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Influence of Proximity Effect in Transformer with Different Loading Conditions

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Abstract: Transformers are major components in power systems and the main impact of harmonics on transformers is an increase in the rated power losses that results in temperature rise inside the transformers. The heat build-up can lead to degradation of insulation, which can shorten the transformers life and lead to eventual breakdown. The contributing factors that cause the increase in transformer losses due to harmonics are an increase in rms current, an increase in the winding eddy currents caused by proximity effect, and an increase in other stray losses. The increase in the rms current translates into an increase in conduction losses(I^2R).The impact of harmonic distortion on winding eddy current losses and the other stray losses. Proximity effect has the largest contribution to winding eddy currents under harmonic load currents. Therefore, losses are the main issues that faces any device in real life so it is very important to detect, quantify and reduce the losses as much as possible. In this paper, MATLAB model for distribution transformer was built to evaluate the losses at different loading conditions.

Keywords: Harmonic loads, other stray losses, Transformer model, winding eddy current losses.

I. INTRODUCTION

The effect of harmonics on transformers is twofold: current harmonics cause an increase in copper losses and stray flux losses, and voltage harmonics cause an increase in iron losses. The overall effect is an increase in the transformer heating, as compared to purely sinusoidal (fundamental) operation . By increasing non linear loads, harmonic levels in distribution networks has greatly increased, and increases in harmonic load current cause additional losses but the harmonic current impact on the winding eddy current lossses caused by the proximity effect is considerably high under harmonic loading conditions. The increase in the rms load current can cause an eventual increase in the conduction losses of the transformer[1].Therefore, transformer losses accounted for are no-load losses and load losses. Basically,this paper shows that influence of proximity effect at different loading conditions by using MATLAB software to develop model for the 200KVA distribution transformer.

II. TRANSFORMER LOSSES IN HARMONIC LOADS

Transformer losses under linear and harmonic loads are divided two categories no load and load loss.

$$P_T=P_{NL}+P_{LL} \qquad \ldots (1)$$

Where P_{LL} loading losses that is divided ohmic losses and eddy loss, P_{NL} no load is due to voltage induced in the core and P_T is total loss of the transformer.

A. Load losses:

Load losses can be stated as follows:

$$P_{LL}=P_{DC}+P_{EC}+P_{OSL} \qquad \ldots (2)$$

P_{DC} is an ohmic loss due to coil resistance and P_{EC} eddy current losses and P_{OSL} other stray loss [2].

1) Eddy current losses in windings:

There are two effects that can cause increase in winding eddy current losses in windings, namely the skin effect and the proximity effect. The winding eddy current loss in the power frequency Spectrum tends to be proportional to the square of the load current and the square of frequency which are due to both the skin effect and proximity effect, [4].i.e.

$$P_{EC} \,\alpha\, I^2 \times f^2 \qquad \ldots (3)$$

The proximity effect contribution to the winding eddy current losses defined as: The HV winding produces a flux density, B, due to a changing current. The flux density, B cuts through the LV winding and core. The flux density that cuts the LV winding induces an emf that produces circulating currents or eddy currents. These eddy currents oppose the current flow of the inductor on the left-hand side of the conductor strip and reduce the current density on the left side of the conductor. But these eddy currents on the right-hand side have an additive effect on the total current that causes an increase on the total current. So a greater current density is developed on the right-hand side of the conductor. This effect is called the Proximity Effect, which is caused by a current-carrying conductor or magnetic fields that induce eddy currents in other conductors in close proximity to the other current-carrying conductor or magnetic fields. These eddy currents will dissipate power, P_{ec} and contribute to the electrical loss in the windings in addition to those caused by normal ohmic losses. The eddy current loss will increase dramatically as the number of winding layers increase [6].

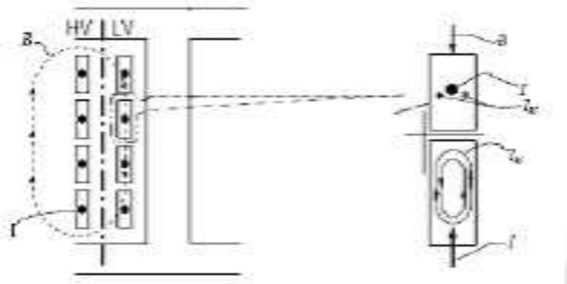


Fig 1.Forming eddy current by proximity effect [4].

2) Other stray losses in transformer:

Each metallic conductor linked by the electromagnetic flux experiences an internally induced voltage that causes eddy currents to flow in that ferromagnetic material. The eddy currents produce losses that are dissipated in the form of heat, producing an additional temperature rise in the metallic parts over its surroundings. The eddy current losses outside the windings are the other stray losses. The other stray losses in the core, clamps and structural parts will increase at a rate proportional to the square of the load current but not at a rate proportional to the square of the frequency as in eddy current winding losses. Therefore, the other stray losses increase with power of 0.8 at low frequencies and decrease at high frequency with power of 0.9.Thus this loss is proportional to square of the load current and the frequency to the power of 0.8[5] .i.e.

$$P_{OSL}=P_{TSL}-P_{EC} \qquad \dots (4)$$

The other stray loss resistance for the primary and secondary side in terms of other stray loss at rated current can be derived as:

$$R_{OSL-R,1}=\frac{P_{OSL-1}}{I^2_{1-R}}$$

$$R_{OSL-R,2}=\frac{P_{OSL-2}}{I^2_{2-R}}$$

Therefore, other stray loss resistances expressions can be used to series in the transformer electrical model.

