Int'l Journal of Computing, Communications & Instrumentation Engg. (IJCCIE) Vol. 2, Issue 2 (2015) ISSN 2349-1469 EISSN 2349-1477

Distribution Transformer Losses Calculation Based on TSFEM

Atabak najafi[1], Ires Iskender[2], Burak Dökmetaş[3], and Saeid Aghaei Hashjin[4]

***Abstract*: Power transformers illustrate the majority of capital investment in transmission and distribution centers. Additionally, interruptions of power transformer have a significant economic effects on the Performance of an electrical network. For this reason the safe and reliable Performance relate directly to the Security and stability of power system. In this study, the computer-based simulation utilizing the three dimensional time stepping finite element methods (3-D), are exploited as a tool for calculate the losses (no-load and load loss) and visualizing magnetic fields on the core and windings of 400 kVA distribution transformers. Then, the experimental results and TSFEM analysis results have been compared.**

***Keywords:* Finite element method, distribution transformer, flux density, core loss**

I. INTRODUCTION

The importance of transformers in the electricity transmission and distribution systems, is an obvious axiom in the modern day's power systems. So evaluating the performance of the transformer is very important. The Finite Element Method (FEM) is a very well-known way of studying the behavior of transformers under different operation condition such as non-sinusoidal or unbalanced conditions. However, traditional studies are always related to the internal magnetic field distribution and other analysis [2], which do not include external equivalent circuit to represent non-linear components such as converter installations, arc furnaces and others .This paper investigates the electromagnetic analysis in a 400 kVA , 33/0.4 kV distribution transformer using time stepping finite element method (TSFEM) . İn the first section, by using electromagnetic analysis, the flux density distribution in transformer core have been investigated. Afterwards, based on the data obtained from the FEM , calculation of load and No-load losses is presented . The results shows that FEM provides an effective method to analyze different electromagnetic Parameters such as magnetic flux lines, flux density, losses, and etc. [5] [6].

II. DISTRIBUTION TRANSFORMER ANALYSIS USING TIME DOMAIN FINITE ELEMENT METHOD

The FEM is a scalar procedure for solving partial differential and integral equations. This technique will either resolve the differential equation and make the problem steady-state or approximate the equations into a system of common differential equations and afterwards apply the scalar integrating method that provide by the standard methods such as Euler's, Runge-Kutta methods ,etc. The basic idea behind the FEM is to divide the region to be studied into minor sub-regions named finite elements. A 3-phase, Dy11, 400kVA, 33/0.400V distribution transformer is studied in this paper. In Fig. 1-a, the 3- dimensional modeling of the distribution transformer is demonstrated under mesh operation and the total magnetic mesh generated is 201323 elements that shows in Fig 1-b. All the meshes have tetrahedral shapes in the Three-dimensional modeling. According to fig. 1, it can be noticed that there is a non-uniform triangle mesh elements concentration distribution around the physical areas of the studied device. The higher the magnetic concentration the greater the number of triangles to characterize the mesh. The specifications of the proposed transformer is shortly illustrated in Table I. The time step that has been chosen about 0.2 ms, for all simulations of this paper. In magnetic field evaluation, the magnetic vector potential (A), include a series of information of magnetic field intensity (H), and magnetic flux density (B). Reference [1] [7] displays the temporary and spatial variations of A.

$$\nabla^2 A - \mu\sigma \frac{\partial A}{\partial t} + \mu J_0 = 0 \tag{1}$$

In this equation, μ is the magnetic permeability, σ is the electrical conductivity, and J0 is the applied current density

$$\frac{\partial A}{\partial t} = jwA \tag{2}$$

3-dimensional FEM solves the following Poisson in order to determine the magnetic flux distribution:

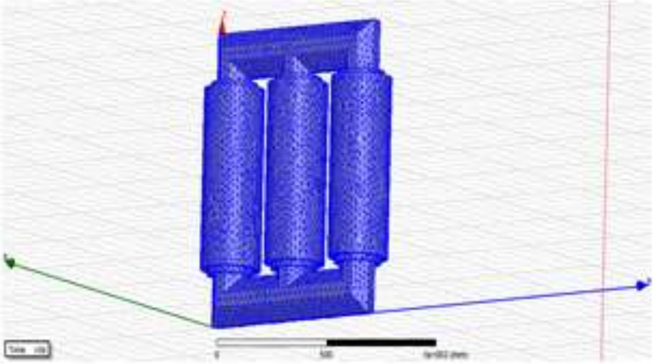
$$\frac{\partial}{\partial x}\left(R\frac{\partial A}{\partial x}\right) + \frac{\partial}{\partial y}\left(R\frac{\partial A}{\partial y}\right) + \frac{\partial}{\partial z}\left(R\frac{\partial A}{\partial z}\right) = -\frac{ni}{s_c} \tag{3}$$

