Reduction of Stray Losses in Tertiary Voltage Bushings in Power Transformer Tanks

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***Abstract*—This paper presents an analysis and computation of stray losses in the tank cover of a 75 MVA three-phase core-type transformer. Stray losses in the region surrounding high current bushings are estimated using 3D Finite Element (FE) simulations. In the considered region the stray losses are high and its reduction is important to avoid the presence of hot spots in the tank cover of power transformer. In this paper, an L-shape non-magnetic Stainless Steel Insert (SSI) is utilized to reduce the stray losses in the region of the Tertiary Voltage Bushings (TVBs) of the transformer. Stray losses in the tank cover are estimated for a level of overload of 30% considering two cases: 1) When there is no SSI and 2) When the SSI is considered. The reduction of stray losses in the tank cover of power transformers helps to avoid the presence of dangerous high temperature spots. Hot spots can degrade the transformer oil and they can produce a potential failure of the equipment during operation.**

Keywords— Stray loss, tank cover, hot spot, Finite Element (FE) simulation, high current bushings, stainless steel plate, impedance boundary, power transformer

I. Introduction

Transformer design should consider avoiding the presence of hot spots in carbon steel structural parts. Low voltage cable leads produce high stray fluxes in the tank of power transformers due to the high current circulating through them. These cables are connected to bushings mounted in the tank walls or cover. High currents produce high stray fields in the vicinity of the bushing holes and this can produce high stray losses and hot spots in these parts of the tank [1]-[5]. In this paper authors analyze the case of tertiary voltage bushings placed in the tank cover.

The use of non-magnetic Stainless Steel (SS) Inserts (SSI) in the part of the tank cover where the high current bushings are mounted can be of great help to reduce stray losses and the presence of hot spots in that region. This solution has also been used to reduce stray losses in tank walls of pad-mounted distribution transformers and in the tank walls of substation transformers [6]-[8]. Different insert geometries can be used for this purpose [9].

Furthermore, distribution transformer manufacturers use non-magnetic SSI to reduce stray losses in tank walls. Inserts have been utilized in tank walls of pole-type distribution transformers, power transformers, and instrument transformers [10]-[14]. There are also manufacturers that cut slots between the bushing holes and these are filled using non-magnetic SS solder. In these cases it is difficult to define the geometry of the SSI used by different manufacturers because they normally polish the welded SSI and if the transformer tank is painted it is not possible to identify the SSI. Although almost all transformer manufacturers used SSI, in general they do not reveal information about it.

Finite element (FE) simulations are a powerful tool for the analysis and identification of stray losses in tank covers, caused by high current bushings in power transformers. In this work numerical computation of stray losses in the tank cover of a power transformer is performed. Authors analyze the use of a non-magnetic inserts in the tank cover in the region where Tertiary Voltage Bushings (TVBs) are mounted.

3D finite element (FE) simulations were performed to calculate the stray losses in the region next to the TVBs of a 75 MVA three-phase core-type transformer. The analysis is done under a 30% overload condition (97.5 MVA) with and without the SSI welded in the tank cover. Linear impedance boundaries were used to model the carbon steel of the tank and permit to compute losses in the tank cover [8]. The highest current in the analyzed transformer is in the TVBs, for this reason, authors decided to compute the stray losses in the region surrounding TVBs.

II. Finite Element Simulations

3D time-harmonic (at 60Hz) finite element simulations with ANSYS Maxwell software [15] were performed to calculate stray losses in the carbon steel tank cover of a power transformer. The analyzed cases are: 1) tank cover without SSI, 2) tank cover with SSI. Linear impedance boundaries were considered in the faces of the tank cover to compute the losses. The characteristics of power transformer under study are shown in Table I. The TVBs region was modeled using a square carbon steel plate of 1.2×1.2 m^2 and thickness c = 0.0127 m. Carbon steel has an electrical conductivity σ_{CS} = 4×10^6 S/m and a permeability μ_{CS} = $200\times4\pi\times10^{-7}$ H/m.

