Improvement of FEM Model for Conducted Emission Analysis of A Lighting Implement

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Abstract—This paper describes the technique of multi-scale numerical modelling of conducted emission for the inverter lighting implement placed in a large space of a shielded room employing the 3-D finite element method. It is experimentally understood that conducted emission is mainly generated by the common mode current, and displacement current is taken into consideration in the model. The validity of the computation was confirmed by the comparison with the measured results of a lighting implement.

Key words: Finite element method, Lighting implement, Conducted emission, Common mode current

I. INTRODUCTION

Recently, unnecessary electromagnetic wave caused by electric and electronic equipments has been becoming a serious problem because of the interference to the other equipments. A kind of this wave called conducted emission, which superimposes onto the power line, flows into the other equipment, and causes malfunctions. For this reason, electric and electronic devices are required to decrease conducted emission. It is experimentally understood that conducted emission is mainly generated by the common mode current.

On lighting implements, a driving method of the inverter commonly used in the implement comparatively generates larger noise than a conventional lighting method. Therefore the establishment of the simulation technology to predict the noise is required at the step of design to build a lighting implement.

Authors have been studying the analysis technique [1], however, in which common mode current has not been considered precisely because of the CPU time.

In this paper, some parts, those are thought to be influenced by the common mode current, are modeled in detail and the other parts are modeled roughly to get highly accurate analyzed results within reasonable CPU time. 3-D finite element method is employed for numerical modelling of conducted emission of the inverter lighting implement on frequency range from 10 to 30 MHz. The validity of this numerical model is confirmed by comparing with the measured results.

II. ANALYSIS METHOD

In this analysis, 3-D finite element method [2] is employed. By considering displacement current, the fundamental equations of the electromagnetic field in frequency domain can be expressed as follows.

\[ \text{rot} H = J + \frac{\partial D}{\partial t} \]  \hspace{1cm} (1)

\[ \text{rot} E = -\frac{\partial B}{\partial t} \]  \hspace{1cm} (2)

\[ \text{div} B = 0 \]  \hspace{1cm} (3)

\[ \text{div} D = \rho \]  \hspace{1cm} (4)

where, \( H \) is magnetic field strength, \( J \) is current density, \( D \) is dielectric flux density, \( E \) is electric field strength, \( B \) is magnetic flux density, \( \rho \) is charge density. Material constitution equations are expressed as follows:

\[ B = \mu H \]  \hspace{1cm} (5)

\[ D = \varepsilon E \]  \hspace{1cm} (6)

\[ J = \sigma E \]  \hspace{1cm} (7)

where, \( \mu \) is magnetic permeability, \( \varepsilon \) is relative dielectric constant, \( \sigma \) is conductivity. The magnetic flux density \( B \) is expressed as follows by vector potential \( A \).

\[ B = \text{rot} A \]  \hspace{1cm} (8)

The following equation is obtained by substituting equation (5) and (8) into equation (1).

\[ \text{rot} \left( \frac{1}{\mu} \text{rot} A \right) = \text{rot}(v \text{rot} A) + \frac{\partial D}{\partial t} \]  \hspace{1cm} (9)

where, \( v \) is reluctivity. And the following equation is obtained by substituting equation (8) into equation (2).

\[ E = -\left( \frac{\partial A}{\partial t} + \text{grad} \phi \right) \]  \hspace{1cm} (10)

where, \( \phi \) is electric scalar potential.

The fundamental equation of the magnetic field in time domain can be expressed by using equation (7), (9) and (10).
\[ \text{rot}(\text{rot}\mathbf{A}) = J_0 + J_e + \frac{\partial D}{\partial t} \] (11)

where, \( J_0 \) is forced current density, \( J_e \) is eddy current density. In this model, non-linear magnetic materials are not used, then the fundamental equation of the magnetic field can be expressed in frequency domain as follows and applied for all part of the analyzed model:

\[ \text{rot}(\text{rot}\mathbf{A}) = J_0 + J_e + j \omega \mathbf{D} \] (13)

\[ J_e = -\sigma \left( \frac{\partial \mathbf{A}}{\partial t} + \text{grad} \phi \right) \] (12)

where, \( \omega \), \( \mathbf{A} \), \( J_0 \), \( J_e \) and \( \mathbf{D} \) are complex numbers. In this analysis, the displacement current \( j \omega \mathbf{D} \) in equation (13) is taken into consideration, whereas eddy current density \( J_e \) is not calculated since the displacement current is more dominant than the eddy current around this frequency. \( \sigma \) is the angular frequency.

III. BASIC ANALYZED MODEL

The calculation model of analyzed region is shown in Fig.1. The LISN (Line Impedance Stabilization Network) is placed on the Ground reference plane and all the 6 faces of the shielded room are supposed to be perfect conductor as ground. The number of elements of this model is 690,609 and that of unknown variables is 645,577.

