Investigation of the thermal impact of stray losses at the high-current LV exit region on the transformer tank wall in GSU transformers

Part II

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ABSTRACT

In high-power Generator Step-Up (GSU) transformers, the high currents carried in the low-voltage (LV) exit region generate intense leakage magnetic flux, which induces stray losses on the tank wall and structural components. Even when total load losses remain within acceptable limits, local stray loss density in compact designs may lead to significant temperature rise and long-term thermal reliability risks.

In this study, stray losses occurring on the tank surface due to leakage flux at the LV exit region of a 730 MVA GSU transformer are investigated under three different design scenarios. The results show that, without altering the compact structural configuration, appropriate material selection and magnetic shunt modification can significantly reduce local loss density and improve thermal performance.

KEYWORDS:

stray losses, transformer tank, GSU transformers

In this study, the effect of the low-voltage turret conductors on the tank cover in their vicinity is analyzed by means of FEM Multiphysics analyses

Table 2. Design parameters of the transformer

Rated power (MVA)	730	
Connection type	YNd5	
Cooling system	ONAN / ONAF / ODAF	
Core leg type	3 / 2	
Frequency (Hz)	50	
Core material	30 PH 110	
	HV Side	LV Side
Rated voltage (kV)	450-400-325	21
Rated Current (kA)	0,937-1,054-1,297	20,07

3. Transformer model and analysis methodology

3.1. Transformer description

The main design parameters of the 730 MVA GSU transformer investigated in this study are given in Table 2.

In this study, the effect of the low-voltage turret conductors on the tank cover in their vicinity is analyzed by means of FEM Multiphysics analyses.

3.2. Finite element methodology simulation model development

In this study, a three-dimensional finite element model of a 730 MVA, 400/21 kV, three-phase, five-limb power transformer is developed. The modeling process is designed to investigate the effect of the leakage magnetic field generated at maximum current level on the tank surface around the turret conductor region.

