POWER TRANSFORMER NO-LOAD LOSSES IN CASE OF NON-LINEAR LOADS

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* This paper presents a simulation model for determining the no-load losses of power transformers in case of non-linear loads.

* A relation associated with core losses and amplitude of high harmonic order are reviewed &analyzed and then a comparison is being carried out on the results obtained by different excitation current in transformer windings.

INTRODUCTION

* Non-linear loads are any loads which draw current which is not sinusoidal and include such equipment as fluorescent lamp, gas discharge lighting, solid state motor drives, electrical energy converters, static converters, rectifiers, arc furnaces, electronic phase control, cycloconvertors, switch mode power supplies, pulse width modulated drives and the increasingly common electronic power supply causes generation of harmonics. Harmonics are voltages and currents which appear on the electrical system at frequencies that are integral multiples of the generated frequency. It results to a significant increase in level of harmonics and distortion in power system. Transformers are one of the component and usually the interface between the supply and most non-linear loads.

Hysteresis losess

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

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

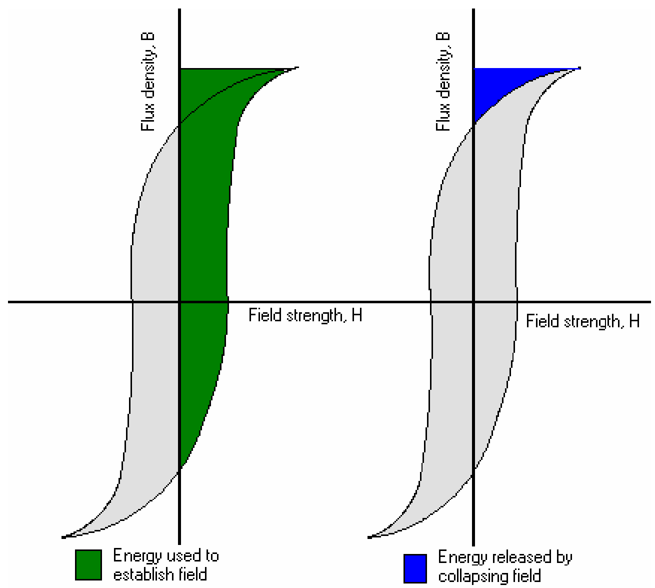


Fig. 1. B-H Loop

Core Eddy Current Losses

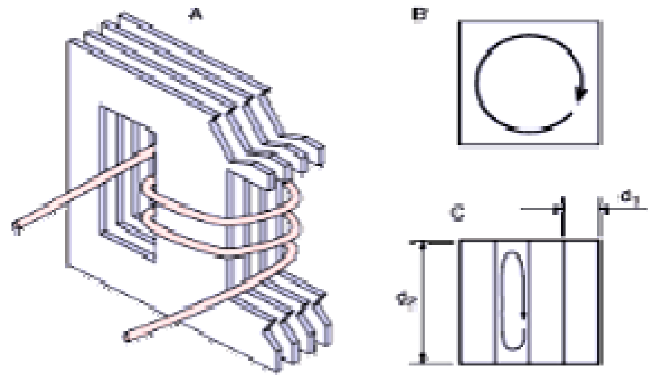


Fig. 2. Core Lamination to Reduce Eddy Current Losses

Eddy current losses are given with following equation:

$$W_e=K_e \cdot B_m^{\,2} \cdot f^2 \cdot t^2 \quad (W/kg) \qquad (2)$$

, where

K_e - the eddy current constant

f - frequency in Hertz

B_m - maximum flux density (T)

t - thickness of lamination strips

Effect of Harmonics on No-Load Losses

$$P_{TL}=P_{NL}+P_{LL} \qquad (3)$$

Where P_{NL} is no-load loss, P_{LL} is load loss, and P_{TL} is total loss.

