ESTIMATION AND MINIMIZATION TECHNIQUES OF TRANSFORMER TANK LOSSES

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ABSTRACT

Transformers are classified among the most important building blocks of any electric power system network. Enhancing the performance of a particular transformer would positively reflect on the quality of its network. Loss minimization may be regarded as the most crucial aspect on which current design efforts are focussed. While rough estimation of the bulk transformer losses resulting from ohmic and core losses is straight forward, evaluation of other losses resulting from stray flux in transformer copper and iron, both active and non-active, parts is known to be more complicated. The purpose of this paper is to present a detailed study of transformer tank losses. While previous studies mainly focussed on relatively large power transformers, this paper focusses on the stray loss investigation for ratings below 100 MVA in part of comprehensive efforts aiming at maximizing efficiency of such transformers. Using finite-element analysis the aforementioned aspects have been investigated in order to deduce optimum tank configurations. Moreover, effectiveness of tank shield sheets on the overall tank losses have also been investigated.

1. INTRODUCTION

In general, power plant manufacturers are under an ever mounting pressure to produce lower loss power plants for reasons of energy conservation and environmental considerations as well as the obvious money savings. There is no doubt that transformers are classified among the most important building blocks of any electric power system network. Thus, enhancing the overall performance of a particular transformer would positively reflect on the quality of its network.

In a competitively increasing global market economy, loss minimization may be regarded as the most crucial aspect on which current design efforts are focussed (see, for example, [1]). While rough estimation of the bulk transformer losses resulting from ohmic and core losses is straight forward, evaluation of other losses resulting from stray flux in transformer copper

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and iron, both active and non-active, parts is known to be more complicated. Until recently many companies have relied mainly on empirical calculations, either derived experimentally from older designs or from papers dating from as far back as the early part of the century, to determine the stray losses on power transformers[2]. For the majority of standard designs empirical relations have served as good gauges of eddy induced loss but for designs of special transformers or units with very tight specification tolerances the same relations have often proved to be inadequate. More specifically, it can be stated that in general the proper evaluation of stray and/or tank losses requires more sophisticated analytical and computational capabilities including electromagnetic field calculation.

The purpose of this paper is to present a detailed study of transformer tank losses. It is known that these losses result from eddy currents induced by stray flux[3-5]. Consequently, tank losses are affected by several factors such as; core magnetic loading, tank wall shapes and thicknesses, clearance between tank walls and transformer active parts, in addition to tank material magnetic and electric properties. While previous studies mainly focussed on relatively large power transformers, this paper focusses on the stray loss investigation for ratings below 100 MVA in part of comprehensive efforts aiming at maximizing efficiency of such transformers. Using finite-element analysis the aforementioned aspects have been investigated in order to deduce optimum tank configurations. Moreover, effectiveness of tank shield sheets on the overall tank losses have also been investigated. Details of the proposed study are given in the paper.

II. THE ANALYSIS STRATEGY

In order to accurately assess tank losses, a complete and thorough idea concerning leakage flux through every part of each of its six walls should be known. This necessitates carrying out a complete 3D electromagnetic field analysis of the whole transformer zone including its active and non-active constituents. A typical transformer-tank configuration, indicating net clearances between transformer active parts and different tank sides, is shown in Fig. 1.
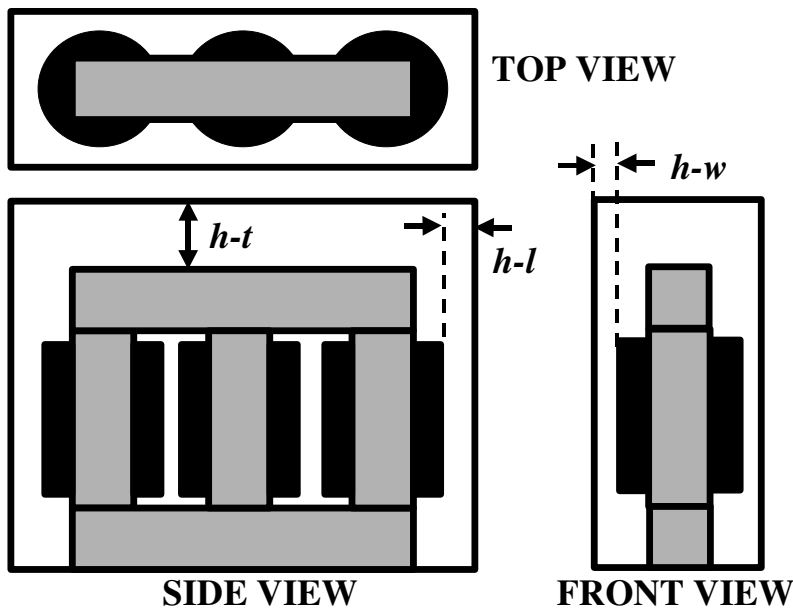

Fig. 1. Typical transformer-tank configuration indicating net clearances between transformer active parts and different tank walls

In Figure 1, the net clearance between the transformer active parts and that tank side, front and top walls have been denoted by h_w, h_l and h_t, respectively.

