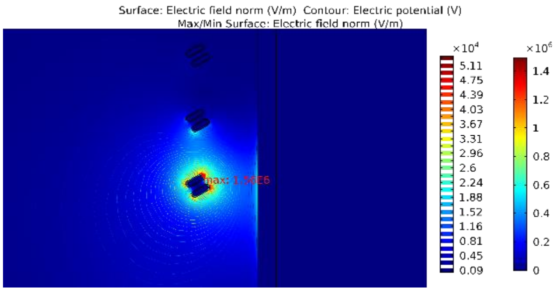


Figure 10. Phase L1-Electric field distribution and electric field contours

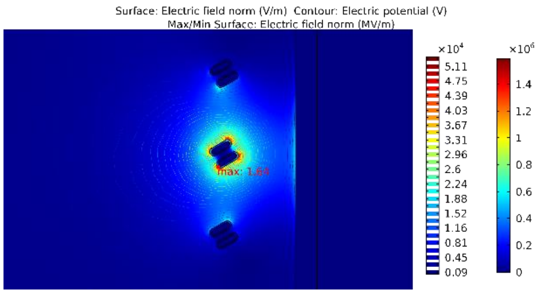


Figure 11. Phase L2-Electric field distribution and electric field contours

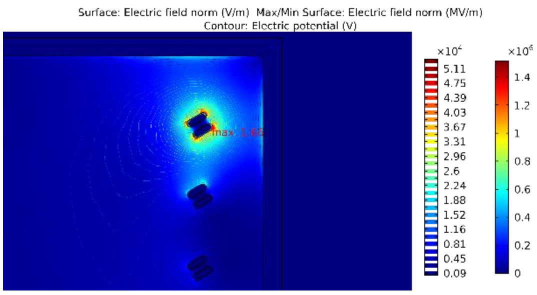


Figure 12. Phase L3-Electric field distribution and electric field contours

VI. CONCLUSION

In the first part of the paper, it is shown that prototype with newly proposed busbar geometry, busbar compartment without supporting insulators, was constructed and built. This geometry successfully passed the dielectric type test: Short-duration power frequency withstand voltage test". In second part of the paper a simple 3D FEM analysis of the prototype under dielectric type test was conducted. The concept of the electrostatic field calculation and "Max/Min Volume" function in COMOSL did not prove itself to be reliable. All FEM results indicated that disruptive discharge should occur which disagrees with the results of the testing. This paper also shows that 2D FEM analysis is in agreement with the test results. The plane in which all the phases are closest to the frame is investigated. Maximum values of electric field amplitude are less then dielectric strength of the busbar insulation and air.

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REFERENCES

[1] L. F. O. Costa, E. Rangel Jr., J. M. de Carvalho Fo., R. C. Barros, "Differences and similarities between ANSI and IEC cultures for MV assemblies—the Brazilian experience", Petroleum and Chemical Industry Technical Conference (PCIC), 23-25 Sept. 2013, DOI: 10.1109/PCICon.2013.6666014

[2] IEC 62271-1:2007, "High-voltage switchgear and controlgear-Part 1: Common Specification", International Electrotechnical Commision, Geneva

[3] KONČAR-Electrical Equipment Inc., BVK-A-17.5, Available: http://www.koncareu.hr , accessed on 2018-02-01.

[4] Phenix TECHNOLOGIES, Field and Lab AC Dielectric Test Sets, 6CP100/50-10, Available: http://www.phenixtech.com , accessed on 2018-02-01.

[5] A. Hoppner, "ABB-Pocket Book – Switchgear Manual", 10th edition

[6] Union Polymer Material Co.,Ltd, Bus bar tubing, S1(n)-10 Halogen Free Bus Bar insulation Heat Shrink Tube, Available: http://www.upolymer.com , accessed on 2018-02-02.

[7] IEC 60071-1:2006, "Insulation co-ordination – Part 1: Definitions, principles and rules", International Electrotechnical Commision, Geneva

[8] HUMIDITY CONVERSION FORMULAS, Vaisala Oyj, P.o. Box 26, FI-00421 Helsinki, Finland

[9] W. Hauschild and E.Lemke, "High-Voltage Test and Measuring Techniques", Springer, 2014, pp. 17 – 80

[10] COMSOL, "AC/DC Module User's Guide", COMSOL, Stockholm, Sweden, 2015

[11] Dong Nguyen Gia Import-Export Trading Co., Ltd, Raychem BBIT-BPTM, Available: http://www.dongnguyengia.com.vn , accessed on 2018-02-02.