$$\begin{aligned}
P_{NL}&=W_h+W_e=K_h\cdot f\cdot B_m^{1,6}+K_e\cdot B_m^{2}\cdot f^2\cdot t^2=K_h\cdot f\cdot B_m+K_e'\cdot B_m^{2}\cdot f^2= \\
&=K_h\cdot K_f\cdot f_n\cdot K_B^{1,6}\cdot B_{mn}^{1,6}+K_e'\cdot K_f^{2}\cdot f_n^{2}\cdot K_B^{2}\cdot B_{mn}^{2}= \qquad (4)\\
&= K_f\cdot K_B^{1,6}\cdot W_{hn}+K_f^{2}\cdot K_B^{2}\cdot W_{en}
\end{aligned}$$

$$P_{NLn}=W_{hn}+W_{en} \qquad (5)$$

Effect of Harmonics on No-Load Losses

$$P_{NL}/P_{NLn}=(K_f{\cdot}K_B{}^{1,6}{\cdot}W_{hn}+K_f{}^2{\cdot}K_B{}^2{\cdot}W_{en})/(W_{hn}+W_{en})\approx$$
$$\approx W'{\cdot}(K_f{\cdot}K_B{}^{1,6}+ K_f{}^2{\cdot}K_B{}^2)/2{\cdot}W'=(K_f{\cdot}K_B{}^{1,6}+ K_f{}^2{\cdot}K_B{}^2)/2 \qquad (6)$$

$$P_{NL=}K'{\cdot}P_{NLn} \qquad (7)$$

$$P_{NL} = P_{NLn} \cdot \sum_{i=1}^{n} \frac{K_{fi} \cdot K_{Bi}{}^{1,6} + K_{fi}{}^{2} \cdot K_{Bi}{}^{2}}{2} = P_{NLn} \cdot K' \qquad (8)$$

, where

i - high order harmonic

K' - constant

$K_e'=K_e{\cdot}t^2$ - constant

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

$K_{Bi} = \dfrac{B_{m\,i}}{B_{m\,1}}$ - high order harmonic magnetic flux density ratio

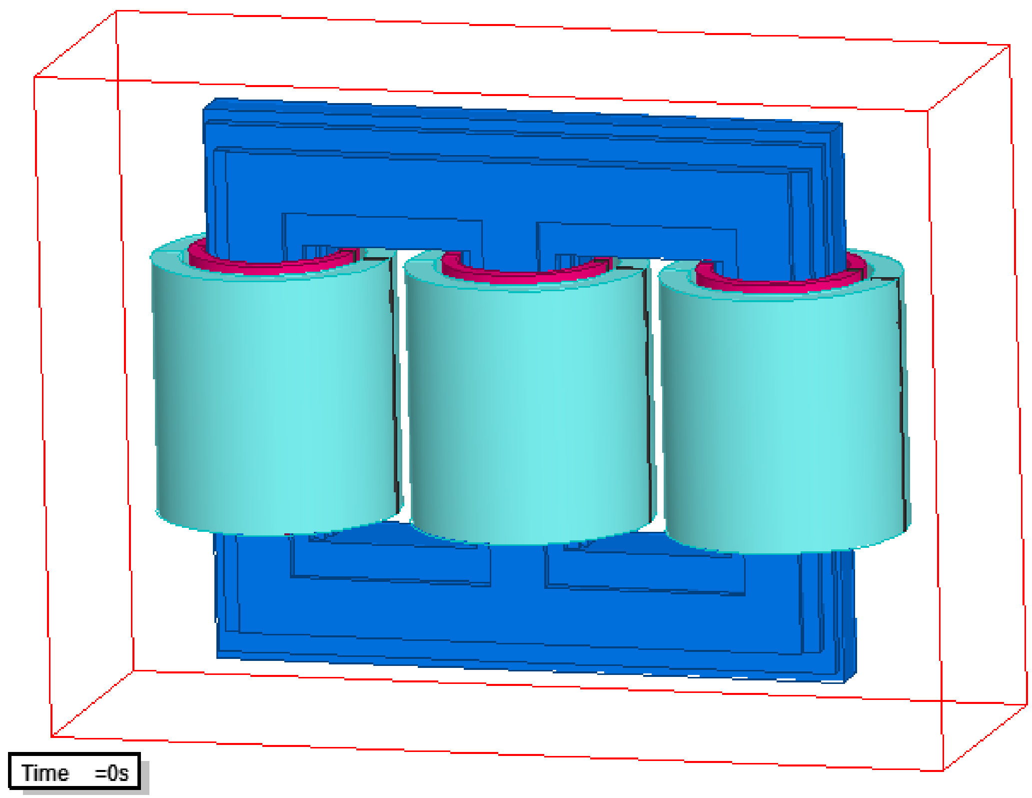
W_{hn}, W_{en} – nominal hysteresis and eddy current losses

