Modelling and Simulation Aspects of Transient Electromagnetic-Mechanical Analysis for Industrial Applications

Zeljko Tanasic[1], Thomas Werder Schläpfer[2], and Jasmin Smajic[1]

[1]University of Applied Sciences of Eastern Switzerland (HSR), Oberseestrasse 10, Rapperswil, Switzerland, jsmajic@hsr.ch
[2]ABB Switzerland Ltd., High Current Systems, Brown-Boveri-Strasse 5, CH-8050 Zurich, Switzerland

For the development and optimization of those power system components that are subjected to high short circuit currents, such as for example Generator Circuit Breakers (GCB) and Insulated Phase Busducts (IPB), an accurate, robust and efficient methodology for performing a transient electromagnetic-mechanical analysis is of paramount importance. The purpose of this paper is to present numerical and modelling aspects of the analysis that are decisive for the accuracy and reliability of the results. The efficient and robust 3-D approach based on Biot-Savart integration for evaluating the electromagnetic force density over electrically conductive domains, the 3-D magnetostatic approach based on the A-field formulation including an air box, and the 3-D eddy-currents approach based on the A-φ-field formulation are compared in order to evaluate the importance and relevance of magnetic bodies consideration (structural steel components) in terms of electromagnetic force and induced eddy-currents for daily design of GCBs.

***Index Terms*—Generator circuit-breakers, isolated phase busducts, short circuit currents, electromagnetic modelling, numerical simulation, and magnetomechanical effects.**

I. INTRODUCTION

SEVERAL IMPORTANT POWER SYSTEM COMPONENTS are subjected to high fault currents (short-circuit (SC) currents) due to their very high power and comparatively low voltage. A typical example of such a device are generator circuit-breakers (GCBs) and isolated phase bus ducts (IPB). For an illustration, the ABB generator circuit breaker (GCB) type HEC 9 designed for largest turbo-generators is constructed to withstand a non-harmonic short circuit current with the peak value of 685kA. Such an electric current results in enormous magnetic forces (due to the quadratic current-force dependence) which makes the mechanical breaker design a demanding task.

Due to the non-harmonic form of the short-circuit current [2] a transient electromagnetic-mechanical analysis is required. The size of a typical GCB and its allowable deformation due to the SC current does not require the so-called strongly coupled electromagnetic-mechanical analysis described, for example, in [3] and [4]. In the area of electrical machines, for example, over the last decade the so-called weakly coupled electromagnetic-mechanical analysis was almost exclusively used [5], [6]. The main characteristic of the said weak coupling is a one directional link between the electromagnetic and mechanical step, i.e. the coupling of the deformed shape after the mechanical analysis back into the electromagnetic analysis is not necessary.

As reported in the recent paper [1], the existing simulation techniques, such as [5] and [6], are not suitable for industrial applications due to the high level of geometrical complexity of real life devices (making the construction of the air box around the device extremely difficult and time consuming) and due to the need for results interpolation between different meshes of the electromagnetic and mechanical simulation. The reference [1] describes in detail the air-box free technique based on the stationary current distribution, Biot-Savart integration, and dynamic mechanical analysis by using the harmonic superposition method [7].

The main purpose and contribution of this paper is manifold: (a) to show the validity and accuracy of the method reported in [1] for industrial applications by comparing it against the classical 3-D magnetostatic analysis based on the well-known A-field formulation, (b) to evaluate the influence of the magnetic bodies (structural components) on the results of the electromagnetic-mechanical analysis, (c) to compare the method reported in [1] against the classical 3-D eddy-currents analysis based on the well-known A-φ-field formulation in order to evaluate the influence of the induced eddy-currents on the results of the electromagnetic-mechanical analysis.

II. NUMERICAL TECHNIQUES AND MODELING DETAILS

The numerical results presented in the paper were obtained by using the following numerical methods:

a. *Method 1* (an air-box free method): presented in detail in the recent publication [1]. This method involves three steps: (i) stationary current distribution, (ii) Biot-Savart integration for obtaining the Lorentz force density, and (iii) the dynamic mechanical analysis based on the modulation of the static force (ii) according to the dynamic SC current.
b. *Method 2* (requires a large air box): has the same steps (i) and (iii) as Method 1 but in the step (ii) it utilizes a classical 3-D magnetostatic analysis based on the A-field formulation for obtaining the magnetic Lorentz force distribution.
c. *Method 3* (requires a large air box and very fine mesh of the involved conductive and ferromagnetic bodies): has the same step (iii) as Method 1 but the steps (i) and (ii) are here merged into one classical 3-D eddy-current analysis based on the A-φ-field formulation for obtaining the magnetic Lorentz force distribution.

The described methods will be explained in more detail in the subsequent full paper.