A is the magnetic potential vector, R is the core sheets reluctivity, n is number of winding turns, Sc is the cross section of the conductors. In the static analysis of the transformer, the magnetizing current is known, while the magnetic potential vector A is unknown. For current computation from start up to steady state, the dynamic analysis of the transformer is required. In this analysis, in addition to the magnetic potential vector, magnetizing current (inrush current) is also unknown in Eq. (3). Since the numerical value of the current density over the whole conducting region is not defined, it is necessary to model the

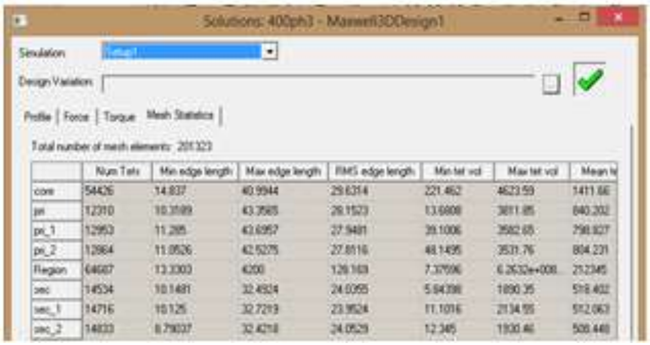
Atabak najafi, Ires Iskender, Burak Dökmetaş, and Saeid Aghaei Hashjin are with Electrical Engineering department, Gazi University, Ankara, turkey.

http://dx.doi.org/10.15242/IJCCIE.AE1115005

voltage source as input, as well as circuit elements of the external circuit between the voltage source and the region under FEM analysis. Delta- Wye transformer connections create Discontinuities in the zero-sequence network as the zero-sequence current can flow at one side of the transformer without flowing at the other side. This effect generates a zero-sequence differential current that can make the differential unit trip. To remove the zero sequence differential current a tertiary winding with delta connected can be used.



(a)



Total number of mesh elements: 201323

	Num Tets	Min edge length	Max edge length	RMS edge length	Min tet vol	Max tet vol	Mean te
core	54426	14.837	40.9944	29.6314	221.462	4623.59	1411.66
pri	12310	10.3189	43.3565	28.1523	13.6808	3811.85	840.202
pri_1	12953	11.285	43.6957	27.9481	39.1006	3582.65	798.827
pri_2	12864	11.0526	42.5275	27.8116	48.1495	3531.76	804.231
Region	64687	13.3303	4200	128.169	7.37596	6.2632e+008	212345
sec	14534	10.1481	32.4924	24.0355	5.84398	1890.35	518.402
sec_1	14716	10.125	32.7219	23.9524	11.1016	2134.55	512.063
sec_2	14833	8.79037	32.4218	24.0529	12.345	1930.46	508.448

(b)

Fig. 1: (a) mesh operation of studied transformer in 3-D (b) number of mesh in each section

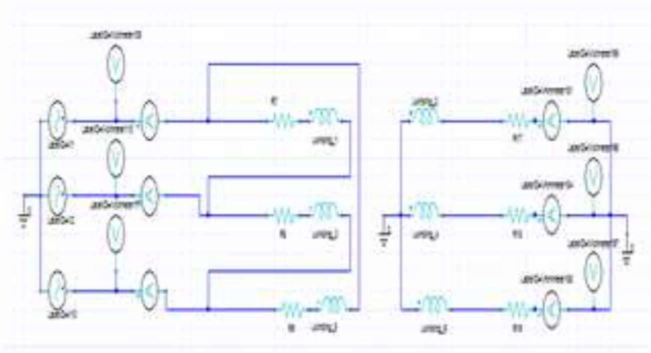


Fig. 2: Δ / Y connected of three-phase transformers

Fig (2) shows the Δ / Y connected of studied three-phase transformers [8]

Curl of the B, used to calculate the magnetic vector potential A:

$$B=\nabla \times A \tag{4}$$

The fundamental equation of the electric circuits is given by;

$$V_S= R_S * I+L_S* \frac{di}{dt} \tag{5}$$

Fig (3) shows the B_H curve of the magnetic material. It can be seen in this fig that saturation flux density is approximately 1.9 tesla.

