Separation of core losses in distribution transformers using experimental methods

Séparation des pertes dans le noyau dans les transformateurs de distribution en utilisant des méthodes expérimentales

J. C. Olivares-Galvan, R. Escarela-Perez, F. de León, E. Campero-Littlewood, and C. Aviles Cruz *

The separation of eddy current and hysteresis losses in transformer cores is obtained using the two-temperatures and the two-frequency methods. Loss calculations for six ratings using the voltage test waveform ratio are included to compare and analyze results. A brief description of the test methodologies, that are easy to apply, is given. An example of the application of the methodologies, the obtained measurements and obtained results are included. In some cases, the results show that eddy current losses for the analyzed ratings are greater than 60% of no-load losses. Results include the impact of no-load losses in total owning cost of transformers.

La séparation des courants de foucault et des pertes par hystérésis dans les noyaux des transformateurs est obtenue en utilisant les méthodes des deux températures et des deux fréquences. Les calculs des pertes pour six puissances, en utilisant le test du ratio de la tension de l'onde, sont inclus dans la comparaison et l'analyse des résultats. Une brève description des méthodologies expérimentales, qui sont facilement applicables, sont données. Un exemple de l'application de ces méthodologies, les mesures et résultats obtenus son inclus. Dans certains cas, les résultats démontrent que les pertes par courant de foucault pour les charges analysées sont supérieures à 60% des pertes sans charge. Les résultats inclus l'impact des pertes sans charge dans le coût total des transformateurs.

Keywords: distribution transformers, loss separation, iron-core losses, eddy current losses, hysteresis losses, two-temperature method, two frequency method, no-load test.

I Introduction

An important aspect of transformer design is the minimization of eddy current losses to increase efficiency [1]-[4]. The presence of losses due to eddy-currents is a subject of great interest because it substantially influences the performance of electric machines. Eddy currents are a cause of Joule effect losses and must be reduced to an economical limit [5]-[6].

The eddy-current problem has been the topic of many studies for more than 100 years and continues to be of great technical and economical interest. As an example, in United States of America in the year 1990 only 92.5% of the energy generated reached the consumers [3], the rest, approximately 229 billion kWh, was dissipated as losses in the transmission and distribution systems. Although the efficiency of distribution transformers has increased steadily with the introduction of improved materials and manufacturing methods [1],[2],[7],[8], 26.6% of the average transmission and distribution losses are associated with the estimated 50 million distribution transformers installed in USA [3].

Transformer no-load losses are sensitive to the transformer operating environment and their measurement is very important. The no-load current of transformers is non-sinusoidal. Therefore, the voltage waveform, distorted due to the harmonic components of the currents, produces voltage drops across the supply series impedance. This distortion is reduced when transformers are supplied from a robust source with a small series impedance. Calculation of no-load losses must consider the presence of this distortion. The following formula has been suggested [9]-[11]:

$$P = \frac{P_m}{P_h + \left(\frac{V_{rms}}{V_{ave}}\right)^2 P_e} \tag{1}$$

where P_m is the measured no-load loss, P_h is the hysteresis loss, P_e is the eddy current loss, V_{rms} and V_{ave} are, respectively, the *root mean square* and *average* values of the voltage test waveform. The ratio V_{rms}/V_{ave} showed a variation of 0.98 to 1.03 in laboratory tests (instruments of 0.1% accuracy). Tables 1 and 2 show the V_{rms}/V_{ave} obtained for a sample of single-phase and three-phase transformers. Tests were conducted to study the influence of distorted waveforms. In [12] it is observed that for cold-rolled sheets P_e=P_h=0.5 is a good approximation. However, the separation of P_m into P_e and P_h is a subject in which different opinions have been expressed [11] and it is clear that eddy-current losses can be an indicator of insulation deficiencies between laminations [13].

The analytical expression to obtain eddy-current losses per unit volume at power frequency excitation according to [14] is:

$$P_e = \frac{\left[t \cdot \pi \cdot B_m \cdot f\right]^2}{6 \cdot \rho} \tag{2}$$

---

* J. C. Olivares-Galvan, R. Escarela-Perez and E. Campero-Littlewood are with Departamento de Energia and C. Aviles Cruz is with Departamento de Electronica of Universidad Autonoma Metropolitana. E-mails: jolivare_1999@yahoo.com; r.escarela@ieee.org; ecl@correo.azc.uam.mx; caviles@correo.azc.uam.mx.

F. de León is with the Department of Electrical and Computer Engineering, Polytechnic Institute of New York University, Brooklyn, NY, 11201, USA. E-mail: fdeleon@poly.edu.

The authors thank CONACYT and PROMEP for financial support.

Table 1

Ratio of V_{rms}/V_{ave} obtained in laboratory tests for three-phase transformers.