Based upon this configuration, 3D finite-element electromagnetic field analysis has been utilized to investigate overall tank losses for original and modified dimensions. Moreover, effect of introducing conductive tank wall shields has also been investigated. Sample results of the carried out computational efforts are presented in the following Section.

III. THE COMPUTATION RESULTS

By the aid of a commercially available 3D finite-element package, this task has been performed for a typical 25 MVA, 66/11 KV, D/Y transformer. Tank dimensions and clearances in accordance with Fig. 1, normalized with respect to the long tank side, are given in Table I.

TABLE I
Tank Dimensions And Clearances Normalized With Respect To The Long Tank Side

Tank Length	1.000
Tank Width	0.320
Tank Height	0.643
Net Clearance To Side Wall "h_w"	0.043
Net Clearance To Front Wall "h_l"	0.102
Net Clearance To Upper Wall (i.e. Tank Cover) "h_t"	0.036

For the tank dimensions under investigation, 3D electromagnetic field analysis have revealed that most of the tank losses are concentrated in its side walls as shown in Fig. 2. It can be easily inferred from this figure that the overall tank losses for the original tank configuration is about 2850 W.

Fig. 2. Distribution of tank losses on its different walls for the original tank dimensions.

The impact of varying the net clearances between transformer active parts and various tank walls have also been computationally investigated. Figs. 3-5 show how losses may change as a result of changing h_w, h_l and h_t, respectively, by 5% and 10% from their initial values.
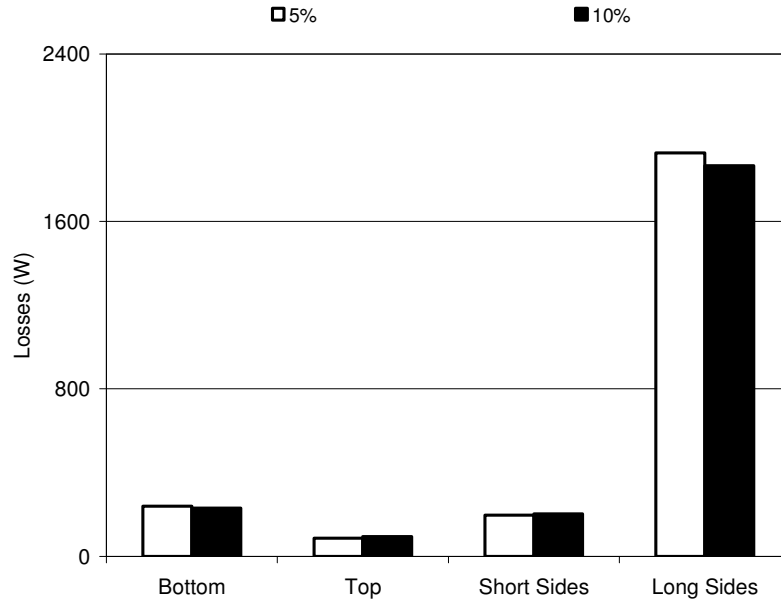

Fig. 3. Distribution of tank losses on its different walls as a result of increasing h_w by 5% and 10%. Overall tank losses are about 2450 W and 2390 W, respectively.
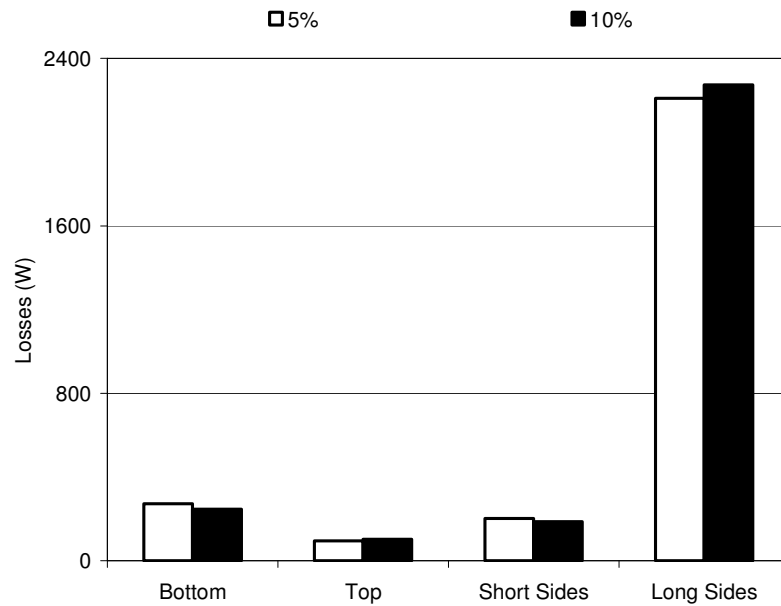