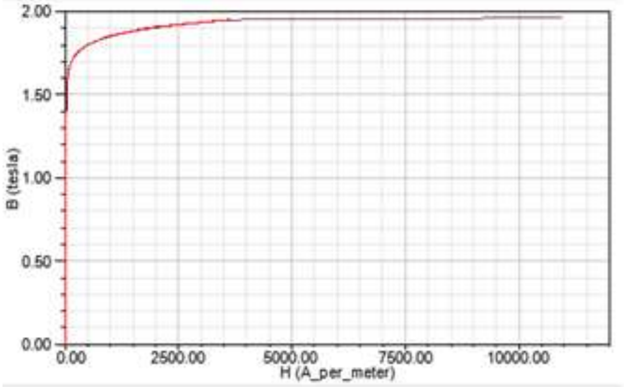


Fig.3: B-H curve of laminating type of M5 material

Fig. 4, shows the flux density distributions in transformer core. There is dependence between the magnetic flux density and magnetic vector potential. Other words, the magnetic flux density is dependent to the Percentage change in the magnetic vector potential. Fig .5 shows the magnetic vector distribution in transformer core.

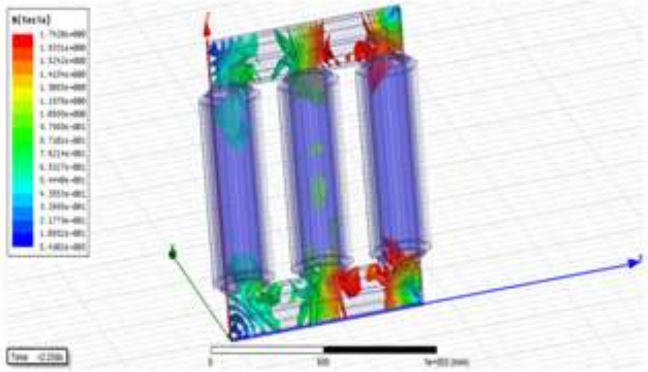


Fig. 4: Magnetic field distribution in transformer core in 3D

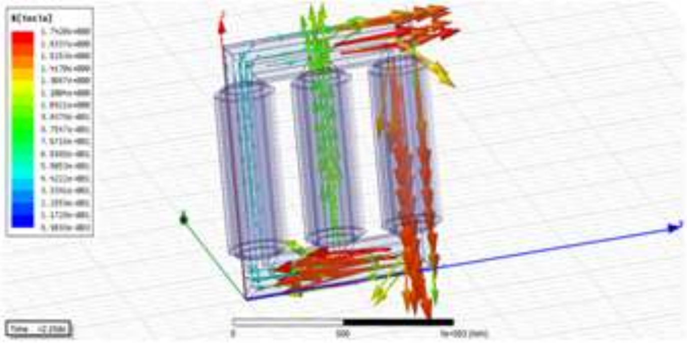


Fig. 5: Magnetic vector distribution in transformer core in 3D model

TABLE I: ELECTRICAL PARAMETERS OF STUDIED TRANSFORMERS

QUANTITY	Value	Unit
Primary voltage	33	KV
Secondary voltage	0.4	KV
Rated power	400	KVA
No.of primary winding turns	4287	....
No.of secondary winding turns	30	....
Primary winding resistance	48.41	ohm
Secondary winding resistance	0.00207	ohm
Width of window	880	mm
Height of window	1020	mm
Height of LV winding	670	mm
Height of HV winding	630	mm

Fig.6 shows the primary maximum induced voltage for the given transformer. Fig. 7, shows the primary current of the given transformer, those changes with time. It can be observed in this Fig. (7) That Inrush current after about 700 ms reduced to the normal value.