Description	V_{rms}/V_{ave}	V_{rms}/V_{ave}	V_{rms}/V_{ave}
15kVA-13200-220/127V	1.0045	1.0091	1.0000
30 kVA -13200-220/127	1.0045	1.0000	1.0000
45 kVA -13200-220/127	1.0000	1.0000	1.0000
75 kVA -13200-220/127	1.0000	0.9955	1.0000
112.5 kVA -13200-220/127	1.0000	0.9955	0.9955
150 kVA -13200-220/127	0.9955	1.0000	0.9909

Table 2

Ratio of Vrms/Vave obtained in our laboratory tests for single-phase transformers.

Description	Vrms/Vave
5 kVA -13200-120/240V	1.0000
10 kVA -13200-120/240V	1.0042
15 kVA -13200-120/240V	1.0042
25 kVA -13200-120/240V	1.0083
37.5 kVA -13200-120/240V	1.0167
50 kVA -13200-120/240V	1.0167

where ρ (Ω-mm^2/m) is the electrical resistivity of the material, t (mm) is the lamination thickness, B_m (T) is the peak value of sinusoidal magnetic flux density assumed as homogeneously distributed, and f (Hz) is the frequency. It is evident from (2) that lamination thickness reduction means a squared reduction of eddy-current losses. On the other hand, hysteresis loss at power frequencies is [15]:

$$P_h = \frac{2\cdot f\cdot b\cdot S\cdot \phi_{\max}^2}{\mu\cdot l\cdot t} \tag{3}$$

where μ (H/m) is the permeability of the material, b (mm) is the length of lamination, S is the shape factor, $\Phi_{\max}$ (Wb) is the peak sinusoidal magnetic flux, and l (mm) is the height of lamination. Details on how B_m and $\Phi_{\max}$ are determined can be found in [16]. As can be seen in (2) and (3) lamination thickness has an opposite impact on hysteresis and eddy-current losses, thus the total core loss as a function of thickness has a minimum [17]-[18].

In [10] a dielectric loss term is included in the no load losses. However, in [19] authors report the measurements of dielectric losses and found that they are 3% of the total no-load losses. These losses are even smaller when transformers have been subjected to a vacuum-treatment drying process that removes the water from the paper insulation. As dielectric losses represent a very small percentage they are neglected and only the iron-core losses are considered in the following sections. Details of calculations and measurements of dielectric losses can be found in [20]-[21].

All the measurements in this paper were carried out on a new transformer before the impulse test. It is important to note that when the tested transformers are old or have been subjected to the impulse test, the no-load loss tends to be higher [22]. The differences are due to local breakdowns of the insulation between laminations, which would result in higher losses [23].

The goal of this paper is to determine P_e and P_h precise values. Moreover, the results of this research can be used to determine a correction factor when harmonic distortion is present in the load currents.

II Measurement of eddy current losses and hysteresis losses

There exist four methods for separating the iron-core losses for transformers [9],[10],[13],[24]-[26]:

1. Two-temperature method.
2. Two-frequency method.
3. Form factor method.
4. Direct current hysteresis method.

In this paper, two methods are used for the separation of no-load loss: the two-temperature method, and the two-frequency method. The two-temperature method has been selected because after the annealing process the cores are available at different temperatures. The two-frequency method is used because the no-load loss is available at two frequencies in many laboratories around the world.

II.A Two-temperature method

One important characteristic of all methods for the separation of iron-core losses is the necessity to produce two measurements. The two-temperature method separates the losses for a set of given conditions. The results are only valid for the tested conditions determined by the (peak) magnetic flux density, frequency and temperature. It is assumed that all tests are performed with sinusoidal voltage excitation.

With the two-temperature method it is possible to separate the core losses of transformers if we have access to two measurements of no-load losses at two different temperatures. The assumptions of this method are [10]:

1. Hysteresis losses are independent of temperature in the small range used here.
2. The iron-core electrical resistivity increases linearly with temperature.
3. Eddy-current losses vary inversely to electrical resistivity, i.e., as temperature increases eddy-current losses decrease.
4. The temperature coefficient of steel α=0.001(1/°C) is known at 20°C.
5. The peak flux magnetic density remains constant.

According to the above assumptions we can write the following expressions [10]:

Table 4

Applied voltage (V) for a sample of seven single-phase transformers using the 12-turn test coil.