Fig. 4. Distribution of tank losses on its different walls as a result of increasing h_l by 5% and 10%. Overall tank losses are about 2780 W and 2810 W, respectively.
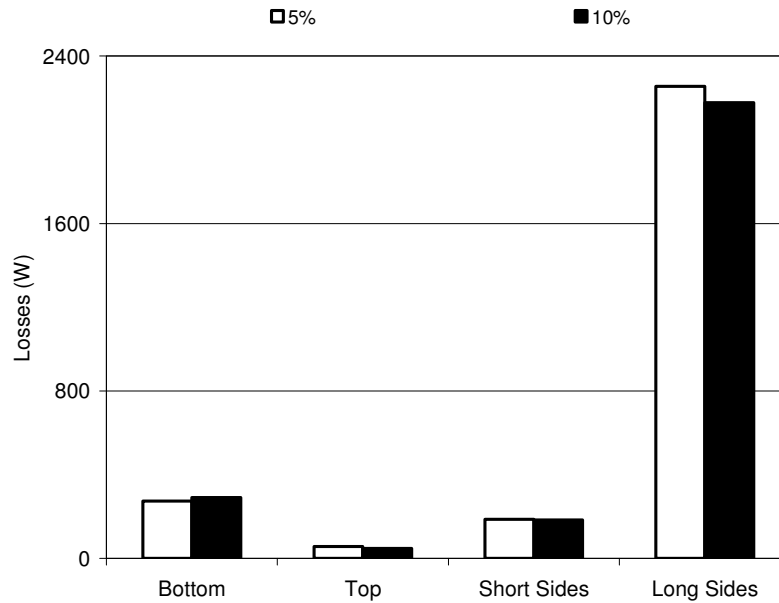
Fig. 5. Distribution of tank losses on its different walls as a result of increasing h_t by 5% and 10%. Overall tank losses are about 2775 W and 2700 W, respectively.

Further computations have been also carried out to investigate the impact of shielding a tank wall by a conductive material. More specifically, the impact of shielding the long tank sides by 3 mm and 5 mm cooper shields were also investigated. Results of these computations are given in Fig. 6.
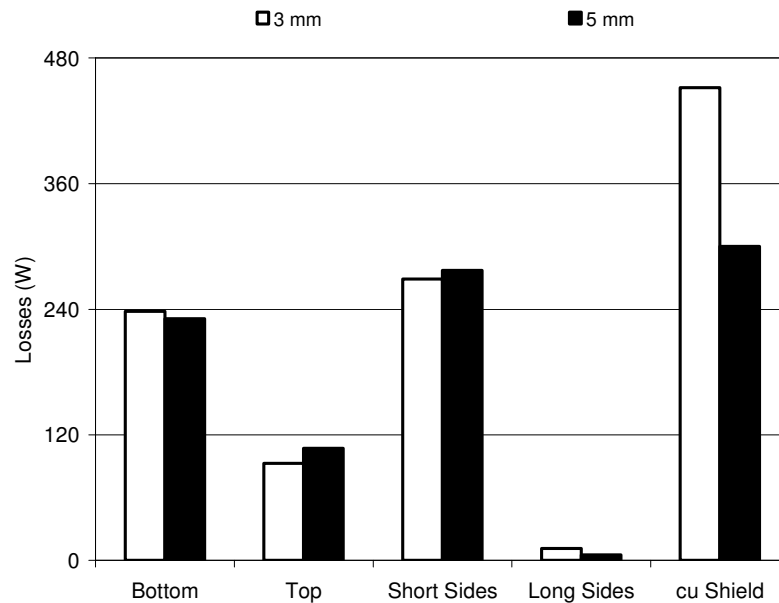

Fig. 6. Distribution of tank losses on its different walls as a result of shielding its long sides by a copper sheets having thickness of 3 mm and 5 mm. Overall tank losses are about 1063 W and 920 W, respectively.

IV. CONCLUSIONS

Many important conclusions can be drawn from the computational results given in this paper. First, it is clear that the bulk of the tank losses are concentrated in the side walls which have the largest surface area as shown in Figs. 2-5. Hence, tank loss minimization should be mainly focussed on the minimization of losses in these sides. Second, while it is always assumed that increasing the clearance between the active parts and a tank wall should reduce the overall tank losses, this assumption might not always be true. More specifically, increasing the clearance with a certain wall should always result in a decrease in this particular wall's losses. However, the increase in this clearance might result in an increase in another wall's dimensions and, consequently, a potential increase in its losses. Net result might be an increase or a decrease in the over all tank losses. This fact is clearly highlighted by results given in Fig. 4, where a further increase in the clearance with the short side resulted in an increase in the losses of the long side that exceeded the decrease in losses of the short side. Third, shielding is extremely effective to dramatically reduce tank losses. However, cost of shield and its loss minimization should be weighed economically. Moreover, the shield thickness is not indicative of its loss elimination capabilities. For instance, Fig. 6 shows that a 3 mm copper shield reduced the overall tank losses from 2850 W to 1063 W (i.e. 62.7% reduction). On the other hand a 5 mm copper shield (i.e. 66.66% increase in the shield thickness) reduced the overall tank losses from 2850 W to 920 W (i.e. 67.7% reduction). This suggests that an optimum shield thickness, both financially and technically, should be investigated while aiming at minimizing tank losses. Finally, it should be stated that future efforts should also be targeted at investigating effects of magnetic shields as well.

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