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Numerical Techniques for Design and Modelling of Distribution Transformers

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Abstract. Power transformer analysis and design focussing on the equivalent circuit parameter evaluation by magnetic field numerical calculation is presented. The proposed method adopts a particular reduced scalar potential formulation enabling 3D magnetostatic problem solution. This method, necessitating no source field calculation, in conjunction with a mixed finite element – boundary element technique, results in a very efficient 3D numerical model for power transformer design office use. Computed results are validated through measurements. Such a methodology is very promising for investigation concerning losses and short circuit voltage variations with the main geometrical parameters.

1. Modeling Techniques

Numerical modeling techniques are now-a-days well established for power transformer analysis and enable representation of all important features of these devices [1,2]. More particularly, techniques based on finite elements present interesting advantages for nonlinear characteristics simulation. The leakage inductance evaluation has been extensively analyzed, as well as eddy current loss in transformer tank walls, iron lamination characteristics and design considerations. Moreover, the combination of boundary and finite elements is widely used for electromagnetic problems since the electromagnetic field is not only confined to the conductors but it expands over extensive parts of air, where the use of a boundary element representation can significantly decrease the computational effort [5,6].

In the present paper a particular scalar potential formulation has been developed, enabling the 3D magnetostatic field analysis. According to our method the magnetic field strength H is conveniently partitioned to a rotational and an irrotational part as follows [3]:

$$\mathbf{H} = \mathbf{K} - \nabla\Phi \qquad (1)$$

where Φ is a scalar potential extended all over the solution domain while **K** is a vector quantity (fictitious field distribution), defined in a simply connected subdomain comprising the conductor, that satisfies Ampere's law and is perpendicular on the subdomain boundary.

The boundary element method is derived through discretization of an integral equation that is mathematically equivalent to the original partial differential equation. The boundary integral equation corresponding to Laplace equation is of the form:

$$c(s)\Phi(s) + \oint_{\Gamma}\left[\Phi(s)\frac{\partial G(s',s)}{\partial n} - G(s',s)\frac{\partial \Phi(s')}{\partial n'}\right]ds' = 0 \qquad (2)$$

where s is the observation point, s' is the boundary Γ coordinate, n' is the unit normal and G the fundamental solution of Laplace equation in free space. Therefore, the matrix form of the equations corresponding to a coupled finite element/boundary element solution domain is partially diagonal dominant sparse and partially orthogonal.

2. Results and Discussion

The proposed reduced scalar potential formulation has been applied in the 3D numerical analysis of a transformer under short circuit for its leakage reactance calculation. The case of the one phase part of a 1000 kVA, two tap 20-15kV / 400V three phase shell type power transformer, shown in Fig. 1, has been considered. Fig. 2 illustrates the perspective view of the one-phase transformer part modeled.

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The field values computed by the proposed 3D formulation (Fig. 4) have been compared to those measured by a Hall effect probe during short-circuit test. Fig. 3 gives the variation of the perpendicular flux density component B_n along the line AB, positioned as shown in Fig. 2, in case of short-circuit with the high voltage winding connections corresponding to 20 kV voltage supply. This figure illustrates the good correlation of the simulated results with the local leakage field measurements.

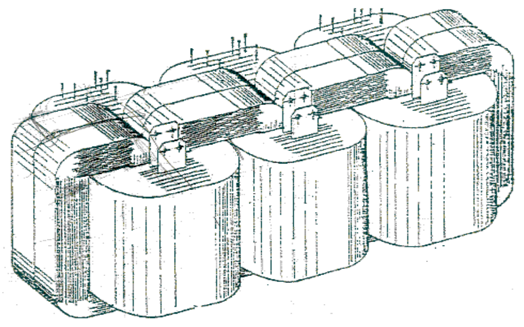

Fig. 1. Active part configuration of the three phase shell type distribution transformer considered.

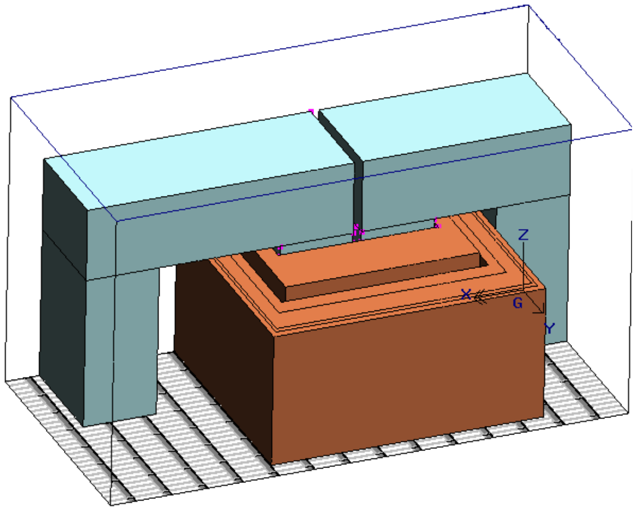

Fig. 2. Perspective view of the one phase transformer part modeled.

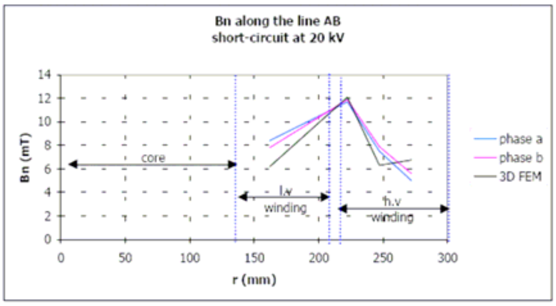

Fig.3. Comparison of measured and computed field values along the line AB

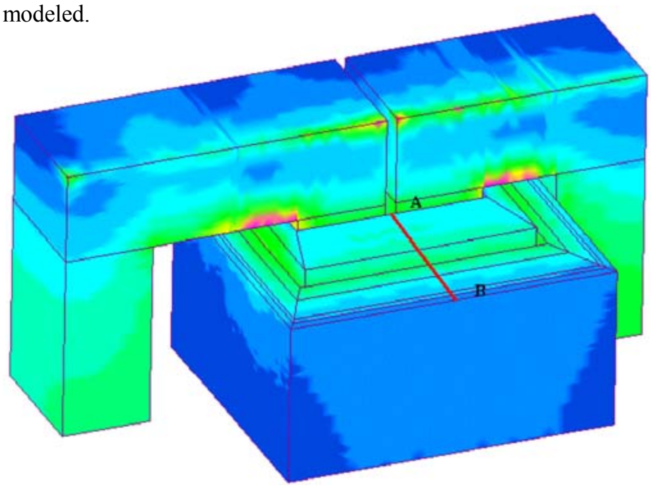

Fig. 4. Magnetic flux density magnitude distribution during short-circuit test

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