Description	D(mm)	E(mm)	F(mm)	G(mm)	A(mm^2)	B(T)	Applied voltage (V)
5 kVA -13200YT/7620-240/120	152.4	25	75	140	7620	1.58	38.5
5 kVA -13200-240/121	152.4	25	75	140	7620	1.58	38.5
5 kVA -33000YT/19050-240/120	152.4	28	80	170	8534.4	1.53	41.8
10 kVA -13200YT/7620-240/120	152.4	34	70	165	10363.2	1.58	52.4
10 kVA -13200-240/120	152.4	34	70	165	10363.2	1.58	52.4
10 kVA -22860YT/13200-240/120	152.4	38	85	170	11582.4	1.52	56.3
10 kVA -33000YT/19050-240/120	190.5	44.2	102	182	16840.2	1.53	82.4

D=Core lamination width; E=Core thickness; F=Width of the core window; G=Height of the core window; A=Area of the core; B=Maximum magnetic flux density

Table 3

Eddy current losses contribution as a percent of the core losses of a 13200V-240/120 V-15 kVA transformer

(at 60 Hz, T_o=25^{o}C)

T_1	$P(T_1)$	T_2	$P(T_2)$	$P_e(T_0)$	$P_{e(pu)}(T_0)$
101.5	54	52.5	55.5	34.01	0.61
101	54	53	55.5	34.72	0.62

$$P(T_1) = P_h + P_e(T_o)\left(\frac{\frac{1}{\alpha}+T_o-20}{\frac{1}{\alpha}+T_1-20}\right) \quad (4)$$

$$P(T_2) = P_h + P_e(T_o)\left(\frac{\frac{1}{\alpha}+T_o-20}{\frac{1}{\alpha}+T_2-20}\right) \quad (5)$$

where: $P(T_1)$ (in W) is the no-load losses measured at a core temperature T_1 (^{O}C), $P(T_2)$ (in W) is the no-load losses measured at a core temperature T_2 (^{O}C), α is the temperature coefficient of resistivity 0.001 (1/^{O}C) for grain-oriented silicon steel, P_h is the hysteresis loss (in W), P_e is the eddy current loss component at reference temperature T_0 (^{O}C).

Solving (4) and (5) simultaneously gives:

$$P_h = \frac{\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_1-20}\right)P(T_2)-\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_2-20}\right)P(T_1)}{\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_1-20}\right)-\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_2-20}\right)} \quad (6)$$

$$P_e(T_o) = \frac{P(T_1)-P(T_2)}{\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_1-20}\right)-\left(\frac{1/\alpha+T_o-20}{1/\alpha+T_2-20}\right)} \quad (7)$$

Converting quantities to per unit yields:

$$P_{h(pu)} = \frac{P_h}{P_h+P_e(T_o)} \quad (8)$$

$$P_{e(pu)}(T_o) = \frac{P_e(T_o)}{P_h+P_e(T_o)} \quad (9)$$

To determine the percentage of eddy-current losses, the no-load loss of two different 15kVA transformer cores were measured at two temperatures. Table 3 shows the temperatures, the measured no load loss and the obtained eddy-current loss at the reference temperature of 20^{O}C and the per-unit loss that correspond to 61% and 62% of the total losses. For safety and convenience a 12-turn coil was used to limit the voltage to 127V and current to 5A. Table 4 shows some examples of calculations of the applied voltage of the 12-turns coil.

II.B Two frequency method

In addition to the two-temperature method, the two-frequency method is also used in this paper. No-load losses at two frequencies are available in many laboratories around the world.

In order to separate the no-load losses of transformers by the two-frequency method, certain assumptions are made:

1. Hysteresis loss varies directly with frequency, while the eddy-current loss varies with the square of the frequency for constant maximum induction density.
2. Excitation voltage is sinusoidal.
3. Temperature of the transformer is constant.

The loss component can be separated by simultaneously solving the following equations:

$$P(f_1) = P_e(f_0)\left[\frac{f_1}{f_0}\right] + P_h(f_0)\left[\frac{f_1}{f_0}\right]^2 \quad (10)$$

$$P(f_2) = P_e(f_0)\left[\frac{f_2}{f_0}\right] + P_h(f_0)\left[\frac{f_2}{f_0}\right]^2 \quad (11)$$

Where $P(f_1)$ (in W) is the no-load losses measured at frequency f_1 (Hz), $P(f_2)$ (in W) is the no-load losses measured at frequency f_2 (Hz), $P_e(f_0)$ (in W) are hysteresis losses at reference frequency f_0 (in Hz), $P_h(f_0)$ (in W) are eddy-current losses at reference frequency f_0 (Hz).

Table 5

Calculated no-load losses using equation (1) for six distribution transformers

		Calculated no-load losses using equation (1)											
Size (kVA)	Measurement of no load losses (W)	$\frac{V_{rms}}{V_{ave}}$	P_h	$\frac{V_{rms}}{V_{ave}}$	P_h	$\frac{V_{rms}}{V_{ave}}$	P_h	$\frac{V_{rms}}{V_{ave}}$	P_h	$\frac{V_{rms}}{V_{ave}}$	P_h	$\frac{V_{rms}}{V_{ave}}$	P_h
		0.98	0.5	1.02	0.5	0.98	0.4	1.02	0.4	0.99	0.4	1.01	0.5
5	30	30.6060		29.4060		30.7301		29.2900		30.3015		29.7015	
10	47	47.9494		46.0694		48.1439		45.8877		47.4723		46.5323	
15	62	63.2524		60.7724		63.5090		60.5327		62.6231		61.3831	
25	86	87.7372		84.2972		88.0931		83.9647		86.8643		85.1443	
37.5	114	116.3028		111.7428		116.7746		111.3020		115.1457		112.8657	
50	138	140.7876		135.2676		141.3587		134.7340		139.3869		136.6269	