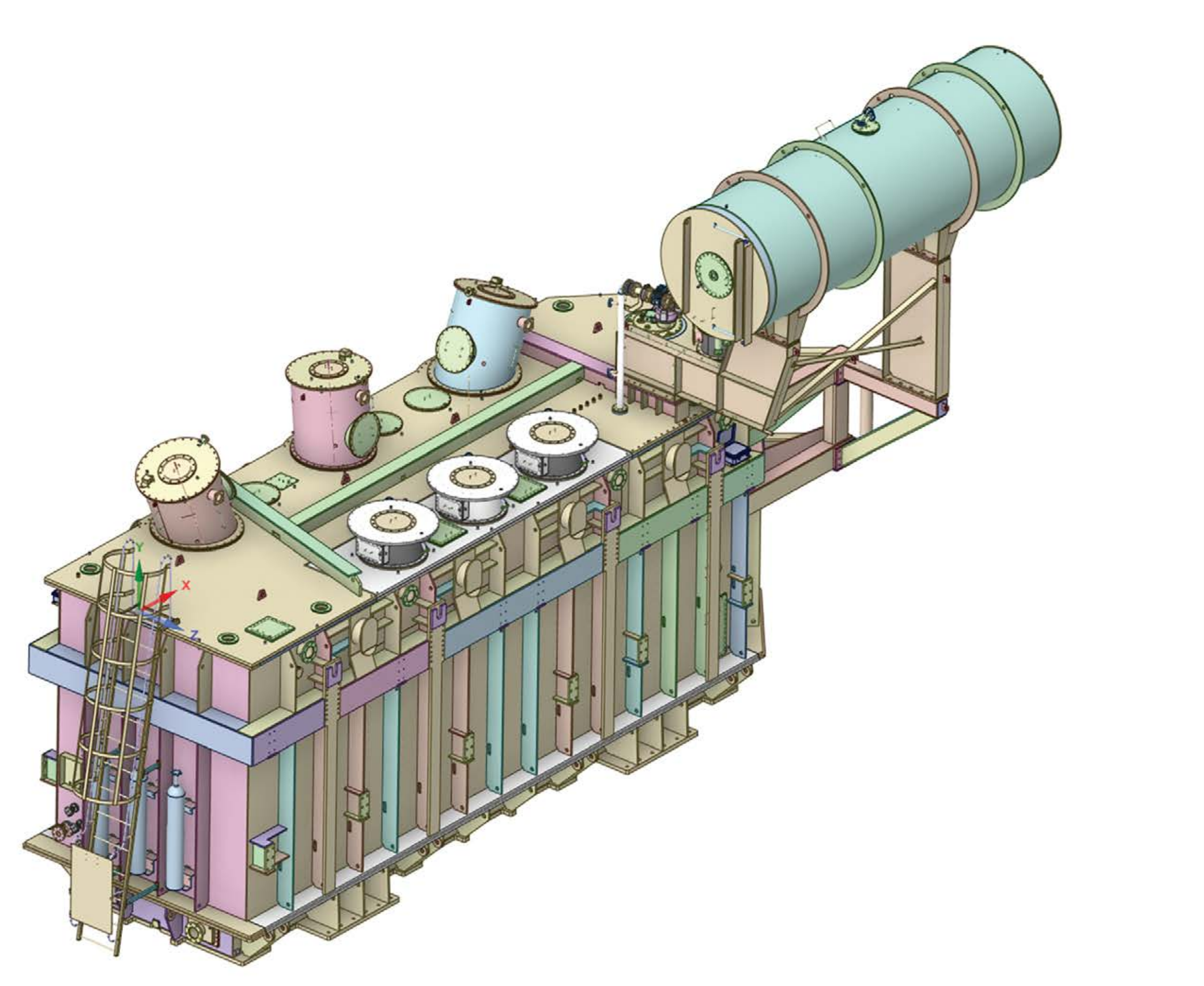

Figure 2. 730 MVA GSU transformer 3D model

In particular, the conductor region in the low-voltage turrets is modeled in detail, and the local mesh density in this region is increased in order to accurately represent the possible magnetic field concentration. The analysis is carried out in 3D.

The solution type is eddy current analysis, and the operating frequency is defined as 50 Hz. Phase currents are defined as RMS values. The modeling workflow diagram is shown in Figure 4.

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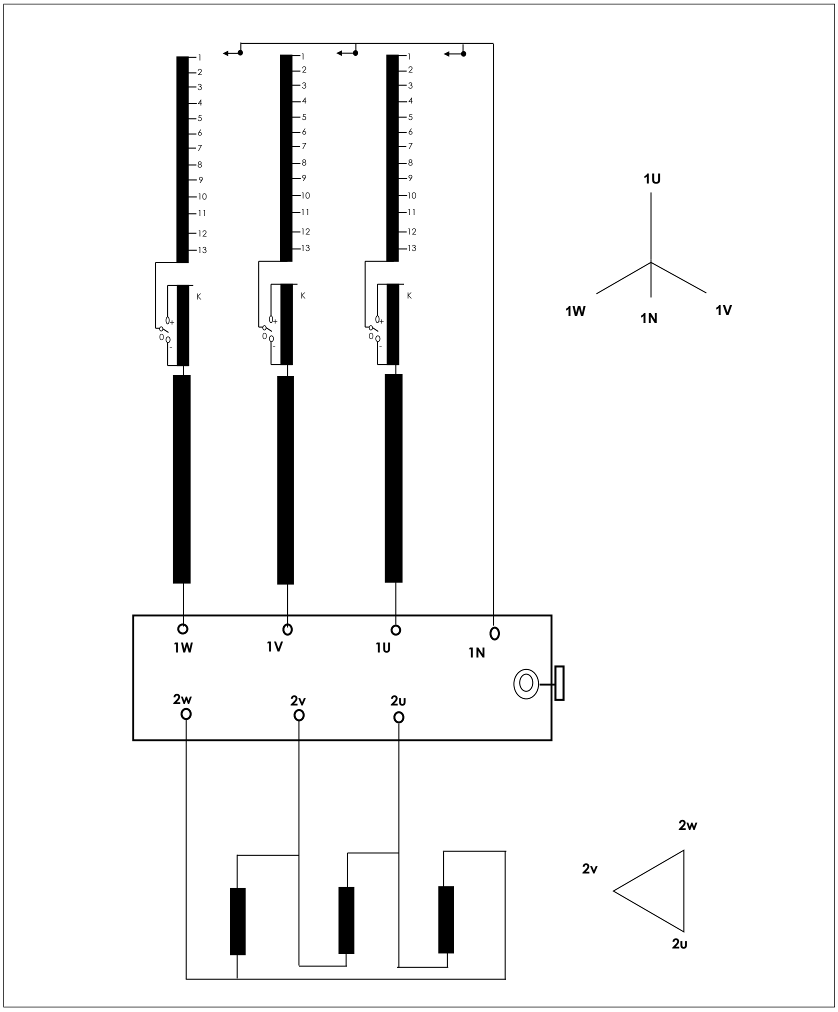