TABLE I
TRANSFORMER POWER CHARACTERISTICS

Transformer rating	75 MVA
Phases	3
Core	Core-type (3 legs)
Connections	HV side: Wye, LV side: Wye, TV: Delta
High Voltage (HV)	115 kV
Low Voltage (LV)	12.47 kV
Tertiary Voltage (TV)	7.2 kV
Cooling	ONAN/ONAF/ONAF

The geometry of the L-shape non-magnetic SSI used in the TVBs region is shown in Fig. 1. Non-magnetic stainless steel has an electrical conductivity σ_{SS} = 1.1×10^6 S/m and a permeability μ_{SS}= $1\times4\pi\times10^{-7}$ H/m. The manufacturers utilize a structural optimization to design the tanks of power transformers [16]-[18]. For this transformer, the optimization method generated a tank design where the bushing holes were assigned to a small region of the cover, where there are limitations of space. Furthermore, the geometry and dimensions of the SSI were optimized taking into account the loss density distribution, but considering as main variable the quantity and cost of stainless steel utilized in the bushing region.

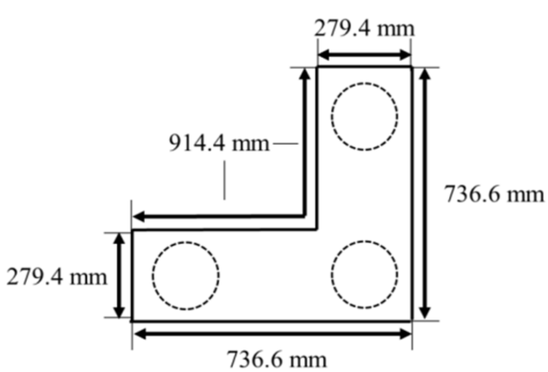


Fig. 1. Geometry of the SSI.

The bushing holes have a radius of 0.08543 m and the separation between them is of 0.4572 m. The copper conductors of bushings have a radius of 0.0254 m. These conductors have a conductivity $\sigma = 58\times10^6$ S/m and a relative permeability μ_r =1. These bushing conductors carry a current I_{bush} = 2.737 kA at 60 Hz for an overload condition of 97.5MVA.

The 3D models utilized in FE simulations are shown in Fig. 2.

Fig. 3 shows the finite element mesh of the model of tank cover with and without SSI. The mesh has a total of 243,000 finite elements.

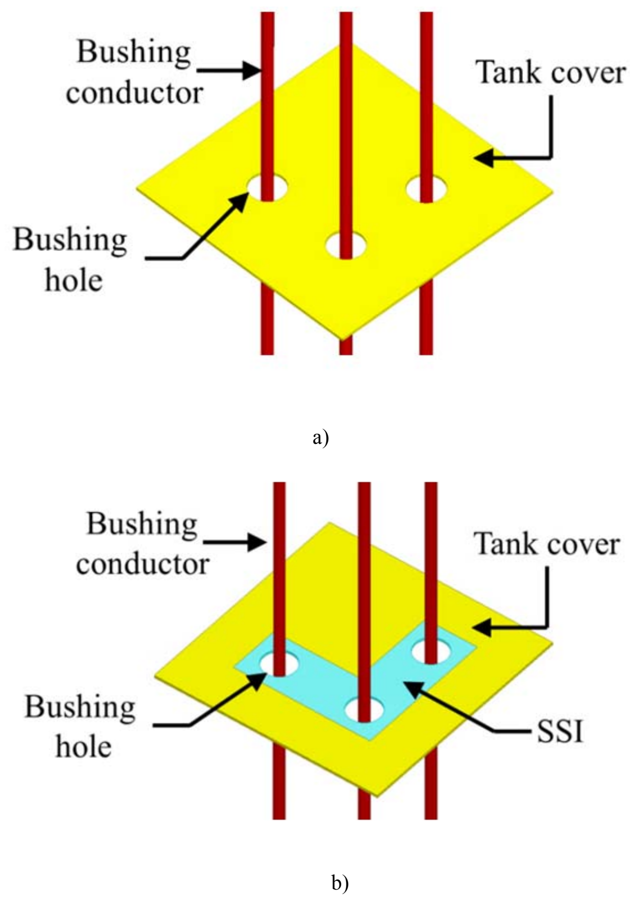
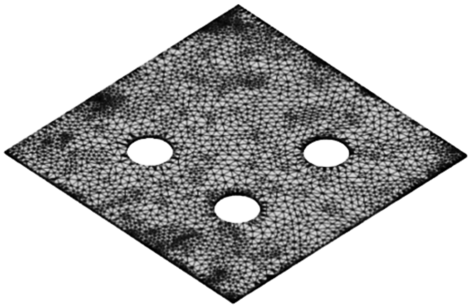