$W'=W_{hn}=W_{en}$ – approximation for equality of nominal hysteresis and eddy current losses

TRANSFORMER DATA

Analyzed power transformer is a type T 50-24, with winding configuration Yz_n5. The rated data of the transformer are: S_n=50 kVA; U_1/U_2=20/0,4 kV; S_i=24 kV; I_1/I_2=1,443/72,17 A; u_{kn}=4 %; f_n=50 Hz; p=±2x2,5 %; Yz_n5. Transformer is presented on Fig. 3.

Ansoft/Maxwell 3D transient simulation model



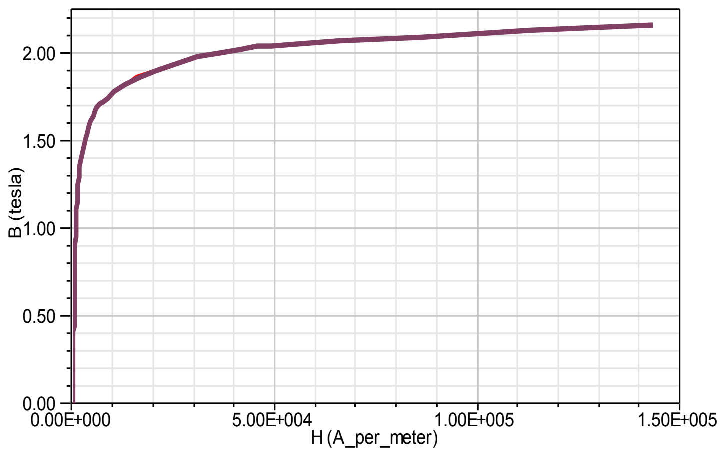


Fig. 5. B-H curve

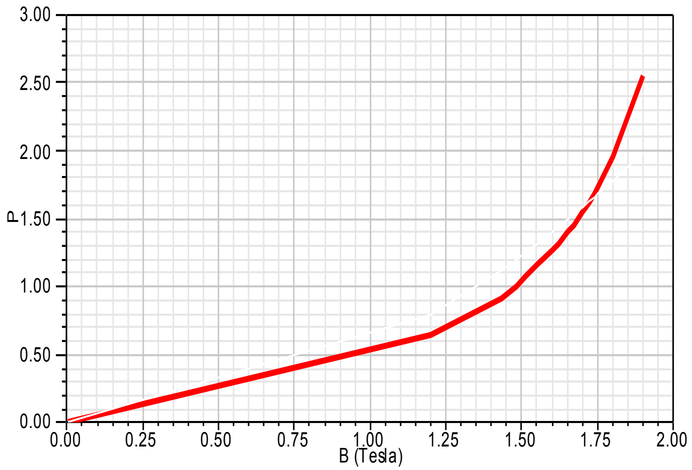


Fig.6. P-B curve

Defined three cases of current load in the transient model

Table 1.

