

Losses Reduction In Distribution Transformers

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Abstract- As electric power distribution systems continue to grow in size and complexity. Reducing losses can result in substantial savings for utility. Other benefits from loss reduction include released system capacity, and possible deferral of capital expenditures for system improvements and expansion.

While losses in distribution lines are due to copper losses, transformer losses occur due to both copper and core losses. An increase in loading will result in an increase of current flow and correspondingly greater amount of loss in the transformer. Moreover, an unbalance in the system load will increase transformer losses. The harmonic currents will cause a small increase in copper losses; however, the high frequency harmonic voltage can cause large core losses. Frequently, utilities are forced to use an oversized transformer to compensate when a large harmonic presence is indicated.

A MATLAB model for the three-phase distribution transformer was built to calculate transformer efficiency at different loading conditions.

Distribution transformers can be more efficient and economical providing that the right technology is considered. Electricity distribution companies could use the total owning cost method to make transformer purchasing decisions. This method allows the total losses over the whole life cycle to be taken into account.

Index Terms - *Distribution transformers; losses reduction, total owning cost*

I. INTRODUCTION

Losses in distribution transformers account for almost one third of overall transmission and distribution losses [1]. The efficiency of a typical modern power transformer is in excess of 97%, which sounds perfectly satisfactory. However, this figure means that up to 3% of all electrical power generated is wasted in transformer losses. These losses are far from negligible, and anything that can be done to reduce them has the potential to deliver huge savings as well as reduced environmental impact [2].

Transformer losses can be divided into two main components: no-load losses and load losses. These types of losses are common to all types of transformers, regardless transformer application or power rating.

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Core losses in transformers, which account for majority of distribution losses at low power, can be reduced by improved core materials and by reducing harmonics. Copper losses, which become more important at high power levels, can be reduced by several methods, including increasing the voltage of the distribution lines, shunt compensation, reduction of harmonics, load balance, and demand side management. There are several methods that can be employed to reduce the harmonics and consequently improve the transformer efficiency such as using filters, and zigzag transformer.

Non-linear loads, such as variable speed drives, computers, UPS systems, TV sets and compact fluorescent lamps, cause harmonic currents on the network. Harmonic voltages are generated in the impedance of the network by the harmonic load currents. Harmonics increase both load and no-load losses due to increased skin effect, eddy current, stray and hysteresis losses. The most important of these losses is that due to eddy current losses in the winding; it can be very large and consequently most calculation models ignore the other harmonic induced losses.

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 [3].

Appropriate investment in an energy efficient transformer leads to reducing energy losses, lowering the environmental pollution, reducing life cycle costs and thus increasing profitability.

II. MODELING AND SIMULATION

Losses are the main issue that faces any device in real life, so it is very important to detect, quantify and reduce the losses as much as possible. MATLAB software was used to develop models for the 200 kVA three phase distribution transformers and to calculate the transformer efficiency at different working conditions.

From the manufacturer data and test report provided by Mazoon Electricity Company, the parameters of the transformer were calculated from the equivalent circuit. Table 1 presents the parameters for the 200 kVA 11kV/ 433V (Δ -Y connection), 50 Hz distribution transformer. The load power factor was assumed to be 0.9 lagging. The model takes into account the resistance of the primary and secondary windings, the leakage inductances, the magnetizing characteristic of the core, and the core losses which is modeled by a resistance.

TABLE 1. PARAMETERS FOR THE 200 kVA

R_1	14.75 Ω
L_1	0.131 H
R_2	0.0062 Ω
L_2	0.067 mH
R_c	728 k Ω
L_m	321.5 H

From the data sheet and the B-H curve provided by Mazoon electricity company the values of the flux density (B in Tesla) and the magnetizing force (H in A/m) were obtained. Fig. 1 shows the flux-current characteristic of the transformer.

The input phase current and voltage waveforms, and the output current and voltage waveforms for 200 kVA three phase transformers at no load are presented in Fig. 2. The excitation current is nonsinusoidal because the transformer is normally designed to operate in the saturation region of the magnetic circuit to save magnetic materials. The excitation current will contain the fundamental and odd harmonics, the predominant one is the third harmonic. Because this current is nonsinusoidal, the flux in the core and hence the induced voltages in the windings will be sinusoidal. Moreover, as can be seen in the figure since the transformer is working at no-load the input phase current is the same as the excitation current.

