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Research Paper

2.5-D multilayer optimisation of an industrial switchgear busbar system

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HIGHLIGHTS

- Optimisation of an industrial switchgear busbar system was conducted.
- The genetic algorithms with numerical solvers were combined to perform the overall design optimisation.
- The optimised design was verified by the two-way coupled CFD-EMAG model.

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ABSTRACT

In this paper, a 2.5-D multilayer model was used to optimise an industrial switchgear busbar system using electromagnetic (EMAG) solutions. Moreover, the optimised design was verified by the two-way coupled CFD-EMAG model which included 3-D geometry. The 2.5-D multilayer approach allowed the robustness of the whole optimisation process to be increased, whereas the coupled EMAG-CFD computation provided the necessary information regarding the temperature field. The genetic algorithm was employed in the optimisation procedure to simultaneously minimise the conductors' cross-section area and the power losses. Therefore, to obtain the unique solution, two objective functions (OFs) with different weights were used. Then the optimised cross-sections from the 2.5-D model were translated into a 3-D busbar system to verify the final temperature for the new design. As a result of the study the new busbar system was proposed. In comparison to the initial design, the copper weight was reduced by 4.5%, whereas the average busbar temperature increase was only 2 to 3 K.

1. Introduction

The importance of switchgears in the power delivery system is increasing. The devices guarantee the reliability of modern electric power distribution systems by fulfilling the delivery, maintenance and protection functions. Therefore, switchgears have to meet the standards regarding the electrical, mechanical and thermal performance. The technical requirements coupled with the marketing and competitive aspects are the main concerns in the process of new device generation development. One of the most important challenges for engineers is to minimise the weight of copper for the busbar system, while the resulting power losses are at most equal to those of the previous system generation.

The price of copper used for busbars inside the switchgear can be roughly estimated as 50% of the total unit price. Thus, any changes in the busbar system have tremendous economic effects, especially when the whole product generation is taken into consideration. To minimise the copper weight, optimisation of the busbar cross-sections is required, but such modifications may increase the heat generation. The reduction in the conductors' cross-section usually results in an increase in the busbar temperature, but the temperature limitation defined in the technical restriction remains [1,2]. Thus the device has to fulfil the thermal standards which are assessed on the basis of the temperature measurements at certain points during the laboratory tests. As a result, the reduction in the power losses and copper weight are equally important during optimisation of the busbar system. The technical restrictions regarding the power losses and copper weight require global optimisation methods. In the literature, a variety of optimisation procedures for electric devices are reported, i.e., decision trees and adaptive trained neural networks (ATNN) [3], the Taguchi Method [4], mixed integer non-linear programming (MINLP) [5], mixed integrated programming combined with the finite element method for the overall design [6], evaluation algorithms for insulator optimisation [7] and many more.

In this paper, stochastic methods were combined with numerical solvers to perform the overall design optimisation. The numerical solution of the electromagnetic field gives insight into the current density distribution in each conduction path [8–10]. Moreover, studies regarding the skin and proximity effects [10], magnetic-field

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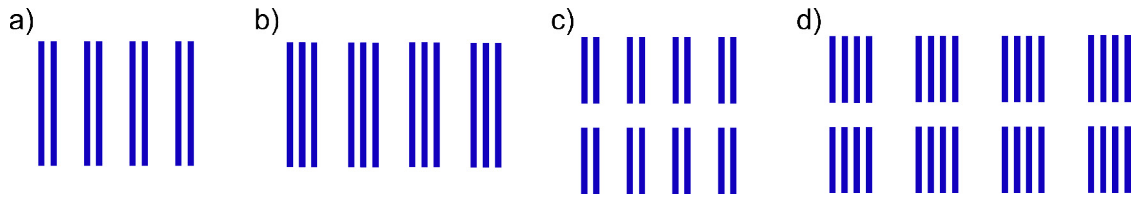

Fig. 1. Cross-section types of busbar system included in the 2-D optimisation procedure.

pollution [11,12], and electrodynamic forces [9,10,13] are possible. On the other hand, the numerical heat transfer allows for the optimisation of the thermal performance of electrical devices [11,14,15]. The combination of a thermal-electromagnetic solution leads to accurate virtual prototypes and increases the robustness of the novel designs [15–17]. For cases with multiple conflicting objective functions (OF), the multi-objective genetic algorithm (MOGA) with fitting functions is a well-suited solution [18].

