Measuring the Impact of High Order Harmonics on the Transformer No-Load Losses

Mihail Digalovski, Goga Cvetkovski, Krste Najdenkoski, Goran Rafajlovski

Ss. Cyril & Methodius University, Faculty of Electrical Engineering & Information Technologies,
Rugjer Bošković 18, P.O.Box 574, 1000 Skopje, North Macedonia
E-mail: mihaild@feit.ukim.edu.mk, gogacvet@feit.ukim.edu.mk, krste@feit.ukim.edu.mk, goran@feit.ukim.edu.mk

***Abstract* – Transformers are normally designed and built for use at rated frequency, sinusoidal voltages and load current. A non-sinusoidal sources and non-linear load on a transformer leads to harmonic power losses which cause increased operational costs and additional heating in certain transformer parts. It leads to higher losses, early fatigue of insulation, premature failure and reduction of the useful life of the transformer. In this work a dry type 500 VA three phase transformer is powered, once directly by to the grid and then through voltage inverter. The no-load losses and high order harmonics are measured using power analyzer. The power losses are also determined analytically obtained by deriving equations for the no-load power losses depending on the harmonics order, its frequency and the amplitude of the magnetic flux density, and compared with the measured ones.**

1 Introduction

In the past years, there has been an increased concern about the effects of nonlinear loads on the power system. Nonlinear loads are such a type of loads that draws current with non-sinusoidal shape. In practice those loads are: fluorescent lamp, gas discharge lighting, solid state motor drives, power converters, static converters, rectifiers, arc furnaces, electronic phase control, cycloconvertors, switch mode power supplies, pulse width modulated drives and the increasingly common electronic power supplies. Harmonics are voltages and currents that appear in the electric power system at frequencies that are integer multiples of the generated frequency. The presence of nonlinear loads results to a significant increase of the level of harmonics and distortion in power system electrical quantities. Transformers are one of the components in the power system that are usually the interface between the supply and most non-linear loads. They are usually manufactured for operating with linear load under rated frequency. Nowadays the presence of nonlinear load results in production of current harmonics. The increased presence of harmonic currents causes extra power losses in the transformer winding and thus, leads to increase in temperature, reduction in insulation life, increase of the power losses and finally reduction of the useful life of transformer [1]. Voltage harmonics increase the power losses in its magnetic core (iron power losses) while current harmonic increase the power losses in its winding and structure. From the above information it is evident that there is a need for detailed analysis of the impact of higher order harmonics on power losses in transformers [2] especially of no-load power losses.

2 No-Load power losses

2.1 Hysteresis power losses

One part of no-load power losses belongs to the hysteresis power losses. Hysteresis power losses originate from the molecular magnetic domains in the core laminations, resisting being magnetized and demagnetized by the alternating magnetic field. Each time the magnetising force produced by the primary of a transformer changes because of the applied ac voltage, the domains realign them in the direction of the force. The energy to accomplish this realignment of the magnetic domains comes from the input power and is not transferred to the secondary winding. It is therefore a loss. This depends upon the area of the magnetizing B-H loop and frequency. Typically, this accounts for 50% of the constant core losses for CRGO (Cold Rolled Grain Oriented) sheet steel with normal design practice. Hysteresis power losses can be determined using the following equation:

$$P_h = K_h \cdot f \cdot B_m^{1,6} \text{ (W/kg)} \tag{1}$$

where:
K_h - the hysteresis constant
f - frequency (Hz)
B_m - maximum flux density (T)

- **Eddy current power losses in the magnetic core**

The alternating flux induces an EMF in the bulk of the iron core that is proportional to flux density and frequency. The resulting circulating current is inversely dependent upon the resistivity of the material and directly proportional to the thickness of the core. The power losses per unit mass of core material, thus vary with square of the flux density, frequency and thickness of the core laminations. Eddy current power losses contribute to about 50% of the no-load power losses [1]. Eddy current power losses are defined with following equation:

$$P_e = K_e \cdot B_m^2 \cdot f^2 \cdot t^2 \text{ (W/kg)} \tag{2}$$

where:
K_e - the eddy current constant
f - frequency in Hertz
B_m - maximum flux density (T)
t - thickness of lamination strips

- **Harmonics effect of no-load power losses**

Transformer manufacturers usually try to design transformers in a way that their minimum losses occur at rated voltage, rated frequency and sinusoidal current. However, by increasing the number of non-linear loads in recent years, the voltages and currents is no longer sinusoidal. Transformer power losses are divided into two major groups, no load and load power losses as shown as:

$$P_{TL} = P_{NL} + P_{LL} \tag{3}$$

where:

P_{NL} - no-load power losses (core losses)
P_{LL} – load power losses
P_{TL} - total power losses.