Fig. 2. a) Tank cover without SSI, b) Tank cover with SSI.

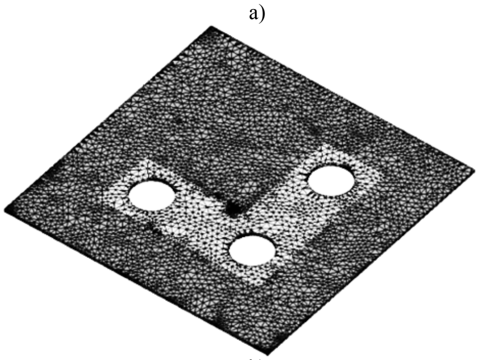
Figs. 4.a and 4.b show the magnetic field strength H distribution at a certain time instant t and the loss density distribution in the bushing region without SSI.

In Fig. 4 one can see a high concentration of magnetic field and losses around bushing holes. A maximum peak magnetic field strength H = 9 kA/m and a maximum loss density of 3.8 kW/m^2 were calculated around holes.

Fig. 5 shows the magnetic field strength distribution at a certain time instant t when the SSI is included, Fig. 6 the stray current losses in the SSI, and Fig. 7 show the loss density distribution in the tank cover.

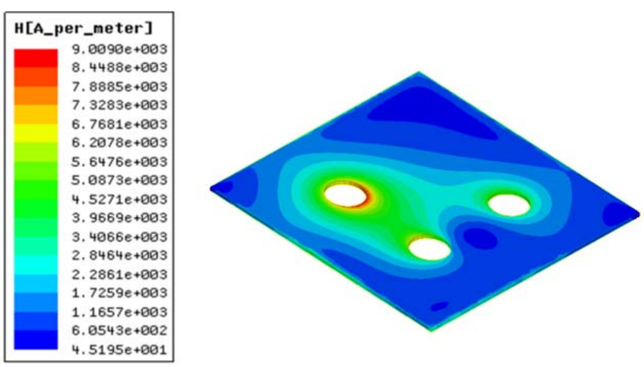


a)

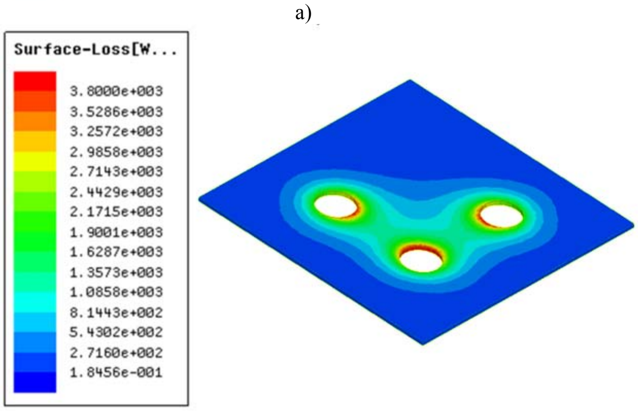


b)

Fig. 3. Finite Element mesh: a) Tank cover without SSI, b) Tank cover with SSI.



a)



b)

Fig. 4. a) Magnetic field strength in (A/m) around the bushing holes region without SSI at a certain time instant *t*, b) Loss density distribution in (W/m^2) around the bushing holes without SSI.