![Fig. 1(a) Position of the implement model in the whole analyzed region](Image)

![Fig. 1(b) Elements of whole analyzed region](Image)

In order to create a detailed fluorescent lamp model and to minimize the FEM calculation error of the space in the lamp with large aspect ratio, the electron density distribution is taken into consideration[3][4][5]. The electron density of a discharge tube is described as following equation (15).

\[ n = n_0 J_0 \left( \frac{2.405 R}{r} \right) \] (15)

where, \( n_0 \) is axial electron density, \( J_0(x) \) is the Bessel function, \( R \) is the radius of a discharge tube.

In case of the fluorescent lamp with a radius of 12.5 mm, the electron density normalized with axial electron density is shown in Fig.2. This figure illustrates that the current of actual lamp tube becomes maximum at the central axis and decreases with approaching to the external wall. Based on this electron density distribution, highly accurate fluorescent lamp model is presented. A finite element model is shown in Fig.3. This model is divided into two parts to consider the current distribution, where the integral value of the electron density in the inner part is equivalent to that in the outer part.

![Fig. 2 Electron density distribution](Image)

![Fig. 3 FEM lamp model](Image)

A LISN is modeled on the ground reference plane. And the resistance of 50 \( \Omega \) is set between the terminal of power line and ground reference plane inside the LISN to obtain the inducted voltage. The internal circuit of LISN is shown in Fig.4. The conducted emission is calculated by integrating the vertical component of the electric field on this part.

![Fig. 4 Internal circuit of LISN](Image)
IV. EXPERIMENTAL VERIFICATION METHOD

A method of verifying analyzed results is to compare with the measured conducted emission from the lighting implement. The measurements are conducted in the shielded room. The lighting implement is set on a mounting table whose height is 0.4 m and the power line of 0.8m is wired straight towards the LISN as shown in Fig.5. The LISN ESH2-Z5 manufactured by Rohde & Schwarz, whose operating frequency is from 9kHz to 30MHz, is set on the ground reference plane and conducted emission, common mode voltage, are measured with a spectrum analyzer 8542E produced by Hewlett-Packard, whose operating frequency is from 9 kHz to 29 GHz.

V. IMPROVEMENT OF FEM MODEL

Powerline, that is thought to be influenced by the common mode current, is modeled in detail to calculate displacement current. Basic model of the power line is shown in Fig. 6. Precise model is shown in Fig. 7.

In order to make a precise model, whole meshes should be decreased, therefore, the analyzed region of the shielded room and measurement area is reduced as compared with the basic analyzed region. The comparison of the analyzed region between precise and basic models is shown in Fig. 8. The analyzed boundary condition of the ground reference plane and the back side plane for the LISN are as ground, same as basic analyzed model. Radiation boundary condition are applied to the top and 3 side faces of the analyzed region (except the floor face and one side face). The radiation boundary condition can be considered with no reflection wave from the face.

VI. ANALYZED RESULTS AND DISCUSSION

A. Influence by Power line modeling

Fig. 9 shows the comparison of analyzed and measured conducted emission noise. Analyzed results of precise model of the power line better agree with the measured results than those of the basic model. Displacement current distribution around the power line is shown in Fig. 10. These figures indicate that the accuracy of the analysis is improved with the detailed mesh of the area thought to be influenced by the common mode current. The calculation error of about 5 to 10dB is observed. One of the reasons is considered that the mesh size between lamp line inside the lighting implement and the implement itself is not adequate to calculate the displacement current. The number of elements of these models, unknown variables and CPU time are shown in Table. I.

![Fig. 5 Conducted emission measurement in the shielded room](image)

![Fig. 6 Basic model of the power line](image)

![Fig. 7 Precise model of the power line](image)

![Fig. 8 Comparison of the analyzed region between precise and basic models](image)

![Fig. 9 Comparison of analyzed and measured results when the power line modeling is improved](image)
B. Influence by Analyzed Region

Fig. 11 shows the comparison of analyzed and measured conducted emission noise when the air space is reduced. The analyzed results of reduced region model are almost the same as those of basic region model. The number of elements of these models, unknown variables and CPU time are shown in Table II. This shows that the measurement environment to be analyzed can be miniaturized and CPU time can be shortened to approximately one seventh for this conducted emission analysis.

TABLE II DISCRETIZATION DATA AND CPU TIME

<table>
<thead>
<tr>
<th></th>
<th>Basic Model</th>
<th>Reduced Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of elements</td>
<td>690,609</td>
<td>229,795</td>
</tr>
<tr>
<td>Unknown variable</td>
<td>778,162</td>
<td>288,338</td>
</tr>
<tr>
<td>CPU Time</td>
<td>4h38min</td>
<td>43min</td>
</tr>
</tbody>
</table>

VII. Conclusion

This paper described the technique of multi-scale numerical modeling of conducted emission for the inverter lighting implement placed in a large space of a shielded room employing the 3-D finite element method. The validity of the analysis was clarified through the measurement. The following conclusions were obtained.

1) The common mode current flows mainly on the power line.
2) The power line should be modeled with the proper element size to be able to calculate displacement current.
3) The measurement environment to be analyzed can be miniaturized for the conducted emission analysis.

Consequently, the calculated results using this model were in better agreement with the measurement than those of the previous model in the frequency range from 10 to 30 MHz, thereby showing the validity of the model.

REFERENCES