Transformer at different Loading Conditions. The transformer was run at different loading conditions. These are full load condition, half load condition, and non-linear load [7]. For each scenario the waveforms for the currents and the voltages are presented, and at different loading conditions. Table 1 summarizes the transformer losses at full load condition.

TABLE I. LOAD LOSSES OF THE 200KVA TRANSFORMER WORKING AT FULL LOAD

Types Of Losses	Rated Losses
I^2R	968.4
Winding Eddy Current	10.4
Other Stray Loss	21.1
Total	1000

TABLE II. TRANSFORMER LOSSES AT DIFFERENT LOADING CONDITIONS

Percentage loading	Losses by Analytical Method	Losses by Simulation
70	700	986.1
80	800	1100.7
90	900	1214
100	1000	1338.7
110	1100	1445
120	1200	1562.3
130	1300	1680.3
140	1400	1797.4
150	1500	1919.4

Fig.3, illustrates the voltages and currents for the transformer primary and secondary windings. As can be seen from the figure the current waveforms in the primary and secondary sides of the Transformer contains harmonics. [3]

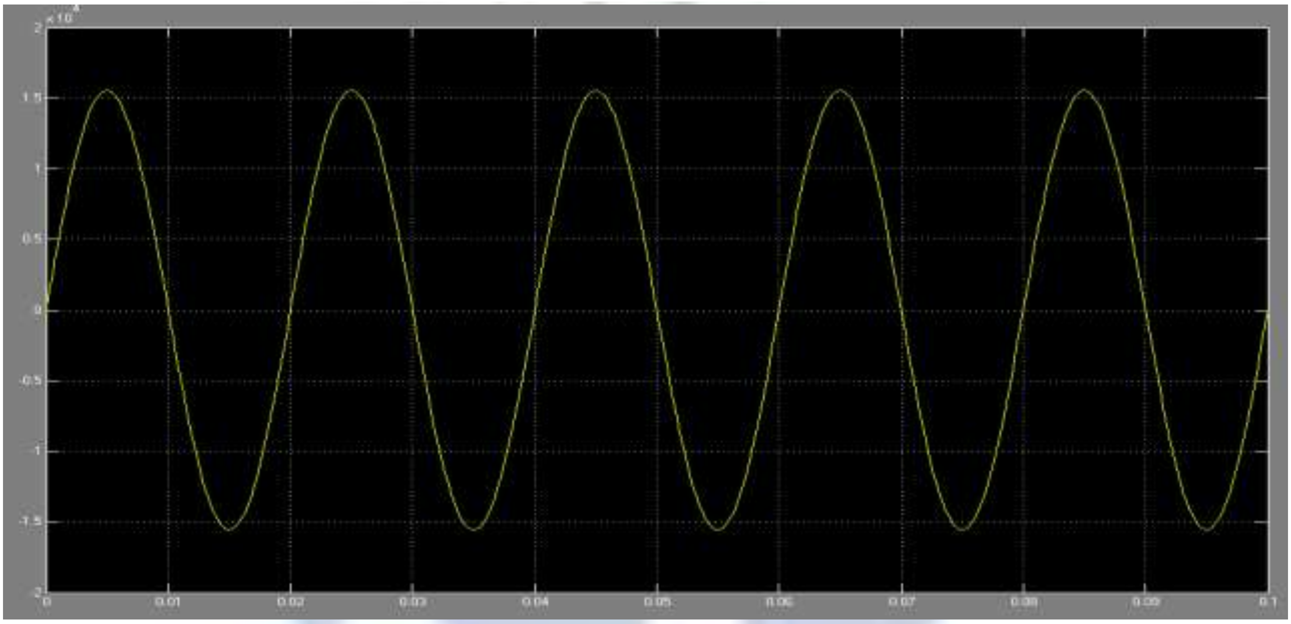


Fig. 2 Voltage waveform: Transformer

Fig. 3 Current wave form 1: Transformer.

