Large-Scale Transient Eddy-Current Analysis of Large-Capacity Inverter Frame by FEM with Infinite Edge Elements

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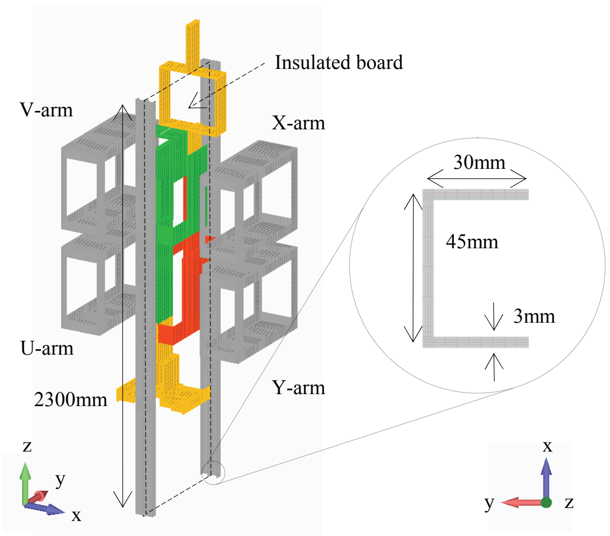
Abstract —This paper deals with the transient magnetic field analysis of a large-capacity inverter and the eddy-current loss estimation by the FEM with infinite edge elements. Making the best use of the computational results, we successfully propose an appropriate frame configuration from the viewpoint of eddy-current loss reduction.

I. INTRODUCTION

In a large-capacity inverter which treats high power, eddy-currents generated in the surrounding structure by the leakage flux may cause a serious heat generation. Therefore, in a design phase, it is indispensable to accurately comprehend the eddy-current distributions [1]. In this paper, we carry out the magnetic field analysis of a large-capacity inverter and evaluate the eddy-current loss [2-5] of the conductive frame of the inverter. In order to attain a high accuracy analysis by using a usual FEM, a huge number of unknowns are required because of the high aspect ratio of the frame thickness and the complicated structure to the whole size scale. Therefore, we utilize the FEM with infinite edge elements for the computational cost reduction [6]. The infinite edge element technique is especially effective for the complicated model such as inverters because we can easily deal with the mesh division of free space. Furthermore, we also successfully propose an appropriate frame configuration from the viewpoint of eddy-current loss reduction based on the computational results.

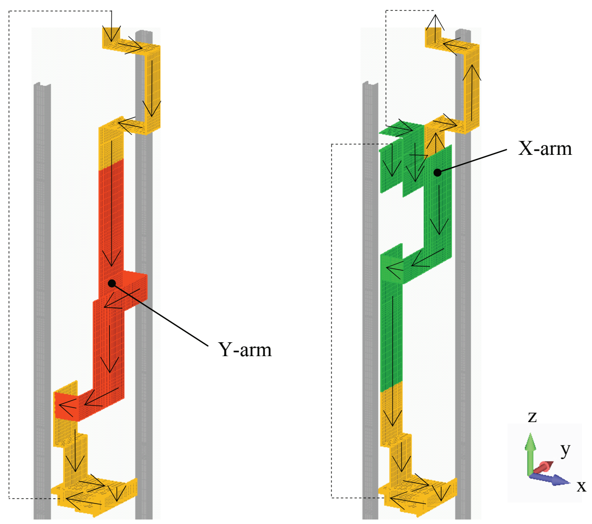


(a) (b)

Fig.1. Investigated model. (a) Main part of large-capacity inverter equipment with IGBT devices. (b) Cross-section diagram of frame.

II. INVESTIGATED MODEL

Fig. 1 shows the investigated inverter with IGBT devices, i.e., a part of the power supply equipment. Considering the skin effect in conductive frame, we properly prepare fine meshes with the size of sixth part of the skin depth. According to the switching of IGBT, the currents flow in UY-phase and XV-phase bus-bars by turns as shown in Figs. 2(a) and (b), respectively. The current wave forms are shown in Fig. 3. Here, the rise-time of the IGBT device in the inverter equipment is 1.5μs.



(a) (b)

Fig.2. Current-pathway of exciting current (half model). (a) Exciting current in UY-phase. (b) Exciting current in XV-phase.

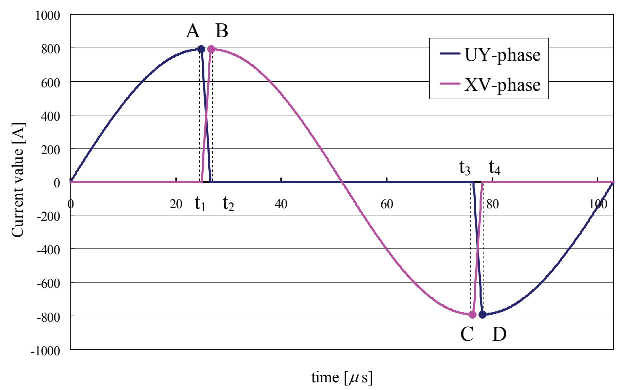


Fig.3. Current wave forms.

III. ANALYSIS METHOD AND NUMERICAL RESULTS

By using the finite element method with infinite edge elements [6], we specify the domain of the frame where the eddy-current loss is strongly generated. In order to reduce the temperature rise caused by eddy-current loss, we appropriately make a cut space in the specified frame portion and substitute non-conductive materials for the frame holding the insulated board. In this section, we propose the effective cut point based on the loss analysis results. Since a current-pathway wholly changes in the model as shown in Figs. 2 and 3, we perform the transient magnetic field analysis with the time interval Δt of 1.56μs except for the rise-time of the IGBT. The specifications of analysis are shown in Table 1.

