AN IMPROVED METHOD FOR VIRTUAL AIR GAP LENGTH COMPUTATION

A. Konrad[1], J. F. Brudny[2]
(1) Dept. of E.C.E., Univ. of Toronto, 10 King's College Rd., Toronto, ON, M5S 3G4, Canada
(2) Elec. Eng. Dept., LSEE, University of Artois, Technoparc Futura, Bethune, 62400 France

Introduction

An approach to the analysis of a single-phase transformer with a virtual air gap is presented. The transformer geometry is shown in Fig.1. The transformer has 4 auxiliary windings embedded in its core and connected to a dc supply. The purpose of these windings is to locally saturate the core. By changing the magnetic permeability of the ferromagnetic core material in the region of the auxiliary windings, a virtual air gap is created. An equivalent mechanical air gap length can be associated with the virtual air gap. It results from an increase in core reluctance with local saturation and is obtained by an analytical approach based on finding the distribution of the magnetic field in the core produced by the auxiliary windings. The accurate calculation of the magnetic field is necessary to obtain both the operating point of the core and the change in core reluctance. The proposed method consists of 5 steps. Steps 1, 2 and 5 are as described in [1]. Steps 3 and 4 are new [2]. The result obtained from the proposed method is compared with experimental and analytical results presented in [1].

Description and Application of the Method

Step 1 is to obtain the reluctance of the core with uniform cross section *without* local saturation. The ac voltage applied to the main windings produces a magnetic flux Φ_m in the core. The corresponding current is obtained from the magnetization curve and the magnetomotive force (mmf) required without local saturation is found. Denoting the mmf by $\Im_m$, the reluctance becomes $\Re_m = \Im_m/\Phi_m$ = 23.93 A-t / 5.359×10^{-4} Wb = 44653.85 H^{-1}.

Step 2 is the calculation of the magnetic field H_a when a dc current of $I_a = \pm 10$A is applied to the auxiliary windings. The region of core across the center of the auxiliary windings is divided into *m* tubes of different lengths (Fig.2). An average value of H_a is obtained by the image method in [1]. H_a is used to obtain the flux Φ_a around the auxiliary windings.

Step 3 is to take into account the induction in the auxiliary windings. Φ_m induces a current in the auxiliary windings, which sets up a magnetic flux that opposes Φ_m. However, instead of a decrease in main flux, an equivalent effect, the reduction of H_a to H_{ia} is considered. H_{ia} along the mean core length is calculated using an equivalent reduced auxiliary winding current I_{ia}. Fig.3 compares the distributions of H_a and H_{ia} in one quater of the core.

Step 4 is the calculation of the equivalent Φ-$\Im$ curve of the core [3] by division of the core into *n* slices according to the variation of H_{ia} along the mean path length of the core. From the equivalent Φ-$\Im$ curve the total mmf, $\Im$, is obtained. Due to symmetry, only one quarter of the core is considered. In this example *n* = 68 (Fig.4). Each slice has a specific value of H_{ia} and its own magnetization curve reformulated in terms of Φ and $\Im$ (Fig.5). The equivalent Φ-$\Im$ curve is obtained from the sum of the mmf-s of each slice for the same value of Φ_m [3]. The total mmf required to establish Φ_m with local saturation is obtained from the equivalent Φ-$\Im$ curve (Fig.6). For a magnetic flux of Φ_m = 5.359×10^{-4} Wb with local saturation corresponding to $I_a = \pm 10$A, the total mmf required is $\Im$ = 239.43 A-t.

Step 5 consists of obtaining the reluctance of the core *with* local saturation: $\Re = \Im/\Phi_m$ = 239.43 A-t / 5.359×10^{-4} Wb = 446781.12 H^{-1}. The increase in core reluctance is $\Delta\Re_m = \Re - \Re_m$ = 402127.26 H^{-1}. Finally, the equivalent length of the virtual air gap is obtained as $\ell_g = \Delta\Re_m \mu_0 S$ = 2.5mm where S = (0.066m)×(0.075m) = 0.00495m^2 is the core cross-sectional area. For comparison, the computed and experimental values of ℓ_g given in [1] for the same level of saturation are 4.5mm and 2.59mm, respectively.

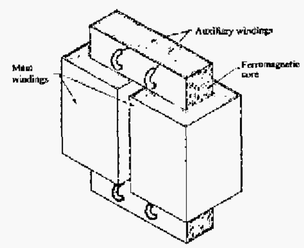

Fig. 1 - Transformer geometry showing 3D windings and core.

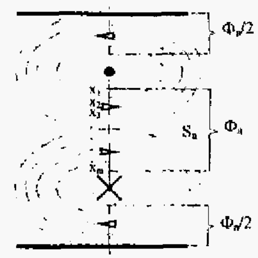

Fig. 2 - Tubes x_1 through x_m around an auxiliary winding.

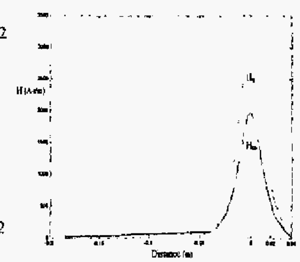

Fig. 3 - 1D fields H_a and H_{ia} along mean length of ¼ core.

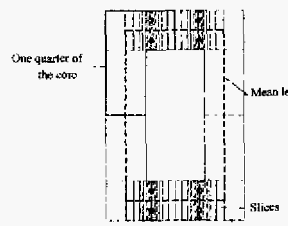

Fig. 4 - Subdivision into *n* slices according to the variation of H_{ia}.

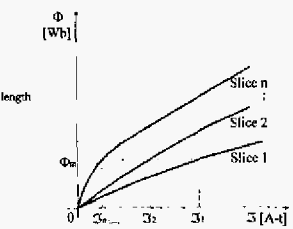

Fig. 5 - Typical magnetization curves of the *n* core slices.

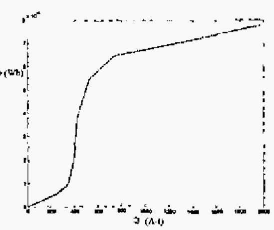

Fig. 6 - Equivalent Φ-$\Im$ curve corresponding to $I_a = \pm 10$ A.

References

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