Figure 3. Connection diagram

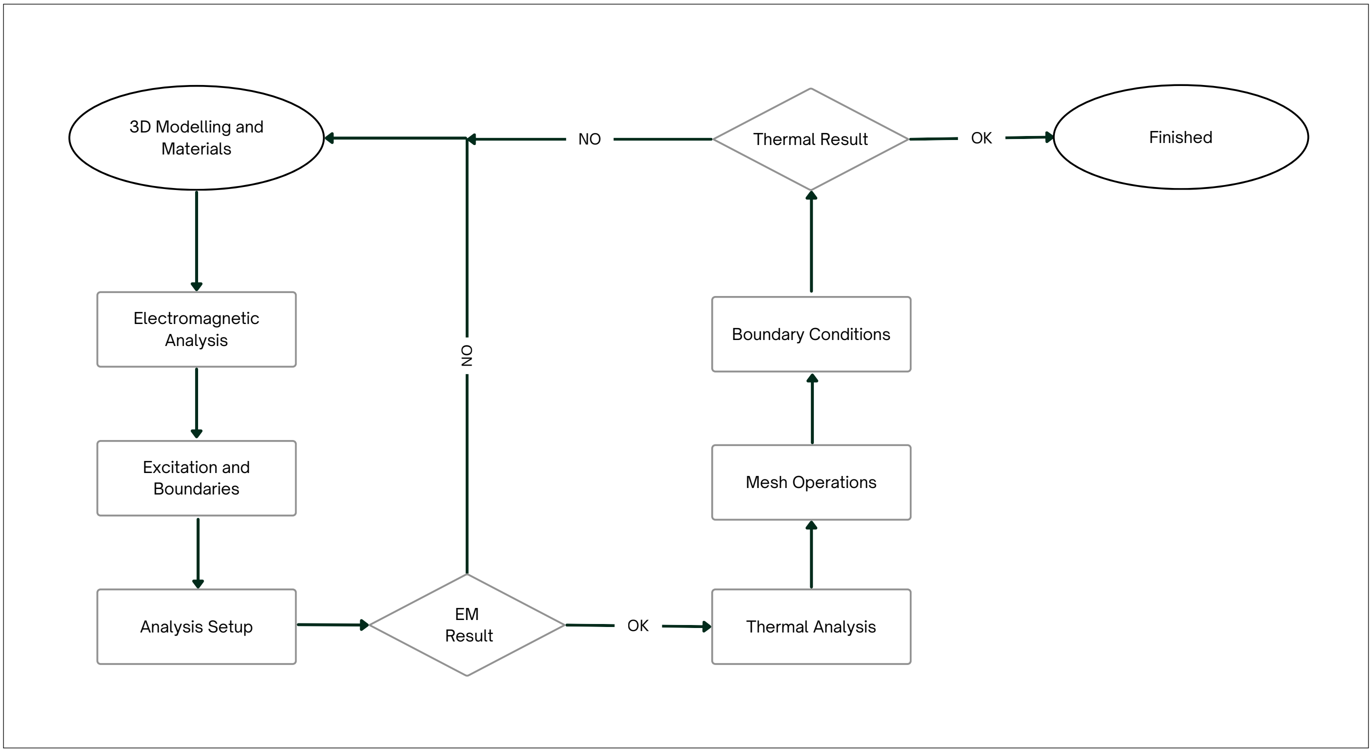

Figure 4. Modeling workflow diagram

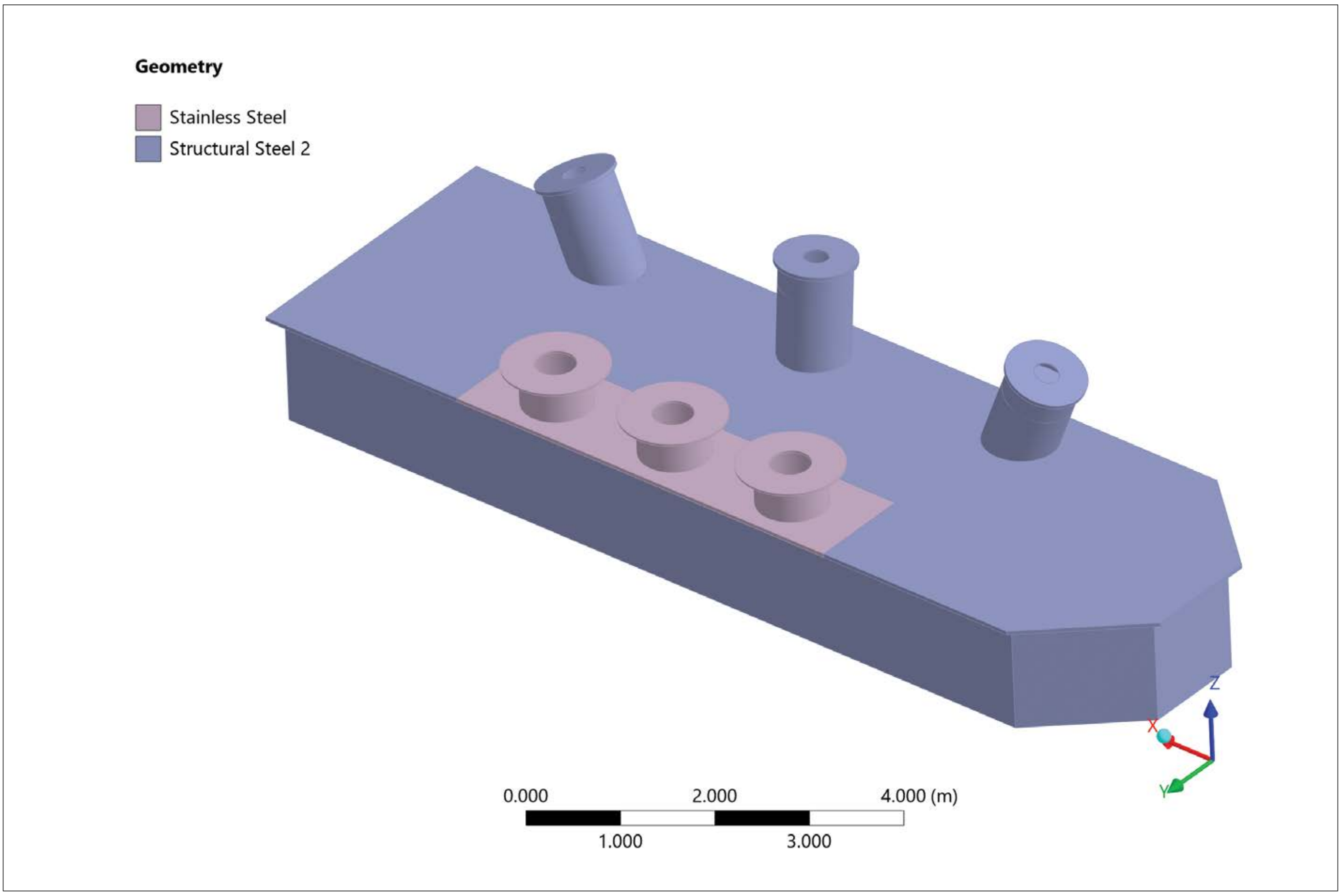

Figure 5. First case tank material structure