Table 1 Specifications of analysis

Number of nodes	1,838,288
Number of finite elements	1,793,250
Conductivity of the flames and boxes (SUS304)	1.218×10^6 S/m
Frequency and current value of the exciting currents	10kHz, 560A

Fig. 4 shows the distributions of eddy-current loss densities before and after switching-points which are illustrated in Fig. 3. Fig. 4 shows that the loss becomes very high immediately after the current-pathway changes. We can find that a very large loss also appears in the portion marked by the black boxes even before the current-pathway changes. In other words, due to the fact that the bus-bars are located away from the insulated board, i.e., the symmetry plane, compared to the other sections of bus-bars, we can consider that the magnetic fields generated by the currents running in opposite direction are not able to efficiently cancel each other out in the portion marked by the black boxes.

Next, we propose the countermeasure for the eddy-current loss reduction in the frame of inverter equipment. Based on the above numerical results, we make a cut space in the part of frame which is indicated by the black box in Fig. 4. Although a large loss has caused in the other frame, the frame is located in the outer circumference of the power supply equipment and is possible to be attached by water-cooled tube. Performing the FE analysis under the condition of cutting frame, we can confirm the proposed countermeasure dramatically reduces the eddy-current loss by 48 % compared to the case of the initial configuration.

In the full paper, the thermal analysis will be carried out based on the loss data obtained by the eddy-current analysis, and the comparison between the numerical and experimental results will be reported. The suitable frame configuration will also be discussed in detail.

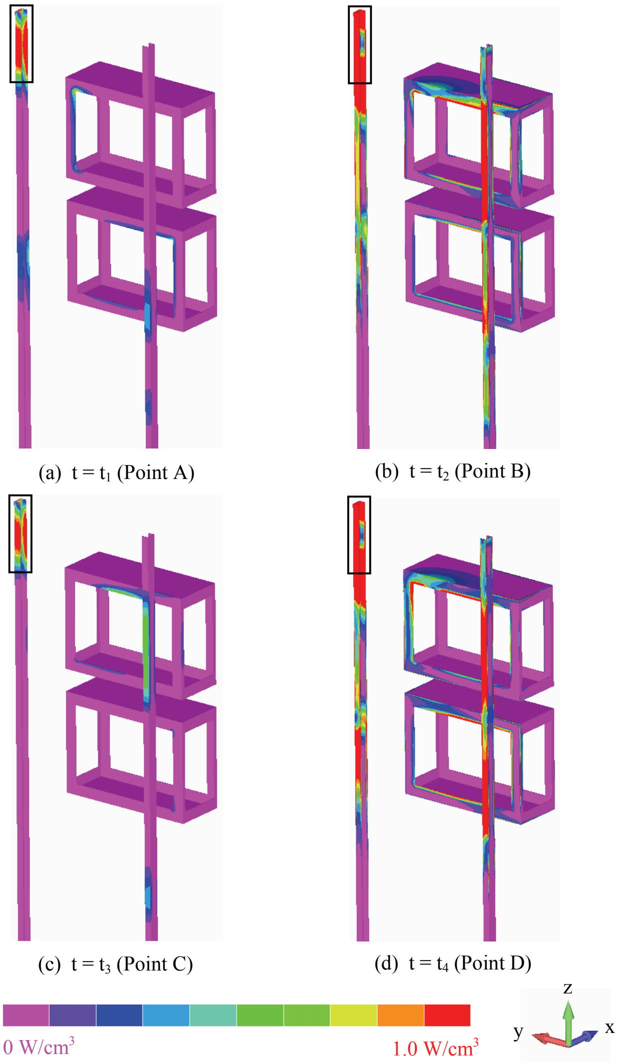


Fig.4. Distributions of eddy-current loss densities.

IV. REFERENCES

[1] T. Tatsuishi, Y. Takahashi, S. Wakao, M. Tobita, I. Tominaga, and H. Kikuchi, "Large-Scale Eddy-Current Analysis of Conductive Frame of Large-Capacity Inverter by Hybrid Finite Element-Boundary Element Method," *IEEE Trans. Magn.*, vol. 45, no.3, pp. 972-975 (2009).

[2] X. Li, S. Wu, Y. Zhou, G. Hu, and G. Long, "Influence of High Temperature Superconducting Transformer Geometry on Leakage Magnetic Field," *IEEE Trans. Magn.*, vol. 44, no. 4, pp. 492-496 (2008).

[3] K. Preis, O. Bíró, H. Reisinger, K. Papp, and I Ticar, "Eddy Current Losses in Large Air CoilsWith Layered Stranded Conductors," *IEEE Trans. Magn.*, vol. 44, no. 6, pp. 1318-1321 (2008).

[4] S. L. Ho, Y. Li, R. Y. Tang, K. W. E. Cheng, and S. Y. Yang, "Calculation of Eddy Current Field in the Ascending Flange for the Bushings and Tank Wall of a Large Power Transformer," *IEEE Trans. Magn.*, vol. 44, no. 6, pp. 1522-1525 (2008).

[5] R. Liu, C. C. Mi, and D. W. Gao, "Modeling of Eddy-Current Loss of Electrical Machines and Transformers Operated by Pulsewidth-Modulated Inverters," *IEEE Trans. Magn.*, vol. 44, no. 8, pp. 2021-2028 (2008).

[6] S. Tamitani, T. Takamatsu, A. Otake, S. Wakao, A. Kameari, and Y. Takahashi, "Finite Element Analysis of Magnetic Field Problem with Open Boundary Using Infinite Element Technique," *14th Biennial IEEE Conference on Electromagnetic Field Computation*, *Chicago* (2010).