Case \ Harmonic Order	K_{B1} (%)	K_{B3} (%)	K_{B5} (%)	K_{B7} (%)
1	100	0	0	0
2	100	2,5	3	2,5
3	100	5	6	5

Results (I case)

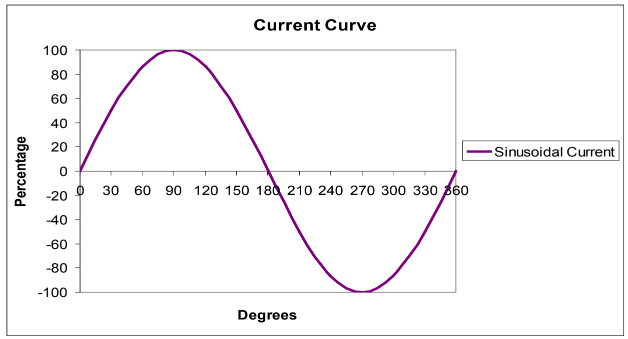


Fig. 8.a) Current curve (I case)

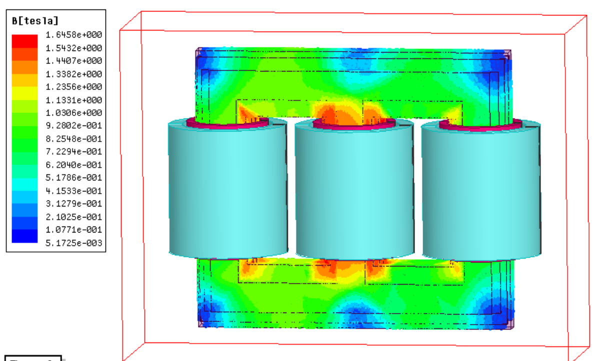


Fig. 9. Distribution of magnetic flux density (I case)

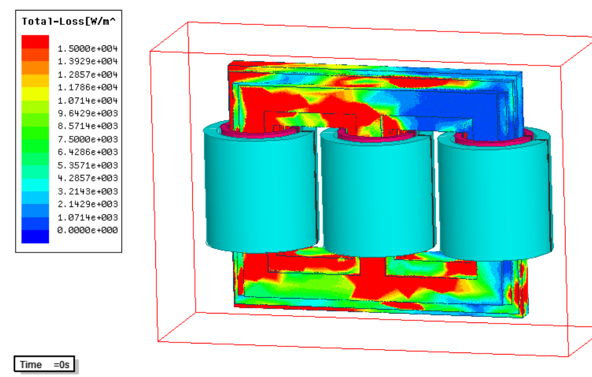


Fig. 10. Volumetric density of no-load losses (I case)

Results (II case)

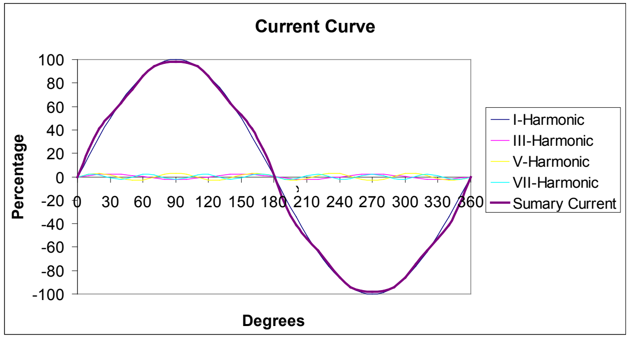


Fig. 8.b) Current curve (II case)

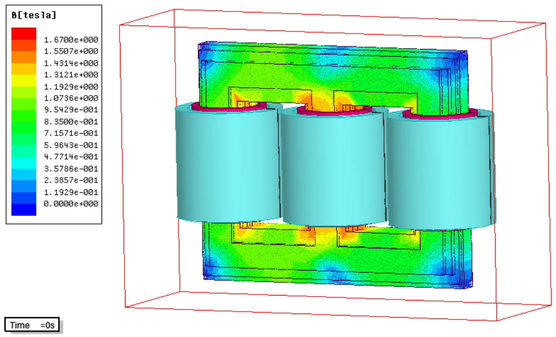


Fig. 11. Distribution of magnetic flux density (II case)