The no-load power losses are given with following equation [4]:

$$P_{NL} = P_{NLn} \cdot \sum_{i=1}^{n} \frac{K_{fi} \cdot K_{Bi}^{1,6} + K_{fi}^{2} \cdot K_{Bi}^{2}}{2} = P_{NLn} \cdot K' \tag{4}$$

where:

i - high order harmonic

K' - coefficient

$K_{fi} = \frac{f_i}{f_1}$ - high order harmonic frequency ratio

$K_{Bi} = \frac{B_{mi}}{B_{m1}}$ - high order harmonic magnetic flux density ratio

3 Measured results

The power losses calculation and measurements are performed on a three phase dry transformer with rated power of 500 VA and rated voltage of 380/42 V. The primary and secondary windings are realized in star connection. The measurement of the power losses and the harmonics spectrum is realized with power analyzer named Haag omni-quant mobil.

The following values are obtained from the measurements for no-load losses in both cases:

- P_{NL}=13.9 (W) – when transformer is supplied from the grid
- P_{NL}=17.7 (W) - when transformer is supplied from the power inverter

In Figures 1 and 2 the measuring equipment is presented. The calculated no-load power losses at an ideal sinusoidal voltage signal from Table 1 are taken as referent, i.e. P_{NLn} according to Eq. 4.

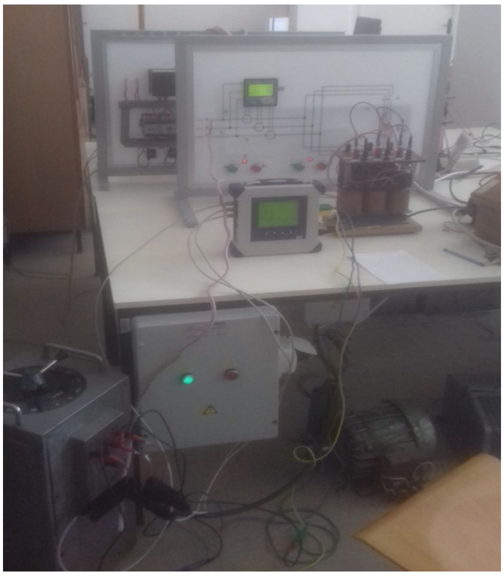

Fig. 1 Supplied from the grid

Fig. 2 Supplied from the power inverter

The analytically determined results are presented below in Table 1.

Table 1 Results from analytical calculations

Supplied from grid						**Supplied from power inverter**					
Harmonic order (/) (measured)	Amplitude of B_m (%) (measured)			Average value for K' (/) (calculated)	Value for P_{NLn} (W)-at an ideal sinusoidal voltage signal (calculated)	Harmonic order (/) (measured)	Amplitude of B_m (%) (measured)			Average value for K' (/) (calculated)	Value for P_{NLn} (W) (calculated)
	L1	L2	L3				L1	L2	L3		
3	0.35	0.40	0.20			3	19	19	19.50		
5	1.70	1.85	1.75			4	3.50	3.80	3.50		
7	1.30	1.25	1.10			5	0.50	0.40	0.30		
9	0.30	0.40	0.30			9	1.50	1.70	1.65		
11	0.35	0.30	0.35			11	0.50	0.60	0.40		
13	0.20	0.15	0.15			12	0.20	0.15	0.20		
15	0.20	0.15	0.10			15	0.45	0.35	0.40		
17	0.20	0.20	0.20								
19	0.10	0.15	0.10	**1.0193**	**13.63**					**1.3161**	**17.95**

4 Conclusion

The results show that harmonics have a great impact on the no-load power losses. The increase of power losses in the case of inverter power supply in relation to the case, for the given harmonic spectrum, is 27.34 %. Based on the presented results it can be concluded that the analytical model has quite good accuracy for determining the increase of no-load power losses from a known harmonic voltage spectrum. The measured value for the no-load losses is 17.7 W, while the calculated one is 17.95, which is a deviation of only 1.4%.

From the presented data it can be concluded that the nonlinear loads in the power system can produce additional power losses in the tower devices in the system especially the power transformers, due to the presence of current and voltage harmonics. Therefore, special attention should be given the design of power transformers especially in the application of novel magnetic materials with better characteristics and lower specific losses.

References

[1] Bureau of Energy Efficiency & Indian Renewable Energy Development Agency, (2006), *"Transformer – Best Practice Manual",* New Delhi, India.

[2] Amit Gupta, Ranjana Singh, (2011), "Computation of Transformer Losses Under the Effects of Non-Sinusoidal Currents", *Advanced Computing: An International Journal (ACIJ),* **Vol**. 2, No. 6, pp. 91 – 104.

[3] Mihail Digalovski, Krste Najdenkoski, Goran Rafajlovski, (2013), "Impact of current high order harmonic to core losses of three-phase distribution transformer", *Proceedings of EUROCON 2013 (IEEE, Region 8),* Zagreb, Croatia, pp. 1531-1535.