Abstract – Losses in transformer tanks are calculated using finite element method/surface impedance and compared for different magnetic shield heights and widths as well as for different distances from the outer winding to the tank. Loss distribution in the tank is shown.

Introduction

Power transformer tanks are shielded to reduce stray losses and prevent local overheating. Shields of different heights made from aluminium and magnetic material were analyzed in [1] and [2]. Influence of the distances from the winding to the tank on the tank loss was analyzed in [3]. The main goal of this paper was to analyze the parameters influencing the shielding efficiency and to make guidelines for the most efficient and cost-effective shielding solutions in transformer design. In this paper only shields made from transformer core steel are analyzed.

The problem was analyzed on a 300 MVA three-phase three-leg transformer using Infolytica’s MagNet. The transformer tank and the clamping plate were modelled with conductivity $\kappa = 5.5$ MS/m and permeability $\mu_r = 250$. Shields were modelled with simplified characteristics $\kappa = 0$ and $\mu_r = 20000$. The thickness of the shield was 15 mm, and it was placed 5 mm from the tank wall. Surface impedance boundary was used on the tank and on the core clamping plate. The tank’s shape was rectangular. The efficiency of tank shielding was analyzed for different values of: shield height (parameter $\alpha$), shield width (parameter $\beta$) and distance from the outer winding to the tank/shield (parameter $d$). Factor $\alpha$ is the ratio of shield to windings heights, and it varied from 1.2 to 1.5. Factor $\beta$ is the ratio of shield width (i.e. shielded area per phase) to outer winding diameter and it varied from 0.7 to 1.01 (maximum). The distance from the outer winding to the tank/shield was: 200 mm ($d_1$), 300 mm ($d_2$) and 400 mm ($d_3$).

Table 1 – Currents and number of turns of the windings

<table>
<thead>
<tr>
<th></th>
<th>Current [A]</th>
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<tbody>
<tr>
<td></td>
<td>Plus tap (+)</td>
<td>Main tap (0)</td>
<td>Minus tap (-)</td>
</tr>
<tr>
<td>LV 640</td>
<td>-1126,0</td>
<td>-1072,5</td>
<td>-1012,0</td>
</tr>
<tr>
<td>HV 260</td>
<td>373,0</td>
<td>433,0</td>
<td>487,0</td>
</tr>
<tr>
<td>RW 48</td>
<td>1126,0</td>
<td>0</td>
<td>-1012,0</td>
</tr>
</tbody>
</table>

The layout of windings is shown in Figure 1 and the transformer layout in the Figure 2. The distance from the yoke to the top of the transformer is 144 mm. The distance from the regulating winding to the tank wall is parameter $d$, except on the side with the tap changer (Figure 2) where it is 1300 mm. In table 1 numbers of turns and currents in the windings are given. The clamping plate is 6364 mm long, 691 mm high and has a thickness of 35 mm.
Variations of the efficiency of tank shielding (tank loss in per unit of power loss in non shielded tank - $\alpha = 0$) with $\alpha$ for three tap positions are shown in Figure 3. The figure shows results for the $d_2$ (300 mm) distance from the tank.
Figure 3 shows that the loss almost linearly decreases with parameter $\alpha$, and only on relatively high parameter $\alpha$ saturation occurs. It is also clear that the shielding efficiency is different for different tap positions for the same shields.

Variations of the tank loss with $\beta$ and for three tap positions and different $\alpha$ are shown in Figure 4.

![Figure 4 - Variations of p.u. tank loss with $\beta$; for $\alpha$ (1,2 – 1,5) and for distance d2 (300 mm)](image)

The influence of the distance from the outer winding to the tank on the efficiency of shielding is shown in the Figures 5 and 6.

![Figure 5 - Per unit tank loss for different distances to the tank (d), for $\alpha = 1,2$](image)
The previous results were obtained for an ideal shield material without losses ($\kappa = 0$). But some losses occur also in the magnetic shields too. The losses in the shields were estimated in the case of plus tap position with $d_1$ distance from the tank and shield characteristics $\alpha = 1,4$ and $\beta = 1,01$, which is one of the cases with the greatest loss. Shields were supposed to be perpendicularly laminated to the tank wall (Figure 7). The flux distribution inside the shields was calculated and it was taken that the highest allowed induction in the shield is 1,5 T. The material of the shields was grain – oriented steel with 1 W per kilogram at 1,5 T. In this way obtained loss in the shields is about 1,5\% of the loss in the non-shielded tank. For transformer shields laminated parallel to the tank wall (Figure 7) the loss is much higher and depends on the width of the shield package. According to [1] and [4] it can be several times more than for the case of perpendicular design. Therefore for tanks with parallel shield design it could be difficult to obtain shielding efficiency lower of about 10\%.

**Loss distribution**

The distribution of tank loss is important for determining the temperature and possible overheating of the tank. Figures 8 thru 10 show loss distribution of the transformer in the main tap position for $d_2$ (300 mm) distance from the tank. Tank loss distribution on a non-shielded tank is shown in Figure 8A.
In the middle phase the loss is lower because of the influence of the flux of the other phases. The maximum local loss is approx. 1400 W/m² and it is on the lateral side opposite to the tap changer. Loss distribution for a shielded tank with shield parameters $\alpha = 1,4$ and $\beta = 1,01$ is shown in Figure 8B. The point with the maximum loss of approx. 700 W/m² is on the end of the shield near the tap changer on the point of discontinuity of the shields.

![Fig. 8 – Distribution of tank loss (d2) in the main tap position, without shields (A) and with shields for $\alpha = 1,4$ and $\beta = 1,01$ (B)](image)

The distributions of tank loss for $\alpha = 1,4$, $\beta = 0,9$ and 0,7 are shown in Figures 9A and 9B respectively. From Figure 9A it can be seen that by reducing the shield’s width there are no significant changes in the loss distribution, and the total loss does not rise much as well. The maximum loss is approx. 700 W/m². Loss distribution for the lowest $\beta$ (0,7) is shown in Figure 9B. The loss is present in the parts between the phases and the maximum loss rises to 900 W/m².

![Fig. 9 – Distribution of tank loss (d2) for the main tap position for $\alpha = 1,4$ and $\beta = 0,9$ (A) and for $\alpha = 1,4$ and $\beta = 0,7$ (B)](image)

Tank loss distribution for shield parameters $\alpha = 1,2$ and $\beta = 1,01$ is shown in Figure 10. The maximum loss is about 1100 W/m². Although the shield surface is about 20% larger than in the case of shields with parameters $\alpha = 1,4$ and $\beta = 0,7$ the total tank loss and the maximum local loss are much smaller.
Conclusion

The results show that for an efficient tank shielding there are no unique shield parameters. The efficiency of shields depends on tank flux distribution (e.g., the efficiency depends on the shape of winding ampere-turns, windings geometry, relative distance from the windings to the tank). Factor $\alpha$ is more important than factor $\beta$, what means that with the same quantity of shield material it is better to make higher shields than wider ones. Local loss, which causes overheating, is also larger in the cases with smaller parameter $\alpha$ than with smaller parameter $\beta$.

References