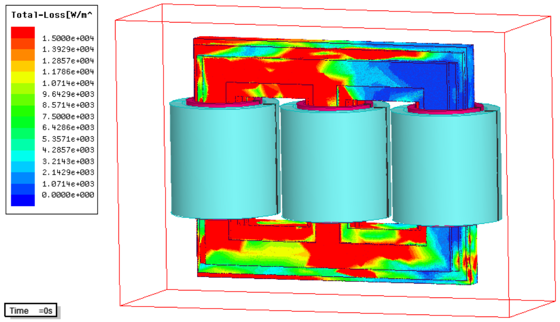


Fig. 12. Volumetric density of no-load losses (II case)

Results (III case)

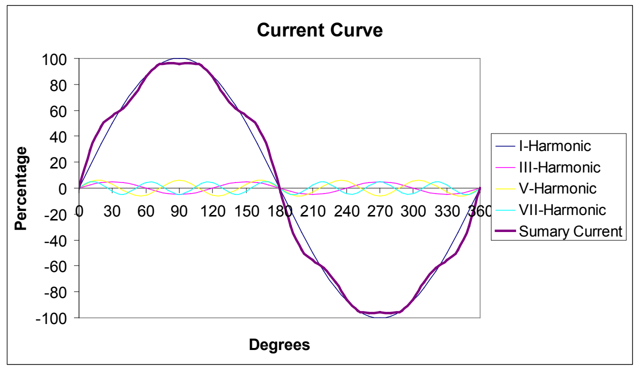


Fig. 8.c) Current curve (III case)

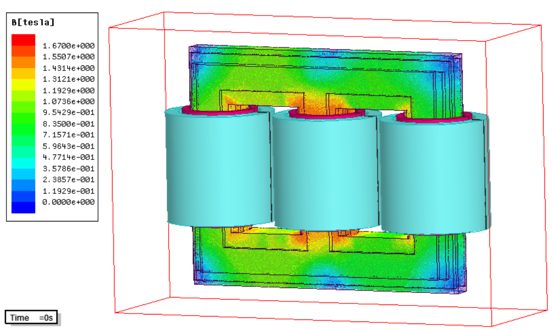


Fig. 13. Distribution of magnetic flux density (III case)

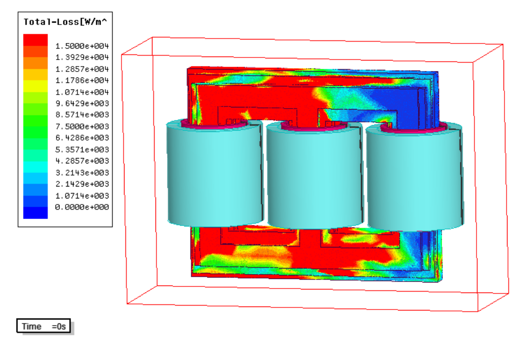


Fig. 14. Volumetric density of no-load losses (III case)

COMPARISON OF RESULTS

Table 2.

Method / No-load Losses	Simulation	Analytical	Measured	Relative Deviation (%)	Increasing of no-load losses (%)
P_{NL1} (W)	170,7	/	168,2	1,49	/
P_{NL2} (W)	174,4	176,6	/	-1,25	2,17
P_{NL3} (W)	197,2	200,2	/	-1,48	15,52

CONCLUSION

* The wide spread utilization of electronic devices has significantly increased the numbers of harmonic generating apparatuses in the power systems. This harmonics cause distortions of voltage and current waveforms that have negative effects on transformers as increased total losses.

* This paper has described power transformer no-load losses, as well as the harmonic impact on no-load losses, and has introduced a methodology based on FEM model, to predict satisfactory the harmonic impact on transformer core. The methodology introduced in this paper may be implemented at the design stage of power transformers for analyzing of no-load losses and take care for its reduction.