A. Modeling of Transformer at different Loading Conditions

The transformer was run at different loading conditions. These are full load condition, half load condition, unbalance load condition, and non-linear load. For each scenario the waveforms for the currents and the voltages are presented, and transformer efficiency is calculated. Table 2 summarizes the transformer efficiency at different loading conditions.

TABLE 2. TRANSFORMER EFFICIENCY AT DIFFERENT LOADING CONDITIONS

Load Case	Efficiency
Full load	98.1 %
Half of full load	98.64 %
Linear unbalance load	96.5 %

B. Modeling of transformer feeding non-linear load

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 transformers contain harmonics. The total harmonic distortion, for the secondary current, reaches 25.46% with fundamental rms value of 262.62 A. The percentage for each harmonic component is presented in Fig. 4. The percentage of harmonic component with respect to peak rated current is depicted in Table 3. According to the IEC and IEEE Standards [4-5], the load losses due to any non-sinusoidal load currents can be calculated as follows:

$$P_{LL}(h) = I^2 R(h) + P_{SL}(h) \quad (1)$$

In order to make the calculation with limited data (only the manufacture certified test report), certain assumptions have been made that are considered to be conservative. All of the stray loss is assumed to be winding eddy-current loss. These assumptions may be modified based on guidance from the manufacturer of the transformer.

The load losses of the 200 kVA transformers working at full load, when feeds balance linear load, is presented in Table 4.

TABLE 4. THE LOAD LOSSES OF THE 200 kVA TRANSFORMERS WORKING AT FULL LOAD

Load losses	3000 W
$I^2 R_{eq}$	2800 W
Eddy Current losses	200 W

If the transformer feeds non-linear load the current waveforms will contain harmonic as presented in Fig. 3. The losses from the winding eddy-current will increase with the square of the load current and the square of the frequency. The winding eddy current losses are expressed as [6]:

$$P_{eddyH} = P_{eddy} \sum I_n^2 n^2 \quad (2)$$

where,

- P_{eddyH} = winding eddy current loss at harmonic frequency
- P_{eddy} = winding eddy current loss at rated load and frequency (transformer feeding linear load)
- I_n = rms current of the n harmonic (per unit of rated load current)
- n = harmonic order

Therefore the eddy current losses increases to 720 W (3.6*200) when the transformer feeding non-linear load, as a result transformer efficiency will decrease. Harmonic can be reduced by designing a single -tuned shunt filter and connecting it across each phase on the transformer secondary side as a result efficiency would be improved.

III. LIFE CYCLE COST OF TRANSFORMERS

To perform the economical analysis of transformer, it is necessary to calculate its life cycle cost, sometimes called total cost of ownership, over the life span of transformer.

Taking only purchase price and the cost of losses into account the Total Cost of Ownership can be calculated by [7-9]:

$$TCO = PP + A \times P_o + B \times P_K \quad (3)$$

where:

PP is the purchase price of transformer,
A represents the assigned cost of no-load losses per Watt,
Po is the rated no-load loss,
B is the assigned cost of load losses per watt,
Pk is the rated load loss.
A and B factors are calculated as follows:

No-load loss capitalization factor (A)

$$A = \frac{(i + 1)^n}{i \cdot (1 + i)^n} \times C_{kwh} \times 8760$$

Load loss capitalization factor (B)

$$B = \frac{(i + 1)^n}{i \cdot (1 + i)^n} \times C_{kwh} \times 8760 \times \left(\frac{I}{I_r}\right)^2$$

where:

i interest rate [%/year]
n lifetime [years]
C_{kwh} kWh price [OR/kWh]
8760 number of hours in a year [h/year]
I loading current [A]
I_r rated current [A]

These formulae assume that energy prices and the loading are constant over the transformer life.

IV. CONCLUSIONS

Typical 200 kVA three-phase distribution transformer was modeled by MATLAB under different loading conditions. Results reveal that the best efficiency was found when the transformer is working at half of the full load. In addition, the worst case to run these transformers is for nonlinear loads. Installing harmonics filters is a must to improve the transformer efficiency.