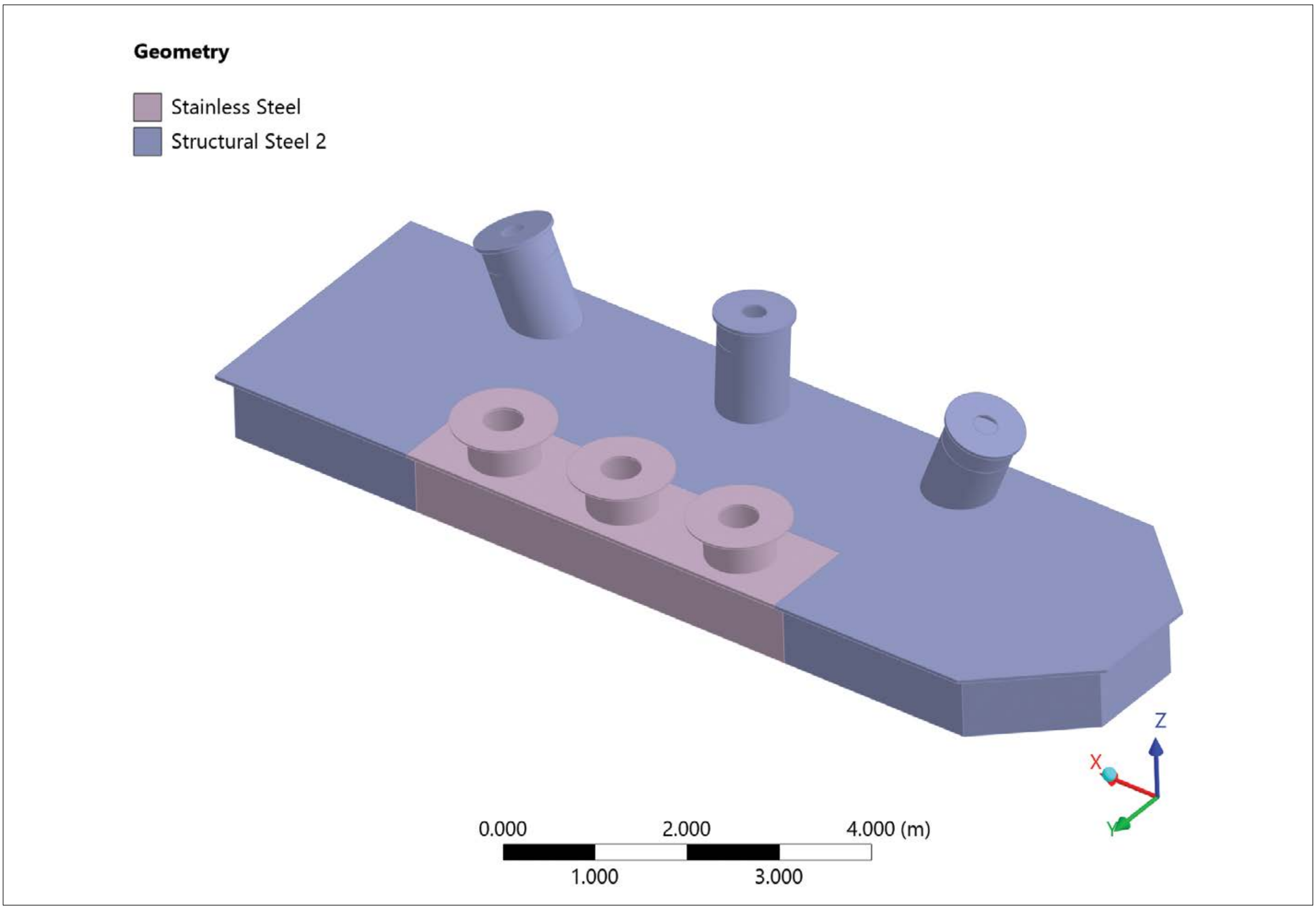

Figure 6. Final case tank material structure

3.3. Electromagnetic analysis

The electromagnetic analysis is carried out at the maximum current level. The windings are excited under current-controlled conditions, phase currents are defined as peak values, and the phase shifts are 120°.