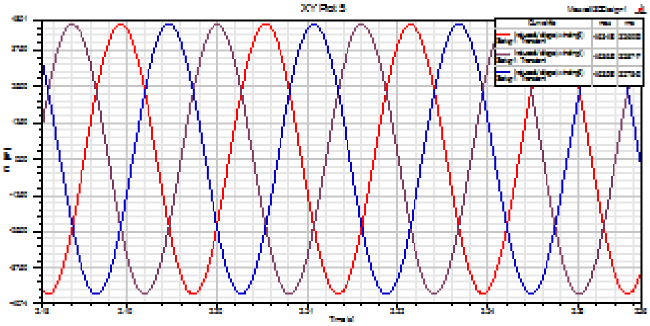


Fig 6: primary induced voltage

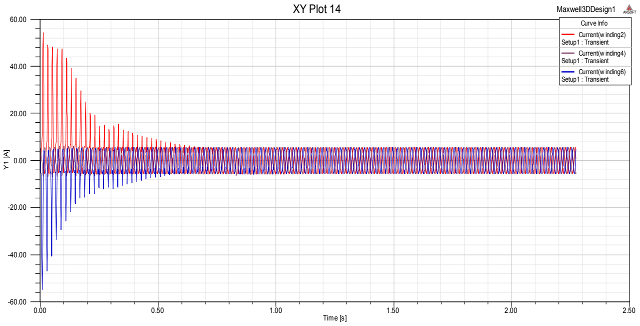


Fig. 7: primary winding current of the distribution transformer

III. ANALYTICAL METHOD

Commonly, Transformer losses are categorized into no load or core losses and load losses .This can be written in Fig. 8 and next equation: [4]

$$P_{TOTAL} = P_{LOAD-L} + P_{NO-LOAD} \qquad (6)$$

Because of the voltage excitation, P_{Core} are the core losses or no load losses. No-load losses are given with following equation:

TABLE II: TRANSFORMER PARAMETERS

R_1	R_2	I_{1L-L} rms	I_{2L-L} rms
48.41	0.00207	4.021	573.1

$$P_{NL} = w_h + w_e = k_h . f . B_m^{1.6} + k_e . B_m^2 f^2 \qquad (7)$$

In this equation k_e is the eddy current constant and k_h is the hysteresis constant. This depends upon the area of the magnetizing B-H loop and frequency. Fig. 9 shows a typical B-H loop. P_{LL}, categorize into P_{dc} losses or windings losses and stray losses that of the electromagnetic fields in the windings, magnetic shields, core clamps, enclosure or tank walls, etc.

Pdc Can be calculated by multiplying the dc resistance of the winding with the square of the load current. The stray losses additionally divided into winding eddy losses and structural part stray losses .Winding eddy losses divided into eddy current losses and rotating current losses. Other stray losses is the losses in the clamps, tank or enclosure walls, etc. This can be shown as:

$$P_{LL} = P_{DC} + P_{EC} + P_{OSL} \qquad (8)$$

To account the total stray losses P_{SL}, we can subtracting P_{dc} from the load losses.

$$P_{SL} = P_{EC} + P_{OSL} = P_{LL} - P_{DC} \qquad (9)$$

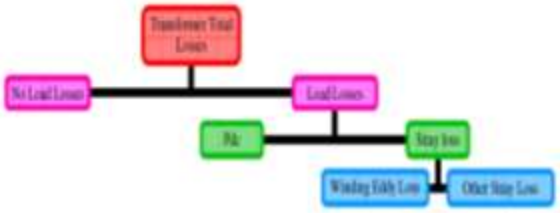


Fig 8: Transformer loss classification

P_{DC} can be computed by following equation:

$$P_{DC} = 3\times (R_2 I2_{2-rms} + R_1 I^2_{1-ms}) =$$

$$3\times (0.00207\times 573.1^2 + 48.41\times 4.021^2) = 1956.73 \text{ w}$$

TABLE III: TRANSFORMER LOSSES UNDER SINUSOIDAL LOAD BASED ON FEM

Types of losses Based on FEM	Analytical losses (w)	Simulation Losses(w) FEM
No load	859	844
DC	1956.73	1798
Winding eddy current	61.32	40
Total	2877	2682

In order to validate the methodology, an investigation was carried out using the prototype already mentioned. If we compare the calculated results based on FEM with analytical method , it can be seen in Table III that ,the calculation of losses based on FEM approximately equal with the analytical method .For this reason analysis of transformer performance using finite element method have accurate results in comparison with other simulation methods.