The total owning cost method provides an effective way to evaluate various transformer initial purchase prices and cost of losses. Electricity distribution companies could use the total owning cost method to make transformer purchasing decisions. This method allows the total losses over the whole life cycle to be taken into account.

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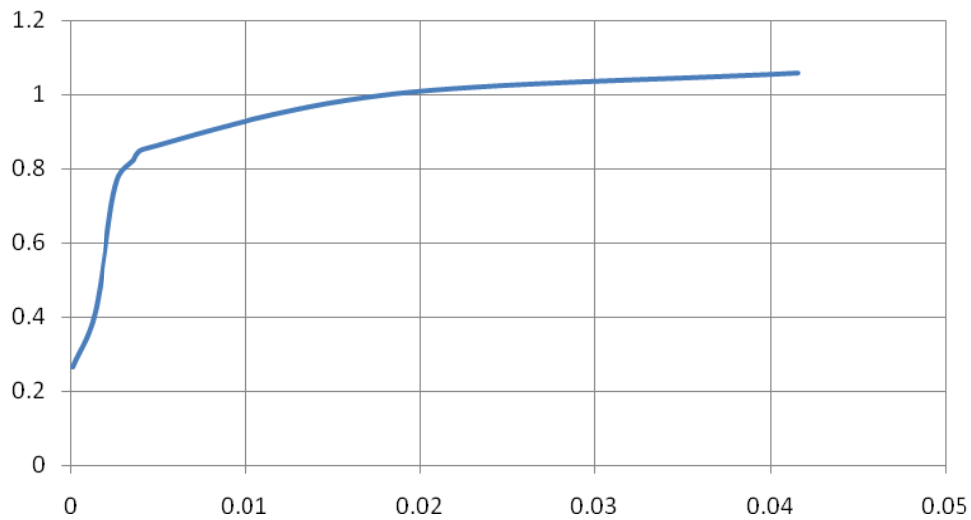