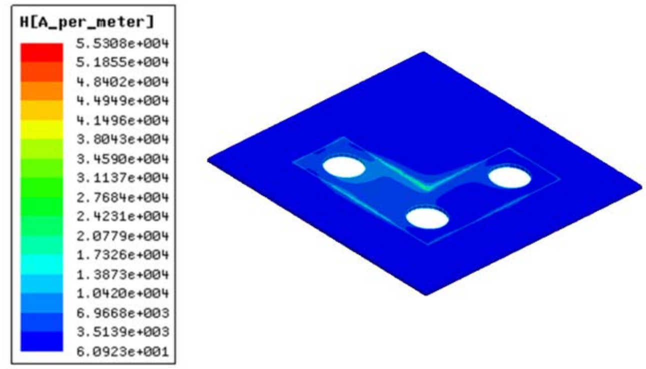


Fig. 5. Magnetic field strength in (A/m) in bushing holes with SSI.

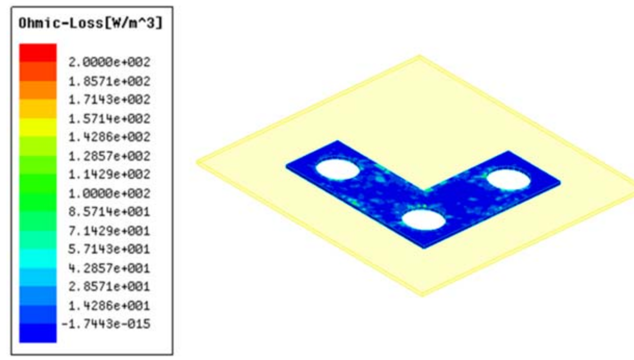


Fig. 6. Eddy stray losses distribution in SSI.

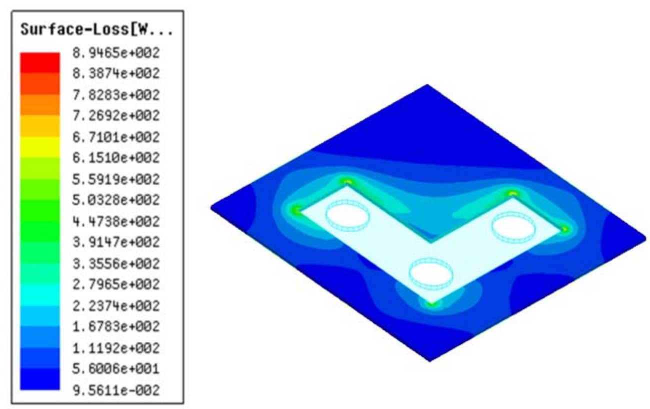


Fig. 7. Loss density distribution in (W/m^2) in tank cover with SSI.

If Fig. 7 and Fig. 4.b are compared it can be seen that the stray losses in the tank cover decrease when the SSI is considered in the tertiary voltage bushing regions.

Table II shows the stray losses calculated in FE simulations.

TABLE II. STRAY LOSSES COMPUTED IN FE SIMULATIONS: (1) TANK COVER WITHOUT SSI, (2) TANK COVER WITH SSI

Simulation	Loss (SSI) (mW)	Loss(cover) (kW)	Total (kW)	% Reduction
(1)	–	1.227	1.227	0
(2)	99	0.2088	0.209	83

A stray loss of 1.227 kW was obtained in the tank cover without SSI.

The stray losses in the region of bushing were decreased when the SSI is considered. A stray loss of 0.2088 kW was obtained in the cover of power transformer and a small stray loss of 99 mW was obtained in the non-magnetic SSI.

