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

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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".

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 KONCAR-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 1. Construction parts of MV switchgear

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

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>
<thead>
<tr>
<th>Test condition</th>
<th>Test voltage 38 kV applied to</th>
<th>Earth connected to frame and:</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L1</td>
<td>L2, L3</td>
<td>1 min</td>
</tr>
<tr>
<td>2</td>
<td>L2</td>
<td>L1, L3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>L3</td>
<td>L1, L2</td>
<td></td>
</tr>
</tbody>
</table>

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

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.

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: \( t_0 = 20 ^\circ C \)
- b) pressure: \( b_0 = 101.3 \text{ kPa} \)
- c) absolute humidity: \( h_0 = 11 \text{ g/m}^3 \)

At the time of the test, the following atmospheric conditions were measured: \( t = 21 ^\circ C, b = 101.9 \text{ kPa}, \text{RH} = 44 \% \). 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 \( \phi_0 = 0 \text{ V} \) is prescribed to the frame and two phases. The potential \( \phi_{\text{max}} = 38 \sqrt{2} \text{ kV} \) 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.

Compared 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 \( \geq 16 \text{ kV/mm} \). No dielectric breakdown of the insulation is expected. The location of the critical points is shown on Fig. 9.

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.

<table>
<thead>
<tr>
<th>( \phi_{\text{max}} ) applied to:</th>
<th>( \phi_0 ) applied to:</th>
<th>( E_{\text{MAX}} ) (MV/m)</th>
<th>Coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>L2, L3</td>
<td>6.99</td>
<td>0.045, -0.435, -0.02</td>
</tr>
<tr>
<td>L2</td>
<td>L1, L3</td>
<td>7.28</td>
<td>0.150, -1.643, 0.362</td>
</tr>
<tr>
<td>L3</td>
<td>L1, L2</td>
<td>5.76</td>
<td>0.136, -0.642, 0.537</td>
</tr>
</tbody>
</table>

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 \( \geq 16 \text{ kV/mm} \). No dielectric breakdown of the insulation is expected. The location of the critical points is shown on Fig. 9.
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 closest to the frame. In this investigation that plane is $y = -0.61\, \text{m}$. Fig. 10 shows the electric field distribution, potential contours and the maximum value of electric field amplitude for the phase L3. Fig. 11 and Fig. 12 show the same data for the phase L2 and L3 respectively.

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: \textit{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 than dielectric strength of the busbar insulation and air.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the company KONČAR-Electrical Equipment Inc., for giving them detailed insight of their product BVK-A-17.5 and for supporting the idea of new busbar system, prototype manufacturing and testing in their facilities.

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