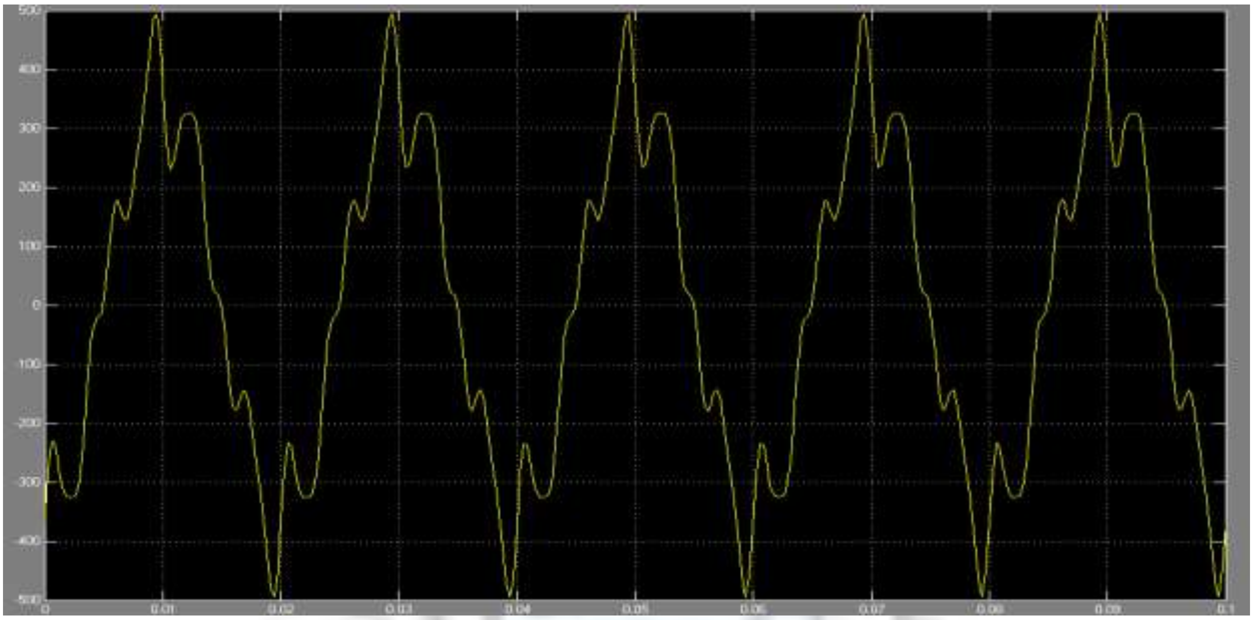
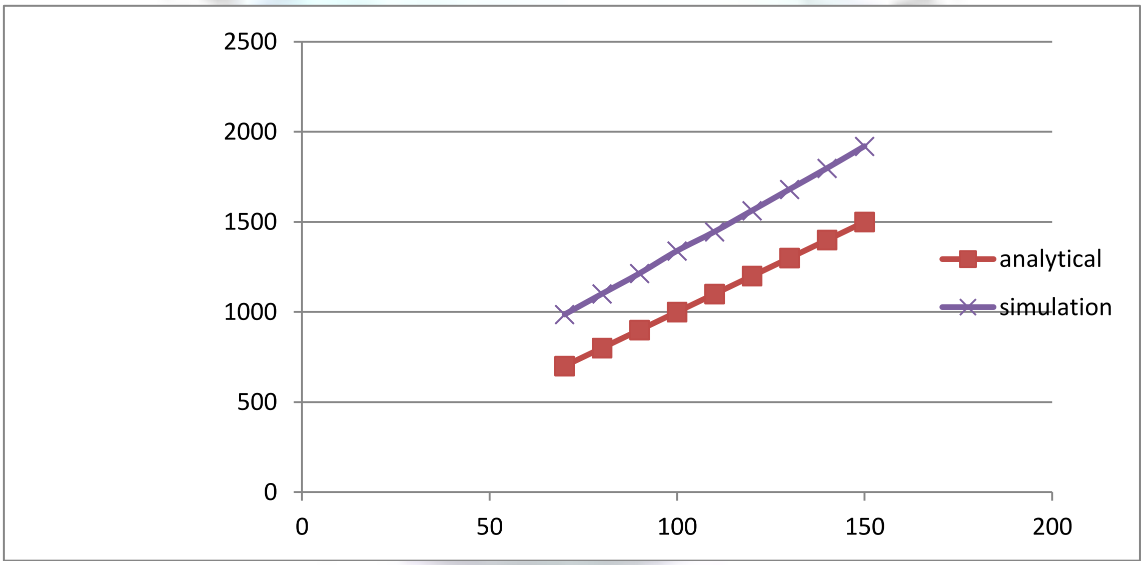


Fig. 4 Current waveform 2: Transformer

Fig.5 Transformer losses at different loading condition, Analytical and Simulation:



Percentage Loading

III. CONCLUSION

Increase of winding eddy current losses due to harmonic load currents can reduce the maximum allowable magnitude of the transformer load current. The winding eddy current losses in transformers which can be the most severe under harmonic conditions are estimated to be proportional to the square of frequency. This prediction is conservative for typical power system harmonic frequencies. The precise impact of a harmonic current on load loss depends on the harmonic frequency and the way the transformer is designed. In a transformer that is heavily loaded with harmonic currents, the excess loss can cause high temperature at some locations in the windings. This can seriously reduce the life span of the transformer and even cause immediate damage and sometimes fire. A number of methods exist to prevent overloading or failure of the distribution system, either by accommodation or elimination of the harmonic currents.

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