For all three cases, the electromagnetic loss distributions obtained from the FEM analysis are used as heat generation sources in the thermal model

As a result of the solution, magnetic flux, eddy current density, and loss distributions are obtained. Due to the high current on the LV side, flux lines are concentrated in the conductor region. This concentration leads to an increase in local eddy currents in the turret region and consequently to an increase in loss density.

In Case 1, as shown in Figure 5, flux lines are concentrated in the turret region due to the material, and local loss increases are identified. In Case 2, as shown in Figure 6, with the use of a different material, the magnetic field guiding effect in this region decreases and differences in the loss distribution are observed. However, in this case, the flux spreading behavior toward other regions of the tank changes. In Case 3, a reduction in losses is observed by increasing the magnetic shunt thickness.

For all three cases, the electromagnetic loss distributions obtained from the FEM analysis are used as heat generation sources in the thermal model. The electromagnetic analysis results are transferred to the thermal analysis as heat generation sources.

In the first case, the material configuration of the tank in the analyzed model is given in Figure 5.

In the Final case, the material configuration of the tank in the analyzed model is given in Figure 6. In order to reduce the temperature rises on the side wall, the material is changed. Since the temperature rises are observed near the upper region, the wall height is reduced and during the analysis the mesh density is shifted toward this region.

3.3.1. Thermal analysis

The thermal analysis is carried out by transferring the volumetric and surface loss densities obtained from the electromagnetic solution to the model as heat generation terms. A steady-state solution is applied.

Both radiation and natural convection boundary conditions are applied on the outer surfaces of the tank. The surface emissivity is defined according to the paint properties, and the air convection coefficient is introduced into the model as temperature dependent. The ambient temperature used in the thermal analysis is defined as 40 °C according to the technical specification. Wind effects and solar radiation are not considered in the present model, since the analysis focuses on the thermal impact of stray losses under controlled ambient conditions. The surface loss density obtained from the electromagnetic analysis is balanced with the total heat flux transferred to the ambient.

On the inner surfaces of the tank in contact with oil, the internal fluid is not modeled directly; instead, an equivalent local heat transfer coefficient approach is used. The ambient and the top and bottom oil temperatures are determined by formulas in the IEC 60076 standard and by the design tools created by BEST Transformer Company. Heat transfer at the inner surfaces is modeled using an effective convection coefficient representing natural oil circulation. The variation of the oil-side convection coefficient with temperature difference is shown in Figure 7, and this curve is used to define the boundary condition in the model.

The temperature distributions obtained for all three cases are compared. The

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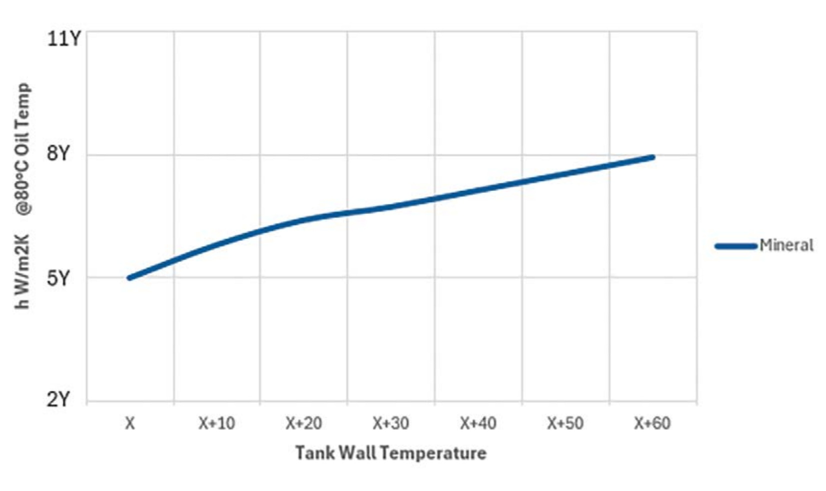


Figure 7. Convection coefficient/temperature chart

> **Changes in tank material and magnetic shunt geometry are observed to produce differences in the temperature distribution in parallel with the variation in electromagnetic loss distribution**

maximum surface temperature and local hot spot distribution in the turret region are evaluated. Changes in tank material and magnetic shunt geometry are observed to produce differences in the temperature distribution in parallel with the variation in electromagnetic loss distribution.