The chosen generator circuit breaker is presented in Figure 1. This breaker has been fully type tested according to the IEEE

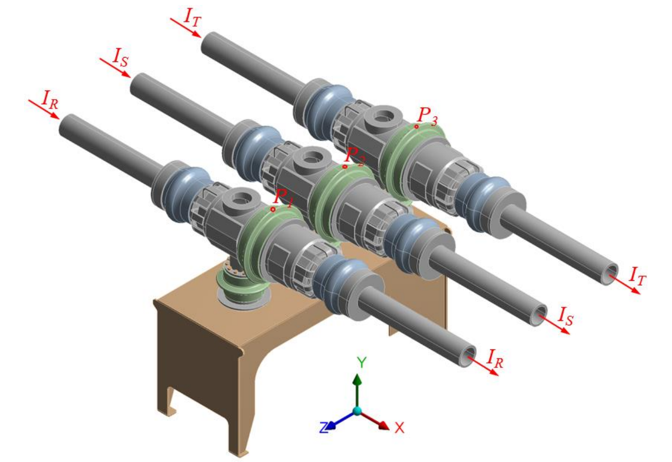

Fig. 1. The geometry of the chosen ABB GCB HECS-100R (rated voltage 25.3kV, rated current 9'000A_{RMS}, and rated short-circuit current 100kA).

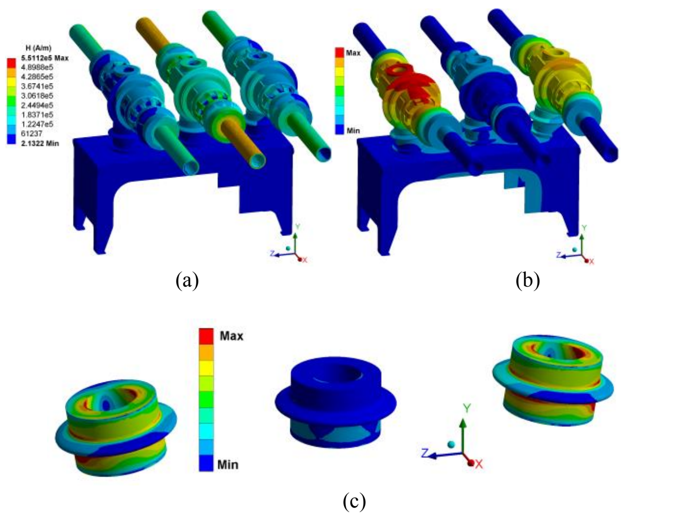

Fig. 2. The static magnetic field (a) distribution of the breaker from Figure 1 is shown (this is a static results for the peak value of the short-circuit current flowing through the middle conductor). The corresponding scaled displacements of the breaker (b) and the corresponding stress distribution over the insulators (c) are presented.

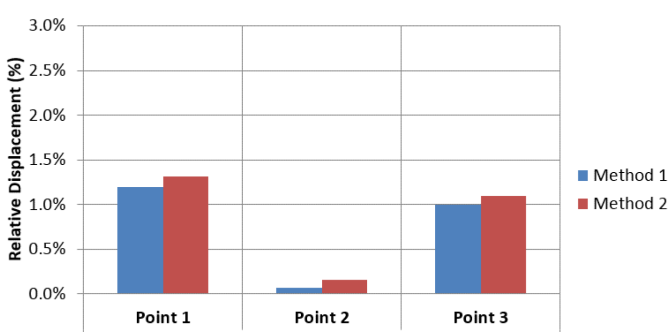

Fig. 3. The results comparison between Method 1 and Method 2 is shown. The normalized displacement of the points P1, P2, and P3 defined in Figure 1 is compared. To reveal the influence of the magnetic bodies only the static result for the peak value of the short-circuit current in the middle conductor is considered. (Method 1: $N_{EL}=3.5\cdot 10^6$, CPU-time[1]=60.7 hours, Method 2: $N_{EL}=5.2\cdot 10^6$, CPU-time[1] =5.6 hours)

[1]Intel(R) Xeon(R) E5-2667 v2 @ 3.3 GHz (8 cores) was used.

C37.013 standard. The geometry is simplified yet contains all parts relevant for the transient electromagnetic-mechanical analysis. The current carrying part of the breaker is also illustrated by depicting the three-phase current system. The model involves flexible and stiff conductors (grey and light blue), insulators (green) and structural components (brown).

The model given in Figure 1 is mechanically fixed at the bottom horizontal surfaces of the pole frame (brown) as well at the inlet and outlet surfaces of the current carrying conductors (grey). The breaker must withstand the mechanical stresses over the entire duration of the short circuit current (80ms, i.e. four cycles) [2].

III. Numerical Results

At the end of the step (ii) of Method 1 the static magnetic field and force density is obtained. This result is depicted in Figure 2a. The obtained force is then modulated in each step of the subsequent mechanical analysis in order to dynamically load the structure of the breaker. Over the entire short-circuit current time (80ms) the displacement of the structure is computed. The corresponding stress distribution is also recorded. These two results are decisive in order to prove the breaker's capability to mechanically withstand the short-circuit current.

Based on the stress distribution in each moment of time the stability of each critical component of the system can be evaluated. As an example, Figure 2c shows the stress distribution over the volume of the support insulators that corresponds to the displacement of the structure shown in Figure 2b.

Method 1 and Method 2 are compared in Figure 3. The presented comparison revealed a very good agreement. Since Method 1 (Biot-Savart integration) neglects the magnetic influence of the structural components and Method 2 take them fully into account, it is possible to conclude that the magnetic influence of the structural components in this arrangement is not significant.

We are working presently on the simulations based on Method 3 and those results will be presented at the conference and in the subsequent full paper.

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