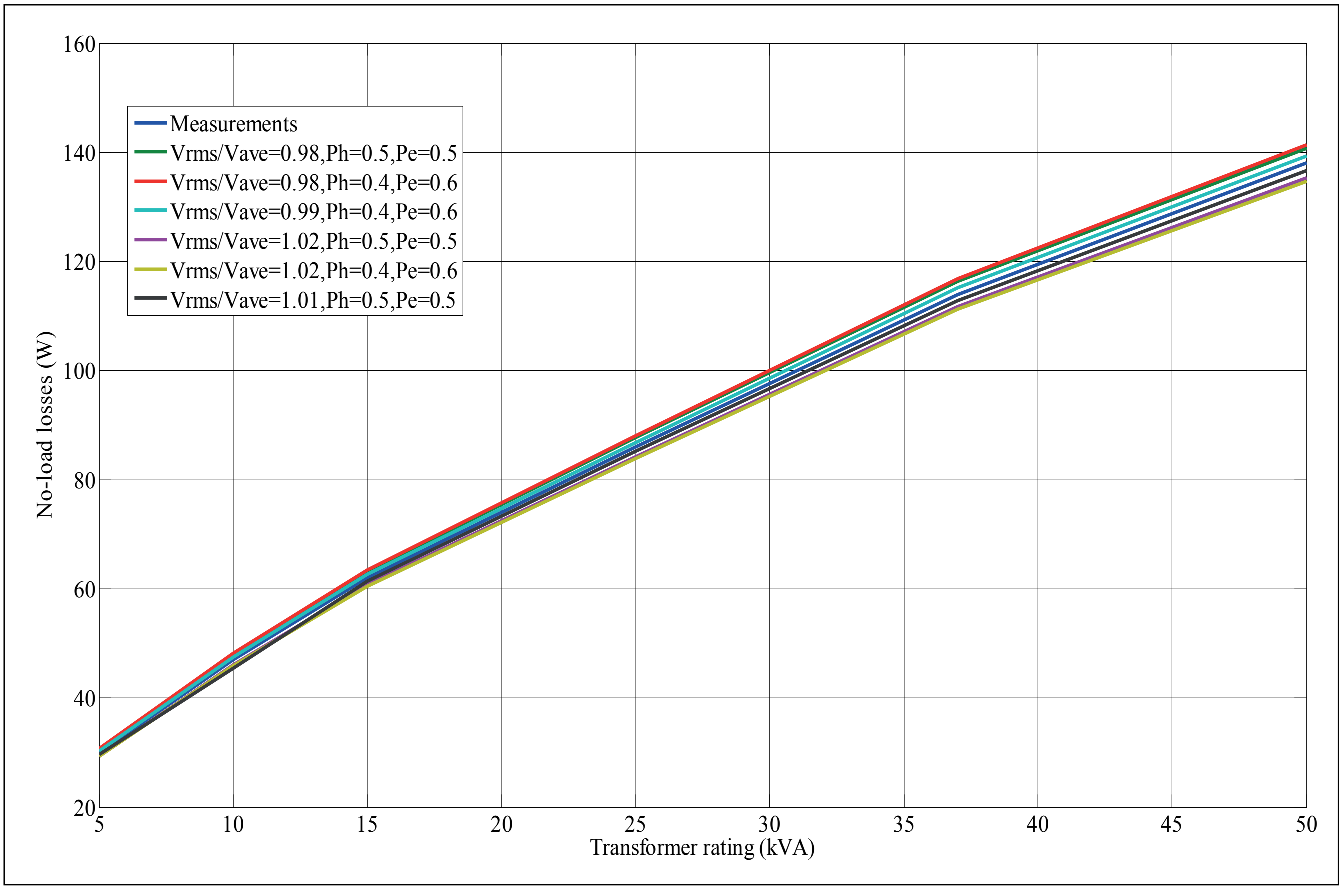

Figure 1: *No-load losses versus transformer ratings from 5 kVA to 50 kVA.*

There is a typographical mistake in the solution of equations (10) and (11) presented in [10]. The correct solution is given by

$$P_1(f_0) = f_0 \frac{f_1^2 P(f_2) - f_2^2 P(f_1)}{f_1 f_2 (f_1 - f_2)} \quad (12)$$

$$P_2(f_0) = f_0^2 \left[\frac{f_2 P(f_1) - f_1 P(f_2)}{f_1 f_2 (f_1 - f_2)} \right] \quad (13)$$

Core loss tests on M3 oriented steels were performed at a flux density of 1.5T at 50Hz and 60Hz and resulted 0.658W/kg and 0.87W/kg respectively. The obtained separation of losses using (12) and (13) is $P_{h(pu)} = 45.92\%$ and $P_{e(pu)} = 54.07\%$ at 60Hz. There is a relative error of 10% between the two experimental methods. This accuracy is considered quite good taking into consideration the complex geometry of the transformer.