This conjugate analysis demonstrates that material selection in the turret conductor region and the magnetic shunt geometry on the LV side are decisive for both electromagnetic losses and thermal performance.

4. Finite element analysis simulation results

As a result of the studies conducted, high losses occurring on the tank wall in the vicinity of the high-current low voltage conductor in the GSU transformer are observed using ANSYS Maxwell, and the local temperature rises caused by these losses are examined using ANSYS Mechanical [15].

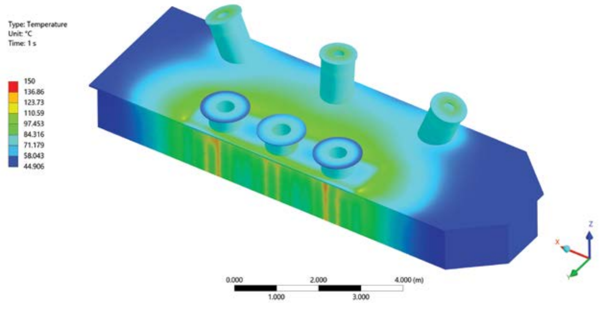
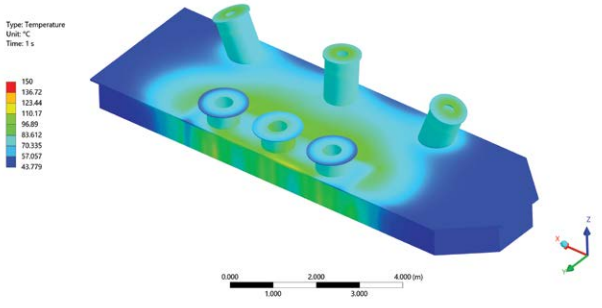
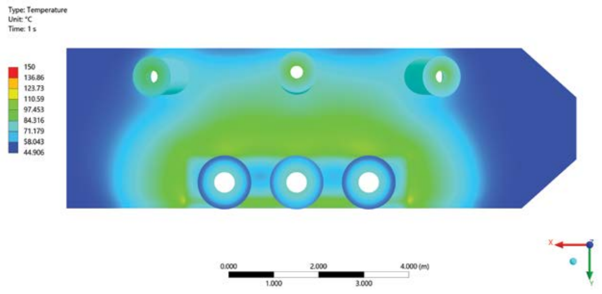
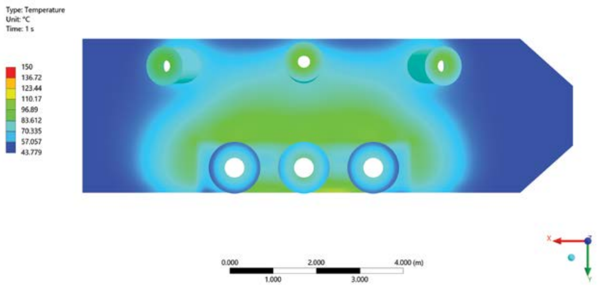
For all three cases, the analyses performed with ANSYS Maxwell show that the losses in the region investigated in the study decrease by approximately 53% between the first and the last case. The temperature distributions in the investigated region resulting from these losses are given in Table 3. When a 53% reduction in losses is achieved through the implemented improvements, the relative difference between the hot-spot temperature and the top-oil temperature rise decreases by approximately 37% between the first and the last case.

5. Conclusion

In GSU transformers, while maintaining a compact design, controlling the local stray losses occurring in the high-current LV turret region is critical for reliable transformer operation. In this study, the electromagnetic and thermal effects occurring on the tank wall are evaluated under three different cases.

