Development of Distribution Transformers Assembled of Composite Wound Cores

Themistoklis D. Kefalas and Antonios G. Kladas
Faculty of Electrical and Computer Engineering, National Technical University of Athens
9 Iroon Polytechneiou Street, Athens 15780, Greece
thkefala@central.ntua.gr

Abstract — The present paper proposes the manufacturing of distribution transformers using a novel type of magnetic core which is called composite wound core. A composite wound core is constructed of a combination of conventional and high magnetization grain-oriented electrical steel and its operating principle is based on the flux density non-uniformity of wound cores. The main advantage of distribution transformers assembled of composite wound cores over conventional transformers is the significant reduction of the manufacturing and operating cost.

I. INTRODUCTION

Losses of the electrical grid worldwide are estimated at about 1,279 TWh/year i.e., 9.2% of global electricity generation. Almost 70% of the losses take place in the distribution grid and a third of that in distribution transformers. This fact renders distribution transformers the second most energy intensive component of the power grid [1]. As a result, even though the transformer is the most efficient of all electrical machines, present energy costs are forcing transformer manufacturers and utilities to reduce transformer life-cycle costs while minimizing the manufacturing cost.

By using wound cores constructed with a combination of different grades of electrical steel [2]-[4], the transformer manufacturer can effectively minimize the sum of the first cost and the cost of future losses of the transformer.

II. CONVENTIONAL DISTRIBUTION TRANSFORMERS

In practice two types of magnetic cores are used, the stack core and the wound core. The wound core is comprised from long continuous strips of grain-oriented electrical steel wound around the coils. The main advantages include reduction of joints and the use of the grain direction of the steel for the flux path.

Conventional one-phase and three-phase, oil-immersed, distribution transformers are constructed by using one or more wound cores assembled about a preformed electrical winding coil as depicted in Fig. 1. Ratings range from a few kVA to a few MVA.

III. DESCRIPTION OF COMPOSITE WOUND CORES

The operating principle of the composite wound core is based on experimental evidence concerning the flux density distribution non-uniformity of wound cores [2], [3]. The flux density is low in the inner steel sheets of the wound core, then it increases to a value higher than the mean flux density of the core, and finally it decreases until the outer sheets. Thus, by using a low cost, standard magnetization,

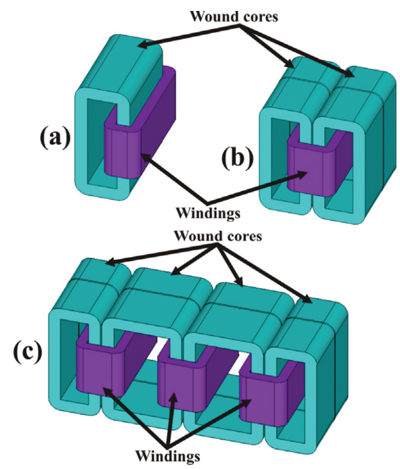

Fig. 1. Conventional wound core transformer (a) one-phase core type, (b) one-phase shell type, (c) three-phase shell type.

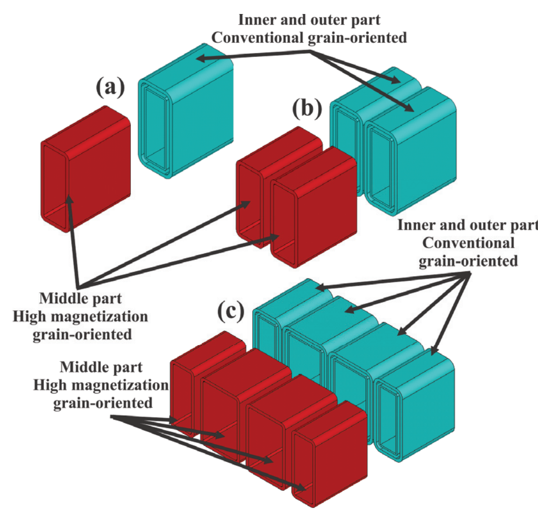

Fig. 2. Composite wound cores comprising (a) one-phase core type, (b) one-phase shell type, and (c) three-phase shell type transformers.

standard loss, grain-oriented steel for the inner and outer part of the wound core, and a high cost, high magnetization, low loss, grain-oriented steel for the rest part of the core, the transformer manufacturer may achieve an optimum tradeoff between the manufacturing cost and the cost of losses.

The evaluation of the optimum position and exact amount of the high magnetization grain-oriented steel, that ensures the minimization of the first cost and the cost of future losses, is depended on several parameters that must be taken into consideration, like the working induction of the wound core, the cost of the conventional and high magnetization grain-oriented steel, the electricity cost, the lifetime of the transformer, and the discount rate.

IV. DISTRIBUTION TRANSFORMERS ASSEMBLED OF COMPOSITE WOUND CORES

In the case of distribution transformers assembled from composite magnetic cores the various transformer topologies remain exactly the same and the conventional wound cores are replaced by the composite wound cores. Fig. 2 shows the parts comprising the composite cores of the one-phase core type, one-phase shell type, and three-phase shell type distribution transformers. The inner and outer part of the composite core is made of conventional grain-oriented steel sheets and the middle part is made of high magnetization grain-oriented steel sheets. The assembled one-phase core type, one-phase shell type, and three-phase shell type, transformers are exactly as those shown in Fig. 1 (a), (b), and (c) respectively.