III Results and discussion

Table 5 (tendencies shown in Figs. 1 to 3) describes a set of cases that are representative of real-life scenarios for V_{rms}/V_{ave}, P_h and P_e applicable to the analyzed transformers and shows the calculated no-load losses using equation (1). Six combinations of V_{rms}/V_{ave} and P_h have been chosen to cover all practical scenarios of the six transformer

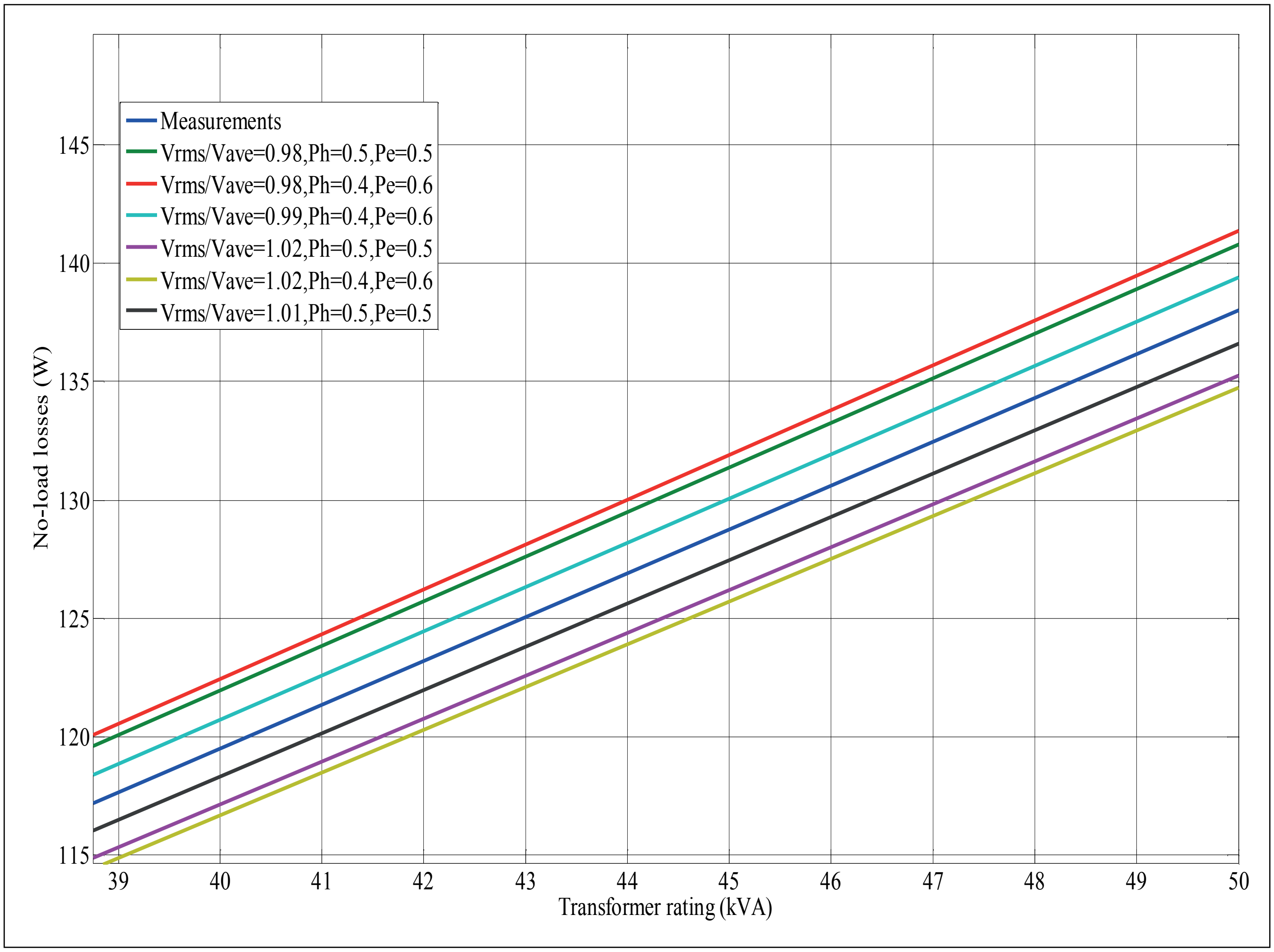

Figure 2: *No-load losses versus transformer ratings at higher transformer ratings (close up).*

ratings that are considered. When V_{rms}/V_{ave}>1.0, no-load losses diminish while if V_{rms}/V_{ave}<1.0, no-load losses increase applying equation (1). In Table 5 there is a percentage of variation between -2.3% and +2.3%.