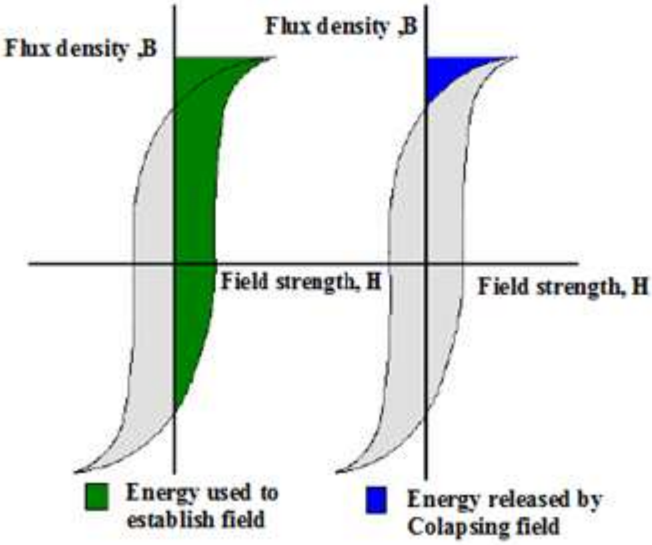


Fig 9: B-H loop

IV. CONCLUSION

In this paper, a 3-phase, Dy11, 400 kVA, 33/0.400 kV distribution transformer using the time stepping finite element method was simulated . In order to visualizing magnetic fields distribution in the transformer core, the three dimensional finite element method (3-D) is utilized . The results given in this paper have illustrated that FEM is a powerful method in order to modeling and calculation of losses and magnetic flux density in transformer core and windings. The results that summarized in table III shows calculated losses based on FEM Approximately equal to the analytical value.

V. REFERENCES

[1] Najafi A, Iskender I ” Evaluating and derating of three-phase distribution transformer under unbalanced voltage and unbalance load using finite element method. In: IEEE 8th international power engineering and optimization conference. IEEE, Langkawi, pp 160–165- 2014

[2] Nicolet A., Delince F., Hainps N., Genon A., Legros W “A Coupling Between Electric Circuits and 2D Magnetic Field Modelling,” IEEE Transactions on Magnetics. vo1.29, no 2. pp 1697-1700, March 1993 http://dx.doi.org/10.1109/20.250732

[3] D. Lin, P. Zhou, W.N.Fu, Z. Badics and Z. J. Cendes, “A dynamic core loss model for soft ferromagnetic and power ferrite materials in transient finite element analysis”, in IEEE Transactions on Magnetics, , Vol. 40, No. 2, pp. 1318–1321. March 2004 http://dx.doi.org/10.1109/TMAG.2004.825025

[4] F. de León and A. Semlyen, “A simple representation of dynamic hysteresis losses in power transformers,” IEEE Trans. Power Delivery, vol.10, pp. 315–321, Jan. 1995. http://dx.doi.org/10.1109/61.368383

[5] Najafi A, Iskender I “A novel concept for derating of transformer under unbalance voltage in the presence of non linear load by 3-D finite element method” Electrical Engineering, published online 23 september 2014

[6] BASTOS, 1. P. A, SADOWSKI "Electromagnetic Modeling by FEM", Marcel Dekker Inc. 490 pp, New York, , isbn: 0-8247-4269-9. 2003

[7] Najafi A, Iskender I “Comparing transformer derating under harmonic load and unbalanced supply voltage based on IEEEc57.110 standard and TESFEM by F HL and K_factor. IREE 9(1):226–234- 2014

[8] DRIES EN, 1; BELMANS, R. 1. M; HAMEYER, K; Methodologies for Coupled Transient Electromagnetic -Thermal Finite-Element Modeling of Electrical EnergyTransducers. IEEE Transactions on Industry Applications, vol. 38, no. 5,p. 1244-1250, September 2002.

[9] DECLERCQ, 1; VAN DER VEKEN, W; Accurate Hot Spot Modeling in A Power Transformer Leading to Improved Design and Performance. IEEE Transmission and Distribution Conference, Proceedings. Vol. 2, p. 920-924, 11-16 April 1999.

[10] S.B.Sadati, A.Tahani, “Derating of transformers under non sinusoidal load”, 11th International Conference on Optimization of Electrical and Electronic Equipment, OPTIM 2008 http://dx.doi.org/10.1109/optim.2008.4602376

[11] C. L. Cheng, C. E. Lin, “A New Scheme of Protective System for Three-Phase Transformers”,IEEE/PES Transmission and Distribution Conference and Exhibition 2002: Asia Pacific ,Conference Proceedings, 2002, Yokohama, Japan, pp. 1808-1813 , 2002 http://dx.doi.org/10.1109/tdc.2002.1177730