V. FE ANALYSIS OF COMPOSITE WOUND CORES CONSIDERING ANISOTROPY

The authors have developed a custom-made 2D FE code based on the magnetic vector potential formulation for the accurate computation of the flux density distribution and no-load loss of conventional and composite wound cores [5], [6]. The laminated wound core is considered as homogeneous and anisotropic at the level of finite elements [5], [7]. This means that in the case of the 2D FE analysis the reluctivity $\mathbf{v}$ is assumed to have two components within each element, the v_p component along the rolling direction, and the v_q component normal to the rolling direction. The directional dependence of the B - H characteristics is taken into consideration by assuming that the loci of constant magnetic field intensity H , forms ellipses in the B_p - B_q plane. The resulting 2D FE technique is computationally cheap as a coarse mesh of a few thousands nodes is enough for the accurate evaluation of the flux density distribution.

Fig. 3 illustrates the areas with different material attributes comprising the 2D FE model of a composite wound core. For the areas A1 to A5, and A11 to A15, the conventional grain-oriented steel is assigned, and for the areas A6 to A10 the high magnetization grain-oriented steel is assigned. Due to the wound core's geometry the reluctivity tensor must be rotated to a different coordinate system in some of the areas of the 2D FE model. Fig. 4 shows the flux density distribution vector plot of a composite wound core constructed of the conventional grain-oriented steel M4 0.27 mm, and the high magnetization grain-oriented steel M-OH 0.27 mm. One half of the wound core geometry is modeled due to symmetry. The FE mesh is comprised from 8,110 first order triangular elements and 4,246 nodes.

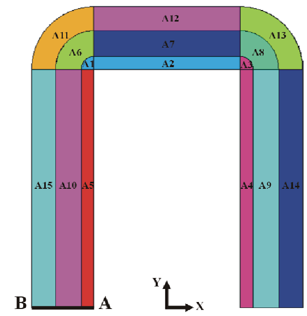

Fig. 3. Areas comprising the 2D FEM model of a composite wound core.

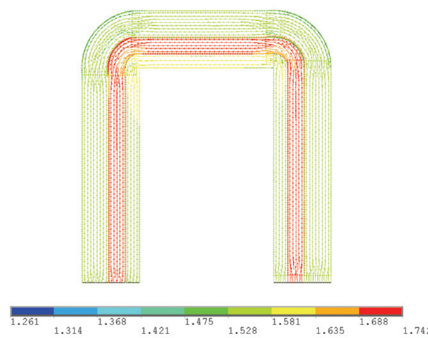

Fig. 4. Flux density vector plot of a composite wound core.

VI. CONCLUSION

The paper proposes a method that is going to provide transformer manufacturers great services in reducing the manufacturing and operating cost of distribution transformers. The specific method can be integrated easily in the design and manufacturing phase of the transformer industry since it does not revolutionize the transformer topology or magnetic materials. Furthermore, existing manufacturing processes used for the production of conventional wound cores can be applied to composite magnetic cores.

VII. REFERENCES

[1] J. C. Olivares, Y. Liu, J. M. Cañedo, R. Escarela-Pérez, J. Driesen, and P. Moreno, "Reducing losses in distribution transformers," *IEEE Transactions on Power Delivery*, vol. 18, no 3, pp. 821-826, Jul. 2003.

[2] T. D. Kefalas, P. S. Georgilakis, A. G. Kladas, A. T. Souflaris, and D. G. Paparigas, "Multiple grade lamination wound core: A novel technique for transformer iron loss minimization using simulated annealing with restarts and an anisotropy model," *IEEE Trans. Magn.*, vol. 44, no 6, pp. 1082-1085, Jun. 2008.

[3] I. Hernández, J. C. Olivares-Galván, P. S. Georgilakis, and J. M. Cañedo, "A novel octagonal wound core for distribution transformers validated by electromagnetic field analysis and comparison with conventional wound core," *IEEE Trans. Magn.*, vol.46, no.5, pp. 1251-1258, May 2010.

[4] R. Pytlech, "Mixed D-core with a distributed air gap as an alternative for medium voltage instrument transformers," *IEEE Trans. Magn.*, vol.46, no.10, pp. 3816-3825, Oct. 2010.

[5] T. Kefalas and A. Kladas, "FEM package for iron loss evaluation and minimization of two grade lamination wound cores," *Journal of Optoelectronics and Advanced Materials*, vol. 10, no 5, pp. 1197-1202, 2008.

[6] B. Cranganu-Cretu, J. Smajic, J. Ostrowski, W. Renhart, and C. Magele, "Software integrated solution for design optimization of industrial devices," *IEEE Trans. Magn.*, vol. 44, no 6, pp. 1122-1125, Jun. 2008.

[7] A. Wilk, J. Nieznanski, and I. Moson, "Nonlinear model of a wound iron core traction transformer with the account of magnetic," *Proc. ICEM*, 2010.