Losses can be evaluated by calculating their cost *CL* ($) throughout the transformer life (25 years):

$$CL = A \cdot NLL + B \cdot LL \tag{14}$$

where *A* ($/W) is the no-load loss cost rate, *NLL* (W) is the transformer no-load loss, *B* ($/W) is the load loss cost rate, and *LL* (W) is the transformer load loss. An in-depth description on how the loss cost rates *A* and *B* are determined is given in [27]. *A*=$8.18/W and *B*=$4.03/W are current values used by Mexican utilities [28]. All the quantities in $ are expressed in USA Dollars. If these values are used to calculate *CL* of transformers in Table 5 it can be found that difference for 50kVA can be as high as $27.5 or as low as $2.5 for 5kVA. If a transformer manufacturer sells 30,000 transformers per year the total difference can oscillate from $74,000 to $824,000 per year in the Total Owning Cost (TOC)—purchasing price plus cost of transformer losses throughout transformer life [29]. Electric utilities usually purchase transformers based on the TOC, i.e., they select the offer that minimizes TOC.

IV Conclusions

In this paper two methods were used to obtain the eddy-current and hysteresis losses as a percent of the core losses: 1) the two-temperature method, which requires measurements at two temperatures; and 2) the two-frequency method, which requires measurements at two different frequencies. Experimental results show that the eddy-current loss is 61.5% of the no-load loss for a 15 kVA transformer at 60 Hz. This is larger than the common rule of thumb according to which the eddy-current loss is 50% of the no-load loss. The experimental work reported here was carried out under well-controlled conditions. The results have practical importance for transformer design engineers since load currents containing harmonic distortion are larger than expected from previous research. The proposed analysis includes the variation of parameters (real-life scenarios to cover the entire range of interest for Mexican utilities) such as: V_{rms}/V_{ave}, P_h and P_e. Results show that when V_{rms}/V_{ave}>1.0 all transformers included in the comparison have lower TOC. If P_h is reduced from 0.5 to 0.4 the percentage of variation of no-load losses increased from 1.98% to 2.38%.

Acknowledgements

The authors wish to thank Mr. Rodrigo Ocon Valdez, technology development manager of IEM S.A. de C.V. (Mexico), for the technical discussions.