Figure 1. The Flux-Current characteristic of 200 kVA transformer

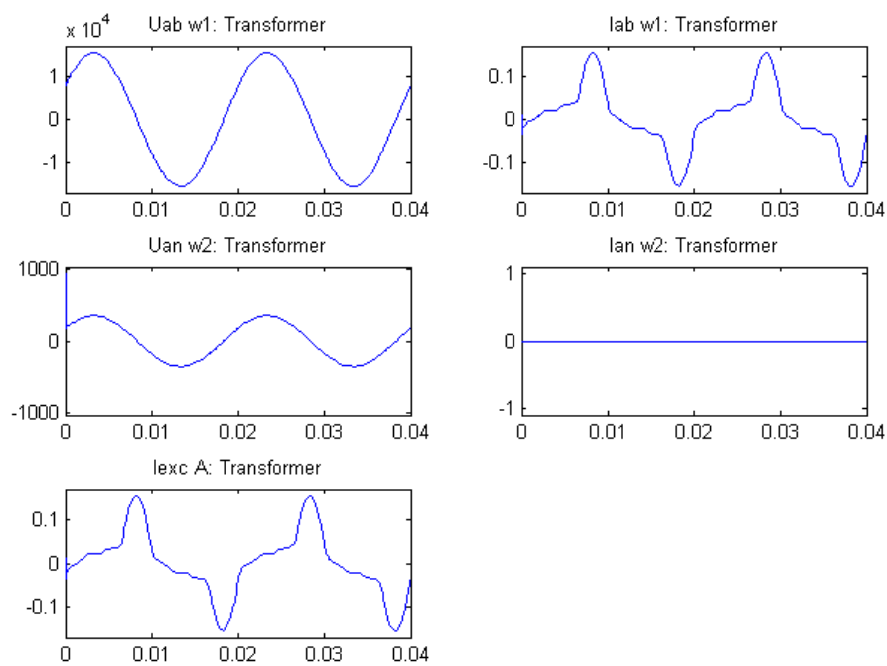


Figure 2. The current and voltage waveforms at no-load

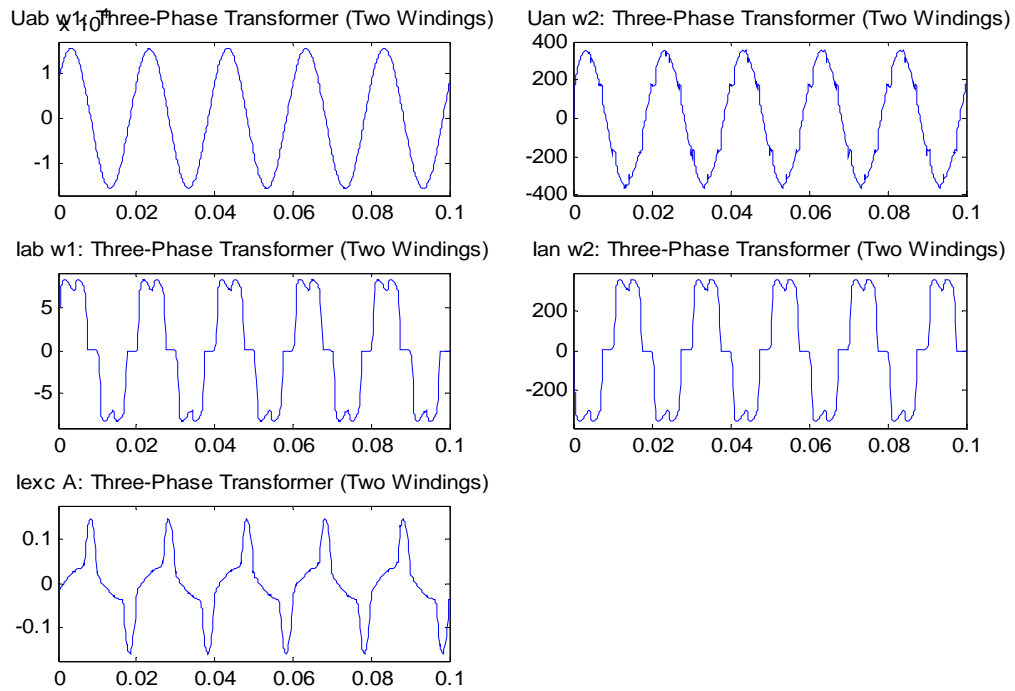


Figure 3. The current and voltage waveforms for the nonlinear load

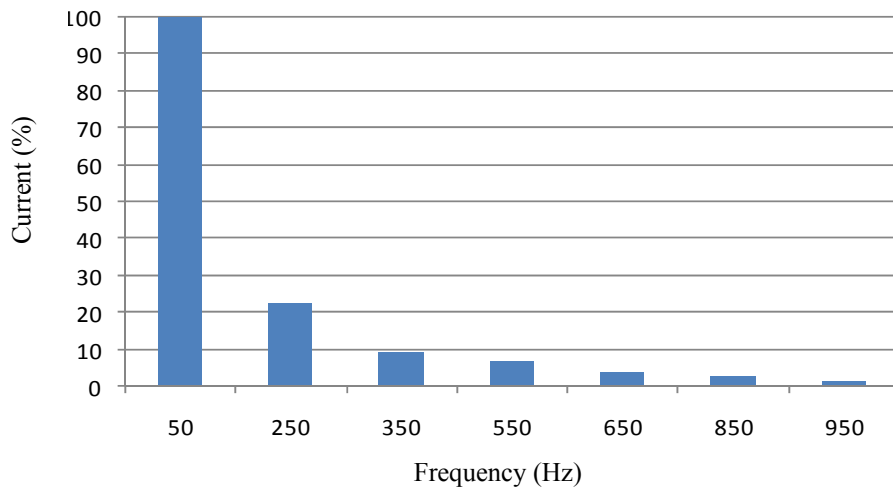


Figure 4. Current harmonic spectrum

TABLE 3. THE PERCENTAGE OF HARMONIC COMPONENT WITH RESPECT TO PEAK RATED CURRENT (377.13 A)

Harmonic order (h)	h^2	Peak Harmonic current (I_h), A	I_h/I_{rated} pu	$(I_h/I_{rated})^2$	$(I_h/I_{rated})^2 * h^2$
1	1	371.45	0.985	0.97	0.9702
5	25	82.6	0.219	0.048	1.1990
7	49	34.28	0.091	0.0083	0.4058
11	121	25.35	0.067	0.0045	0.5432
13	169	13.41	0.036	0.0013	0.2190
17	289	9.66	0.026	0.00068	0.1954
19	361	5.38	0.014	0.000196	0.07076
Summation				1	3.6