Calculations of Transient Eddy Current Field and Dynamic Short Circuit Forces in a Large Power Transformer

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Abstract—In this paper, the T-Ω finite element method (FEM) is proposed to study the three dimensional (3D) transient eddy current field and electromagnetic forces acting upon the coils in power transformers. The radial press stress on the coil sections are included in the computation. The axial vibration, displacement and dynamic force of the coil sections are analyzed by modeling the coil as a mass-spring.

I. Introduction

During the short circuit (SC) process in a large power transformer, a gigantic force would appear and act on the coils to result in serious damage, both structurally and electrically. In extreme cases, the force may distort the coil and result in detrimental short circuits among adjacent coil sections. Hence it is important to assess the robustness of the transformer against SC damages, particularly in large transformers in which a SC could have very serious consequences. In this regard, the SC current and the 3D transient eddy current field have to be studied carefully before one can evaluate the distribution of the SC forces on the coils. Noting that the coil sections and the structures would vibrate and hence are not static during the SC process, the traditional static model is insufficient to describe a transformer SC problem. A dynamic force model is therefore necessary [1].

In this paper, the T-Ω finite element method is used to compute the 3D transient eddy current field and the electromagnetic forces acting on the coils in the transformer. The elastic bearing multi-span model is used to compute the radial press stress upon the coil sections. The axial vibration, displacement and dynamic force of the coil sections are analyzed by modeling the coils as mass-springs.

II. Formulations

To analyze the electromagnetic force of the coil in the transformer, the 3D transient eddy current field satisfying the following equations have to be evaluated first [2].

$$\nabla \times \rho \nabla \times \mathbf{T} - \nabla(\rho \nabla \cdot \mathbf{T}) + \frac{\partial}{\partial t}\mu(\mathbf{T} - \nabla\Omega) = -\frac{\partial \mu \mathbf{H}_S}{\partial t} \quad \text{in } V_1 \quad (1)$$

$$\nabla \cdot \mu(\mathbf{T} - \nabla\Omega) = -\nabla \cdot \mu \mathbf{H}_S \quad \text{in } V_1 \quad (2)$$

$$\nabla \cdot \mu(\nabla\Omega) = \nabla \cdot \mu \mathbf{H}_S \quad \text{in } V_2 \quad (3)$$

where, V_1 is the eddy current area such as tank wall and clamping plates (by ignoring eddy current in the coils), V_2 is the non eddy current area, $\mathbf{H}_s$ is magnetic density in space due to the source current.

III. Calculations of a 240MVA Transformer

A 240MVA power transformer (a sketch of 1/8 of the structure is shown in Fig.1) has been designed with its transient field, force and stress on the coils being computed using the proposed algorithm. Table I shows the calculated results agree well with the measured ones. Fig.2 shows the radial stress of the coil sections along the height of the low voltage (LV) coil. Fig.3 gives the SC force of a coil section on the upper end-region of the coil. Because the ampere-turn distributions are not uniform along the height of the coils, the computation of the axial force and the displacement of the coil sections is rather complex. Table II gives axial maximum displacements of coil sections.

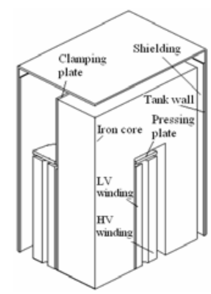

Fig. 1 The solved model

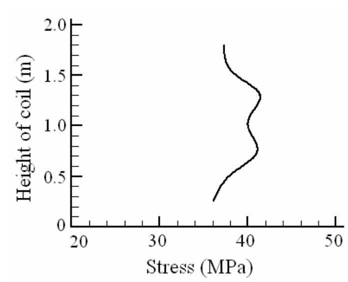

Fig. 2 Radial stress on the LV coil

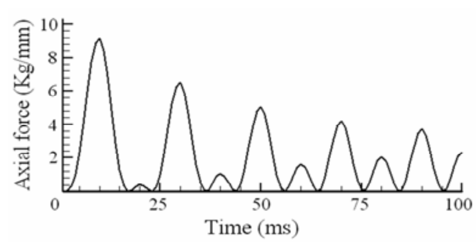

Fig.3 The transient force of a coil section

TABLE I
MAGNETIC FLUX DENSITY ALONG THE LV WINDING (10^{-4} T)

Height (mm)	442	486	597	900	1057	1125
Computed	66.4	99.2	48.5	4.88	29.7	57.2
Tested	61.0	87.5	49.8	4.62	31.3	63.5
Error (%)	8.85	13.4	-2.6	5.6	5.1	-9.92

TABLE II
DISPLACEMENT OF COIL SECTIONS (mm)

No. of sections	dis. (down)	dis. (up)	No. of sections	dis. (down)	dis. (up)
1	8.3	5.7	17	5.8	7.6
5	8.0	6.7	21	4.7	7.7
9	7.4	7.0	25	3.5	6.0
13	6.7	7.4	29	2.1	3.6

IV. References

[1] S.L. Ho, Y. Li, S.H. Wang, Numerical Analysis of Transient Force and Eddy Current Loss in a 720MVA Power Transformer, *IEEE Trans. Magn.*, Vol.40, No.2, March, pp.687-690, 2004.

[2] G. Meunier, H.T. Luong, Computation of coupled 3D eddy current and electrical circuit by using T_0-T-Ω formulation, *IEEE Trans. Magn.*, 34(5), pp.3074-3077, 1998.

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