Analysis on the Shielding Effect of the Power Transformer Tank

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Abstract—The MV/LV transformer without a tank in the underground substation can produce remarkable interference with the computer Cathode-Ray Tube (CRT) displayers above the ground, because of the generated power frequency magnetic field. To resolve such problem, a tank with high conductivity or/and high permeability is needed to enclose the transformer. To evaluate the shielding effectiveness, the finite element method is adopted to calculate the leakage magnetic field outside the transformer tank with different materials. The calculated results show that the steel tank is able to achieve an enormous shielding effectiveness.

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1. INTRODUCTION
The shielding effectiveness of the power transformer is a very important target in transformer design. When the transformer is located near to the computer Cathode-Ray Tube (CRT), even very small power frequency magnetic field intensity can generate remarkable interference. According to the IEC 61000-4-8 (1993) [1], the environment of power frequency magnetic field is defined as five levels based on its magnitude. Different electronic devices can work normally at different level. According to our test, the CRT can not normally display or the screen will dither obviously, when the background magnetic field intensity is greater than 1A/m (or the magnetic flux density is greater than 1.256 µT)—worse than the first level environment [1]. If such sensitive electronic devices locate just above the underground substation, they will be interfered and can not work normally.

Usually, the dry transformers are employed in such MV/LV (Middle voltage/Lower voltage) substations. Therefore, from the engineering point of view, it is not necessary to set any tank to the transformers. However, from the electromagnetic inference point of view, a tank of metal or ferromagnetic material must be set as the electromagnetic shielding. Due to the high conductivity of metal materials, the induced eddy current in the metal tank is large, which can reduce the leakage field outside the tank. Due to the high permeability of ferromagnetic material, the magnetic field is bounded inside the tank, so that the field outside the tank is reduced. By considering such two kinds of behavior together for ordinary materials (e.g., steel), the analysis and the design of the tank become complex. It is almost impossible to calculate the leakage field outside the tank by analytical solutions. In contrast, the numerical computation method must be used to obtain the result of such complex problem.

In this paper, aluminum, steel and an assumptive material with zero-conductivity and a high relative permeability of 10000 are chosen to analyze and compare their shielding effect. The three-dimensional finite element method is adopted to calculate the leakage field outside the transformer tank. The paper is organized as follows: Section 2 introduces the parameter of a MV/LV transformer and its three-dimensional finite element model. Section 3 analyzes the simulation results and compares the shielding effectiveness of tanks with different materials.

2. THE TRANSFORMER AND ITS FINITE ELEMENT MODEL
The data of the concerned three-phase MV/LV transformer is in Table 1. To simplify the finite element simulation model, only the A phase is analyzed. The schematic diagram of the transformer in the underground substation and the cared region is shown in Fig. 1. The thickness of the tank is 2 mm, and the observed line of the cared region is 2 m above the top of the transformer tank.

The finite element method is adopted to calculate the leakage magnetic field outside the transformer tank. Due to the high conductivity of aluminum and steel, the induced eddy current in the tank is large, which can generate magnetic field and ultimately contributes to the shielding effectiveness. Therefore, to correctly evaluate this eddy current effect, the transformer tank region is finely meshed. The meshed model of the transformer and the metal tank are shown in Fig. 2.
3. CALCULATION RESULTS AND ANALYSIS

The leakage magnetic flux density along the observed line is calculated. In order to obtain the shielding effectiveness, the leakage magnetic flux density outside the metal tank is compared with the no-tank situation. In the simulation model, the no-tank situation is calculated by setting the tank material parameter as air. The shielding effectiveness is evaluated by using the reduction ratio of the leakage field, which is defined as follows:

\[ R = \left| \frac{B_{\text{material max}} - B_{\text{air max}}}{B_{\text{air max}}} \right| \times 100\% \]  

(1)

The comparison results of aluminum, steel and material 3 (the assumptive one defined above) are shown in Table 2.

Table 2: Shielding effectiveness of different material tank.

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity (S/M)</th>
<th>Relative Permeability</th>
<th>Maximum B (µT)</th>
<th>Reduction Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0</td>
<td>1</td>
<td>4.20</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>1.03E+07</td>
<td>2.00E+03</td>
<td>0.134</td>
<td>96.81%</td>
</tr>
<tr>
<td>Aluminum</td>
<td>3.80E+07</td>
<td>1</td>
<td>0.219</td>
<td>94.79%</td>
</tr>
<tr>
<td>Material 3</td>
<td>0</td>
<td>1.00E+04</td>
<td>0.647</td>
<td>84.60%</td>
</tr>
</tbody>
</table>

From the results in Table 2, it can be seen that when there is no tank to enclose the transformer, the leakage magnetic flux density in the cared region reaches 4.20 µT, which exceeds 1.256 µT, the first environment level of the IEC 61000-4-8 (1993), so that the display of the computer CRT will be influenced. However, when the transformer is enclosed by the high conductivity metal or the high permeability material tank, the leakage magnetic flux density in the cared region is reduced greatly to be under the value of the first environment level.
In addition, Table 2 shows that both the steel and the aluminum can obtain better shielding effectiveness than Material 3, because the induced eddy current on the high conductivity material tank is large, which can generate inverse direction magnetic flux density to counteract the original leakage magnetic field. Besides, the steel achieves the best among the three materials, which means that the shielding effect of the material with both high conductivity and high permeability is better than the one only with high conductivity, and the one only with high permeability. This is an important conclusion for the power frequency magnetic shielding. The transformer enclosed by such material tanks can maintain the leakage magnetic field in a very small magnitude. Therefore, the computer CRT can be in its normal working status. The leakage magnetic flux density distribution along the observed line is plotted in Fig. 3, which also shows the enormous shielding effectiveness of the materials.

4. CONCLUSIONS

The MV/LV transformer without a tank in the underground substation can generate great leakage magnetic field, which exceeds the value of the first environment level defined by the IEC 61000-4-8 (1993). In this case, sensitive devices such as computer CRT displayers can not display normally near the underground substation. In order to resolve such interference, a tank of high conductivity or/and high permeability is needed to enclose the transformer to shield the leakage magnetic field. Among the three analyzed materials, aluminum, steel and Material 3, the steel tank with both high conductivity and high permeability achieves the best shielding effectiveness. With such tank, the maximum leakage magnetic field in the cared region can be reduced twenty times, so that the field is much smaller than the value of the first environment level.
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REFERENCES