The numerous examples of electromagnetic unit optimisation are usually limited to the numerical solution of either electromagnetic or thermal processes [19–21]. The real processes within the switchgear unit require a solution of coupled thermal and electromagnetic phenomena. Hence, a multiphysics approach is required for the optimisation process [8]. Because the optimisation procedure is computationally expensive in large and complex 3-D geometries, simplification of the geometry is often practised. In the case of motors and electric transformers, 2-D analyses are commonly employed [22,23]. However, the results obtained on the basis of such 2-D models can significantly differ from the results obtained from 3-D models. Unfortunately, the discrepancy between the two approaches is unknown in advance. Thus conclusions drawn from the 2-D analyses should be interpreted with some caution. Nevertheless, the 2-D formulations require significantly lower computational power at the cost of limited accuracy. To mitigate the disadvantages of 2-D models in motors and actuators optimisation, 2.5-D multi-layer models are utilised [24,25]. In this method, the device is subdivided into multiple layers in which fields may be assumed to be 2-D. In the case of the busbars, the 2-D solution is usually sufficient due to the same geometry along the current path [8,26]. The studies regarding the busbar optimisation have successfully utilised the 2-D approach to reduce the power losses [27] and to achieve more uniform current distribution in conductors [28].

In this paper, the 2.5-D multi-layer model of a switchgear busbar system was considered. Such an approach is commonly used for the calculation of electric motors [25,29]. To the best knowledge of the authors, this method was employed for busbar system optimisation for the first time. Firstly, the 3-D busbar system geometry was translated into a 2.5-D model. For the 2.5-D model, five characteristic 2-D cross-sections were identified. For the 2-D cross-sections, the optimisation procedure in the electromagnetic solver (EMAG) was performed. The optimisation procedure utilised GA and two objective functions with different weights to simultaneously minimise the power losses and busbar cross-section. Finally, the results obtained from the 2.5-D model were transferred into the 3-D model to verify the new optimised design. The 3-D model was based on the previously validated numerical solution [30], so the verification procedure included the coupled Computational Fluid Dynamics (CFD) – EMAG analysis to estimate the thermal performance of the busbar system. Because the busbar temperature is the main concern for a new switchgear design, the verification procedure was crucial to assess the optimisation results.

2. Geometry and mesh

In the analysis, the busbars system from the industrial switchgear [30] was investigated. The studies were subdivided into the optimisation and verification procedure. During the optimisation studies the 2.5-D multilayer approach was utilised. The results from the previous work [30] were employed to identify the crucial cross-sections regarding the EMAG and CFD calculations. As a result, the five major busbar cross-sections with respect to the geometry and heat transfer capabilities were selected. Despite the geometrical similarities, some cross-sections had different conductor dimensions, which were reflected in the total conductive area, the heat transfer capabilities and the dimensional constraint definitions for the optimisation procedure.

The main geometrical differences between the cross-sections were in the number of conductors in each path. Thus only four busbar cross-sections are shown in Fig. 1. The location of the selected cross-sections is depicted in Fig. 2, while the details regarding the cross-section dimensions are shown in Table 2. The 2-D models (see Fig. 1) were enclosed in the air space that was similar for each corresponding cross-section. The computational domain sizes for EMAG studies were carefully chosen to minimise the influence of the boundary conditions (BC) and they resulted in the domain dimensions of 2430 mm × 225 mm, 1740 mm × 330 mm, 1650 mm × 360 mm,

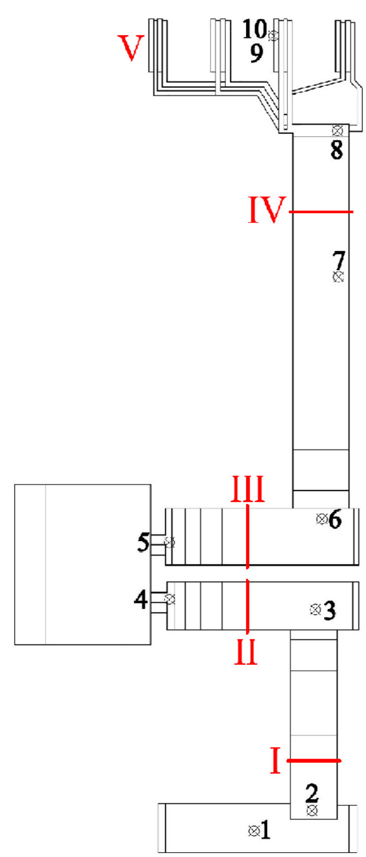

Fig. 2. Location of cross-section utilised in the 2-D optimisation procedure (red) and location of busbars measurements points (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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