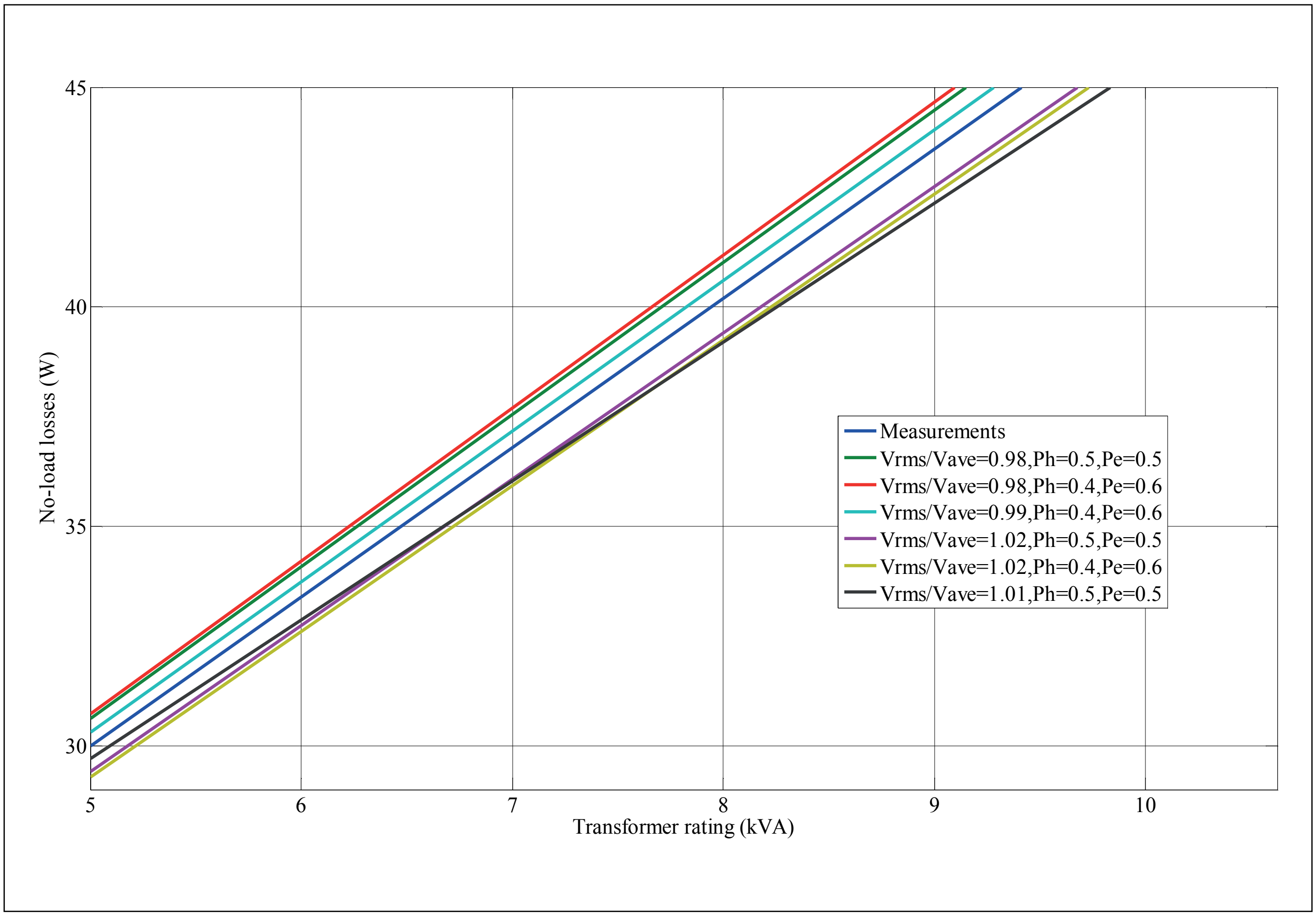

Figure 3: *No-load losses versus transformer ratings at lower transformer ratings (close up).*

References

[1] P. S. Georgilakis, *Spotlight on Modern Transformer Design*, Springer, 2009, London, UK.

[2] D. J. Allan, "Power transformers- the second century," *Power Engineering Journal,* January 1991, pp. 5-14.

[3] P. R. Barnes, *The feasibility of replacing or upgrading utility distribution transformers during routine maintenance,* April 1995, ORLN-6804/R1, p. xvii, xviii, xix.

[4] P. Georgilakis, N. Hatziargyriou, and D. Paparigas, "Al Helps Reduce Transformer Iron Losses," *IEEE Computer Applications in Power,* October 1999, pages; 41-46.

[5] J. A. Tegopoulos, *Eddy Currents in Linear Conducting Media,* Elsevier, 1985, Netherlands, p.9.

[6] A. Krawczyk, J. A. Tegopoulos*, Numerical Modeling of Eddy Currents,* Clarendon Press Oxford, 1993, p 7.

[7] M. F. Littmann, "Iron and Silicon-Iron Alloys," *IEEE Transactions on Magnetics,* Vol. 7, No. 1, March 1971, pp. 48-60.

[8] T. H. Harrison, B. Richardson, "Transformer Loss Reduction," *Cigre* 12-04, 1988 Session.

[9] M. J. Heathcote, *The J &P Transformer Book,* Twelfth edition, Butterworths, 1998, England, pp. 327-328.

[10] D. S. Takach, R. L. Boggavarapu, "Distribution transformer no-load losses," *IEEE Transactions on Power Apparatus and Systems,* Vol. 104, No. 1, January 1985, pp. 181-193.

[11] R. S. Girgis, discussion of reference [10], p. 193.

[12] W.R. Henning, discussion of the paper: R. Arsenuau, et al, "A Method for Estimating the Sinosoidal Iron Losses of a Transformer from Measurement made with Distorted Voltage Waveforms," *IEEE Transactions on Power Apparatus and Systems,* Vol. 103, No. 10, October 1984, pp.2912-2918.

[13] E. G. Reed, *The Essentials of Transformer Practice, Theory Design and Operation,* Second edition, USA, 1927, p. 38-43.

[14] R. Feinber (editor), *Modern Power Transformer Practice*, The Macmillan Press, 1979, Great Britain, pp. 128-129.

[15] J. Barranger, "Hysteresis and eddy-current losses of a transformer lamination viewed as an application of the Poynting theorem," *NASA Technical Note,* November 1965: 1-18.

[16] Members of the Staff of the Department of Electrical Engineering of Massachusetts Institute of Technology, *Magnetic Circuits and Transformers: A First Course for Power and Communication Engineers*, Wiley, New York, 1943, volume 2 of Principles of Electrical Engineering Series.

[17] J.G. Benford, "Separation of losses in oriented silicon steels from 0.13 to 0.34mm thick," *IEEE Transactions on Magnetics*, 20,1984, pp. 1545-1547.

[18] M.F. Littmann, "Properties of grain oriented 3% silicon steel for transformer with minimum cost of ownership," *Journal of Applied Physics,* 53, 1982, pp. 2416-2418

[19] J. C. Olivares-Galvan, Y. Liu, J. M. Cañedo, R. Escarela-Perez, J. Driesen, and P. Moreno, "Reducing losses in distribution transformers," *IEEE Transactions on Power Delivery,* Vol. 18, No. 3, July 2003, pp. 821-826.