A loss reduction of 83% was obtained in the cover using a non-magnetic SSI in the region surrounding the bushing holes.

III. Parametric Finite Element Analysis

A parametric FE analysis was performed to calculate the stray losses in the tank cover with and without a non-magnetic SSI. The current in the bushing was varied from 0 to 20 kA.

Fig. 8 shows the obtained stray losses in the tank cover region where the TVBs are mounted for three bushings and both cases: with and without non-magnetic SSI. As it can be seen in this figure the stray losses increase when the current in the bushings is increased for both cases. Stray losses of around 3 kW were obtained for I_{bush} current of 4 kA when no SSI is installed in the cover. On the other hand, losses of around 3 kW were also found for I_{bush} current of 10.5kA with SSI. These results indicate that, hot spots can be avoided even when high currents flow in the bushings if SSI is installed in the tank cover. Moreover, the utilization of SSIs in tank covers permits high currents in the bushing regions without overheating problems.

Fig. 9 shows the stray losses in the SSI, calculated using FE simulation, it can be seen that stray losses are low in the SSI even when bushings currents are high. A bushing current I_{bush} = 20 kA resulted in an average stray loss of 5 W in the SSI.

With the results shown in Table II and Figs. 8 and 9 one can see the high effectiveness of the use of non-magnetic SSIs in power transformers in regions of high current bushings.

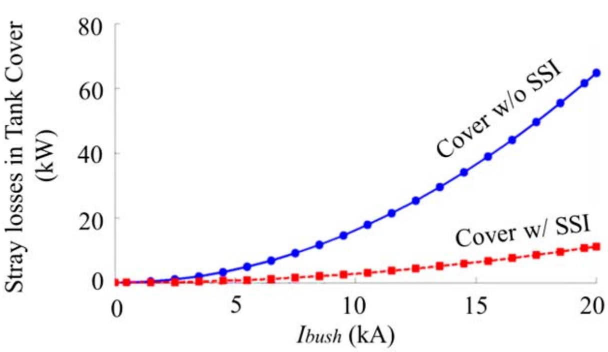


Fig. 8. Stray losses with (w/) and without (w/o) SSI in tank cover.

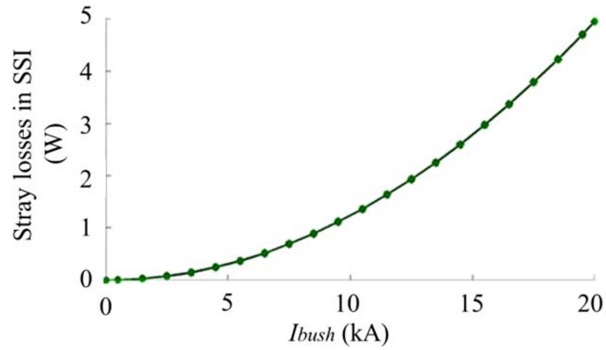


Fig. 9. Stray losses in the SSI.

IV. Conclusions

FE simulations were performed to calculate the stray losses in the tank cover of a power transformer in the region close to the high current bushings. Stray losses were computed in the region of TVBs under overload condition (30%). The tank cover was analyzed with and without non-magnetic stainless steel plate.

High stray losses were found in the TVBs region. In order to reduce stray loses a non-magnetic SSI was welded in the tertiary voltage bushings region. The loss reduction obtained using a non-magnetic SSI in transformer cover was of 83%.

Stray losses in the tank cover with and without SSI for a wide range of electric currents in tertiary voltage bushings of power transformers were calculated using parametric FE simulations. The reduction of this type of losses when using SSI in tank covers of power transformers was verified.

Results show that the use of non-magnetic SSI in the TVB region for currents I_{bush} > 4 kA will help to avoid heating problems and the presence of hot spots in the tank cover of power transformers. Authors recommend including in the design methodology the analysis of the stray losses in the regions where conductors carrying high currents are close to the tank walls (low voltage bushings).

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