

Geometry optimization of magnetic shunts in power transformers based on a particular hybrid finite element – boundary element model and sensitivity analysis

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Abstract –In the present paper, the influence of magnetic shunt geometry on the transformer leakage field and short-circuit impedance is examined. The magnetic field computation is conducted with the use of a particular hybrid finite element-boundary element formulation, facilitating the parametric investigation of magnetic shunt effects through application of appropriate boundary conditions. A design sensitivity analysis for the optimization of the shunt geometry ensuring a desired change in short circuit impedance has also been developed, in conjunction with the proposed magnetic field model.

TRANSFORMER MODEL BASED ON A PARTICULAR HYBRID FINITE ELEMENT-BOUNDARY ELEMENT TECHNIQUE (FEM-BEM)

For the transformer magnetic field simulation, a particular hybrid FEM-BEM formulation was adopted. Figure 1 illustrates the three-dimensional one phase part model of the considered three-phase, wound core power transformers, consisting of the Low Voltage (LV) and High Voltage (HV) winding of one phase as well as the iron core parts that surround them. The model proposed represents two regions:

- 1) the active part (FEM region), by a tetrahedral finite elements. A scalar potential formulation, necessitating no prior source field calculation [1] is used for the derivation of the magnetic scalar potential Φ in the mesh nodes.
- 2) the area between the active part and the tank walls (BEM region), represented by triangular boundary elements.

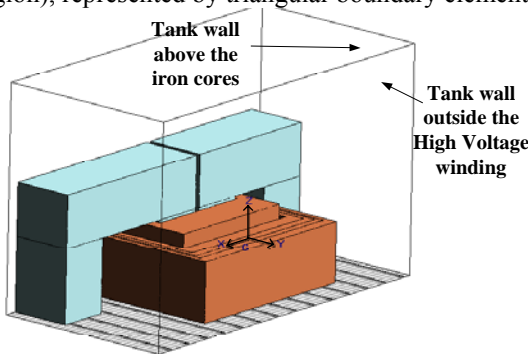


Fig. 1 Perspective view of the transformer one phase part modeled.

GEOMETRY OPTIMIZATION OF MAGNETIC SHUNTS
BY USING SENSITIVITY ANALYSIS

In cases where the difference between the actual (measured) and specified transformer short-circuit impedance value does not satisfy the limitations imposed by international standards [2], design modifications should be implemented in order to meet the specifications. Appropriate magnetic shunts placed along the transformer tank walls can increase the magnetic leakage field and the winding leakage inductance.

The proposed hybrid FEM-BEM technique has been used for the transformer leakage field evaluation and its variation due to the introduction of magnetic shunts. Table I summarizes the simulated short-circuit impedance (U_k) results for a 400 kVA, 20-15 kV/400V transformer by using a coarse (comprising 2.000 elements) and a dense mesh (comprising 90.000 elements). Although only the dense mesh provides accurate results with respect to the measured value of U_k , the coarse mesh provides acceptable accuracy for U_k variations due to the magnetic shunts. An investigation of the influence on U_k of the shunt distance from HV windings for the first type of shunt of Table I has also been conducted, and the respective results are shown in Fig. 2.

Table I. Short-circuit impedance value for different geometry of magnetic shunt on a 400 kVA transformer

Geometry of magnetic shunt	U_k (%)	
	Coarse mesh	Dense mesh
Initial value (no shunt)	7.43	6.75
Magnetic shunt on the tank wall near the HV winding	7.60	6.92
Magnetic shunt on the tank walls near the HV winding and above the iron cores	7.71	7.02

Based on the hybrid FEM-BEM computation of the transformer leakage field, the optimal configuration of the magnetic shunt geometry can be derived through sensitivity analysis. The objective function to be minimized is of the form:

$$F = (U_k^{\text{calculated}} - U_k^{\text{specified}})^2 \quad (1)$$

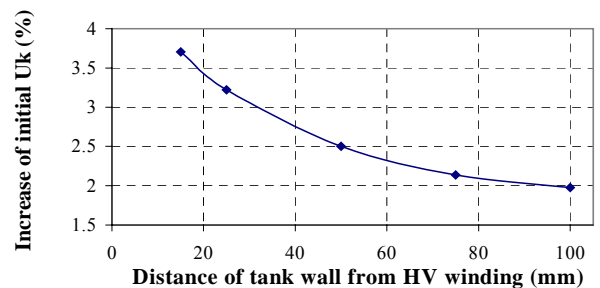


Fig. 2. Short-circuit impedance variation with the distance of magnetic shunt placed on the tank wall.

REFERENCES

- [1] A. Kladas, J. Tegopoulos, "A new scalar potential formulation for 3D magnetostatics necessitating no source field calculation," *IEEE Trans. Magn.*, vol. 28, pp. 1103-1106, 1992.
- [2] IEC 60076-1, "Power transformers – Part 1: General," 2000.