[20] E. Wasilenko, M. Olesz, "On-site loss tangent measurements of high voltage insulation," *Sixth International Conference on Dielectric Materials, Measurements and Applications,* 1992, Pp. 170 –173.

[21] H. Kurita, T. Hasegawa, and K. Kimura, "Dielectric loss of high voltage/high frequency transformers used in switching power supply for space," *19th Annual IEEE Power Electronics Specialists Conference,* 1988, Vol. 2, pp. 1120 –1126.

[22] D. J. Ward, R. H. Wong, "An Analysis of Loss measurements on Older Distribution Transformers," *IEEE Transactions on Power Apparatus and Systems,* Vol. 103, No. 8, August 1984, pp. 2254-2261.

[23] R. Beaumont, "Losses in transformer and reactors," *Cigre* 12-10, 1988 Session.

[24] R. M. Bozorth, *Ferromagnetism,* IEEE PRESS, IEEE Magnetic Society, 1978, pp. 782-783.

[25] J. G. Benford "Separation of losses in oriented silicon steels from 0.13 to 0.34mm thick," *IEEE Transactions on Magnetics,* 20, 1984, 1545-1547

[26] M. Fogiel (Director), Staff of Research and Education Association, *The Electrical Machines Problem Solver,* Research and Education Association, 1983, USA, p. 150.

[27] B. W. Kennedy, *Energy-efficient Transformers,* McGraw-Hill, New York, 1998.

[28] J. C. Olivares-Galvan, F. de León, P. S. Georgilakis, R. Escarela-Perez, "Selection of Copper versus Aluminum Windings for Distribuztion Transformers," *IET Electr. Power Appl.,* 2010, Vol. 4, Iss. 6, pp. 474–485.

[29] J. E. Cota-Felix, F. Rivas-Davalos, S. Maximov, "A new method to evaluate mean life of power system equipment," *20th International Conference on Electricity Distribution,* Paper 1011, Prague, 8-11 June 2009.

Juan Carlos Olivares-Galvan was born in Michoacan, Mexico, in 1969. He received the B.Sc. and the M.Sc. degrees in Electrical Engineering from Instituto Tecnologico de Morelia (Mexico), in 1993 and 1997, respectively. He received the Ph.D. degree in electrical engineering at CINVESTAV, Guadalajara, Mexico in 2003. He is currently Professor at the Departamento de Energía of Universidad Autonoma Metropolitana. He was with Electromanufacturas S.A. de C.V., where he was transformer design engineer for eight years. He was a Visiting Scholar at Virginia Tech, Blacksburg, in 2001. His main interests are related tothe experimental and numerical analysis of transformers.

Rafael Escarela-Perez was born in Mexico City, Mexico, in 1969. He received the B.Sc. degree in electrical engineering from Universidad Autonoma Metropolitana, Mexico City, in 1992 and the Ph.D. degree from Imperial College, London, U.K., in 1996. He is interested in the numerical modeling of electrical machines: transformers and synchronous generators with solid rotors. He has been involved with research and lecturing since 1996 at Azcapotzalco Campus of Autonomous Metropolitan University of Mexico (UAM).

Eduardo Campero Littlewood was born in Mexico, D.F. in 1947. He obtained his B.Sc. in Electrical Engineering from the National Autonomous University of Mexico (UNAM-1969) and his M.Sc. in Electrical Engineering from Imperial College of Science, Technology, and Medicine, University of London, in 1977. He worked in industry from 1969 to 1975. He has been involved with research and lecturing since 1977 at Azcapotzalco Campus of Autonomous Metropolitan University of Mexico (UAM), where he is professor since 1992. His main research interest is simulation and analysis of electrical machines.

Francisco de Leon was born in Mexico City in 1959. He received the B.Sc. and the M.Sc. (summa cum laude) degrees in Electrical Engineering from the National Polytechnic Institute (Mexico), in 1983 and 1986 respectively, and obtained his Ph.D. degree from the University of Toronto (Canada) in 1992. He has held several academic positions in Mexico and has worked for the Canadian electric industry. Currently he is an Associate Professor at Polytechnic Institute of NYU, Brooklyn, NY. His research interests include the analysis of power definitions under nonsinusoidal conditions, the transient and steady-state analyses of power systems, the thermal rating of cables and the calculation of electromagnetic fields applied to machine design and modeling.

Carlos Aviles Cruz was born in Mexico City in 1966. He is graduated in Electronics Engineering (1989) from the Universidad Autonoma Metropolitana. He received the master degree in signal and image processing from the National Institute Polytechnic of Grenoble- FRANCE (1993). He received the Doctor degree in signal and image processing from the National Institute Polytechnic of Grenoble- FRANCE (1997). Actually he is full time professor at the Universidad Autonoma Metropolitana- Mexico City. The Doctor Aviles is author and coauthor of about 35 national and international articles and also co-author of two books.