In the first case, the local temperature rises under the existing magnetic struc-

Table 3. Comparison of temperature distributions

First case isometric view	Last case isometric view
	
First case top view	Last case top view
	

tural material are evaluated. In the second case, only the structural material in the LV turret region is replaced with stainless steel, and the loss density associated with the leakage flux distribution is analyzed. In the third case, the magnetic shunt thickness on the LV side is increased in order to reduce the losses on the tank surface through the flux guiding effect.

The electromagnetic analyses are carried out using the three-dimensional finite element method, and the obtained loss distributions are transferred to the thermal model. In the final case, it is determined that even at a rating of 730 MVA and current levels exceeding 20 kA, the local temperature rise remains below critical insulation limits. The results show that different material selection in the LV side of tank wall region and modification of the magnetic shunt thickness are effective design parameters for ensuring thermal performance while preserving the compact structure.

For all three cases, the analyses performed with ANSYS Maxwell show that the losses in the region investigated in the study decrease by approximately 53% between the first and the last case

6. References

[1] Krishnavel, Alagarsamy, Dusmata Kumar Mohanta, and M. Jaya Bharata Reddy. "Well-being analysis of GSU transformer insulation incorporating the impact on power generation using fuzzy logic." *Frontiers in Energy* 7.3 (2013): 288-299.

[2] CIGRE, *Technical Brochure 455: [Guide for Transformer Maintenance]*, France, 2011.

[3] Sermsukroongsakul, Surin, et al. "A study of remaining lifetime assessment of generator step-up transformer using degree of polymerization." *2019 IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia)*. IEEE, 2019.

[4] Kulkarni, Shrikrishna V., and S. A. Khaparde. *Transformer engineering*. Vol. 1. New York: Marcel Dekker, 2004.

[5] Reddy, Ankireddypalli S., and M. Vijaykumar. "HOTTEST SPOT AND LIFE EVALUATION OF POWER TRANSFORMER DESIGN USING FINITE ELEMENT METHOD." *Journal of Theoretical & Applied Information Technology* 4.3 (2008).

[6] Mikulić, Stipe, and Damir Žarko. “Stray Losses in Structural Components of Power Transformers.” *Energies* 19.2 (2026): 322.

[7] ANSYS Inc., C.P.U., Available at: www.ansys.com [Accessed 26 February 2026].

[8] S. Magdaleno-Adame, “Detection and reduction of high temperature in high current turrets of generator step-up (GSU) transformers – Part I,” Transformer Magazine, vol. 9, no. 2, pp. 108–116, Apr. 2022.

[9] S. Magdaleno-Adame, “Detection and reduction of high current turrets of GSU transformers – Part II,” Transformer Magazine, vol. 9, no. SE1, pp. 88–95, May 2022.

[10] Sitar, Robert, and Žarko Janić. “Determination of local losses and temperatures in power transformer tank.” *Journal of Energy: Energija* 67.3 (2018): 0-0.

[11] Dağlı, İrem, et al. “TRANSFORMATOR BAĞLANTI İLETKENLERININ TANK KAPAĞINDA OLUŞTURDUĞU KAYIPLARIN AZALTILMASI.” (2022).

[12] Altay, Ramazan, et al. “Investigation of magnetic wall shunt combinations on 650 MVA power transformers by finite element methods.” *Transformers Magazine* 11.2 (2024): 94-102.

[13] Çeçen, Mehmet, Bilal Gümüş, and İrem Hazar. «Determining the Positions and Dimensions of Horizontal Magnetic Shunts in Transformer Tank Walls Using Parametric Analyses Based on the Finite Element Method.» *Applied Sciences* 14.16 (2024): 6930.

[14] JFE Steel Corporation, *JFE Electrical Steel Sheets Catalogue*, Tokyo, Japan.

[15] Souza Melo, André de, et al. “Identifying hot spots in GSU power transformers using multiple methods.” *IET Science, Measurement & Technology* 14.2 (2020): 233-240. ■

PEER REVIEWED

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