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Investigation and Analysis Efficiency of a Sinusoidaly and Non-Sinusoidaly Supplied Transformer under Linear and Non-Linear Loading

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Abstract:- The single line diagram of the transformer is shown in Figure 1. Primary and secondary voltage supply and current load harmonic values are also measured to determine transformer parameters.

When Figure 4, Figure 5, Figure 6 and Figure 7 are examined, the results obtained are examined for the efficiency of the transformer and the annual cost of losses for 4 operating conditions.

Keywords*:- Transformer, Efficiency, Distorted and Non-distorted Voltage and Current, Power Engineering.*

I. INTRODUCTION

Modern electrical distribution systems, especially 120/208 volt harmonic voltage systems, generally provide highly distorted harmonic load current, increasing transformer losses and decreasing energy efficiency.[1].

Transformers, motors, generators etc. since the supply voltage of electrical machines is in distorted harmonic wave form, this harmonic current creates additional dielectric and thermal in these machines and creates increased core loss, especially in laminated sheets. [2].

It is sufficient to model the transformer iron core as a shunt linear inductance and a resistor connected in parallel. To model the nonlinear behavior of the core, voltage dependence should also be included [3]

One of the factors determining the use of transformers is the increasing number of photovoltaic power plants and distorted load currents in our homes and industries, resulting in consumers' need for a stable and undistorted sine wave supply. [4]

II. EFFICENCY AND APPLICATION

The efficiency of the transformer is found by the ratio of output power to input power.

$$\eta = \frac{P_ç}{P_g} = \frac{P_ç}{P_ç + P_K} \quad (1)$$

$$P_K = P_{cu} + P_{fe} \quad (2)$$

It includes the results of a transformer fed with distorted and non-distorted voltage and current, Efficiency were taken experimentally. Efficiency can be increased by reducing iron and copper losses.

As mentioned before harmonic section, a transformer to which a non-sinusoidal voltage is applied or a transformer with non-linear load causes harmonics to occur. The resulting harmonic also causes heating. It also causes a decrease in the life of the transformer, resonance between the transformer windings, and damage to the insulation.

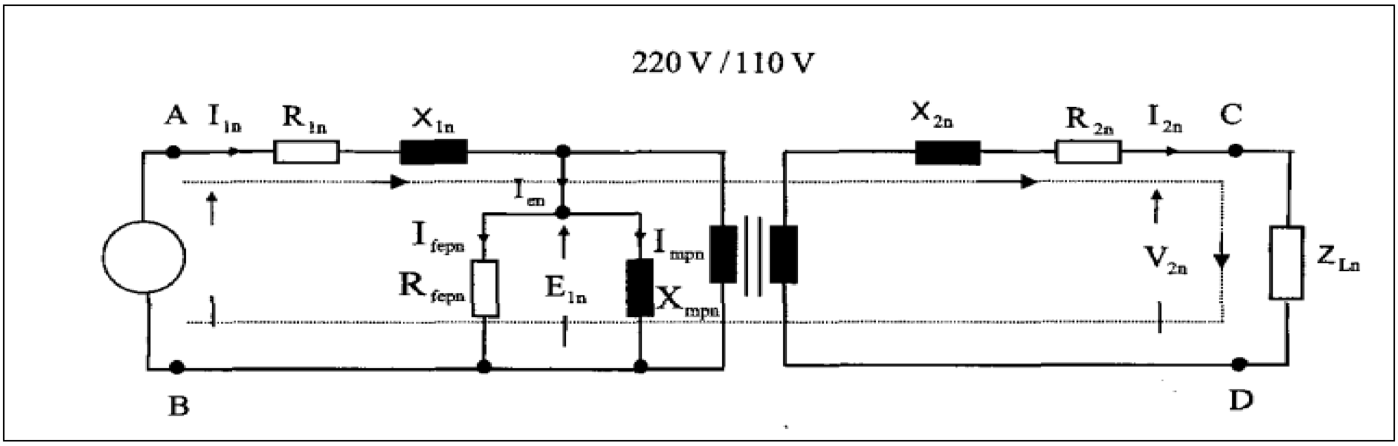

Fig 1: Single Line Diagram of the Transformer

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III. ANALYSIS AND MODELING

For each harmonic frequency, each harmonic excitation current (I_extn)¯and each harmonic core voltage are found using the primary and secondary winding parameters.

These parameters; Primary and secondary winding resistances (R_{1n}, R'_{2n}), Leakage reactance (containing harmonic frequency) (X_{1n}, X'_{2n}), A-B and C-D shown in Figure 1 are terminal points. [8]

Source impedance: $\bar{Z}_{sn}$ Load impedance: Z_{Ln} Primary Winding Current I_{1n} , Secondary Winding Current: I_{2n}.

According to Figure 1. transformer performance is calculated with basic formulas containing 4 parameters in the equivalent circuit (R_{1n}, R'_{2n}) (X_{1n}, X'_{2n}) primary and Secondary winding resistances and reactances , R_{fen} (Non-linear iron core resistance), X_{mn} (Non-linear magnetization inductance)

- *Power Equations*

$$R_{sn}.I_{1n}^2 = R_{1n}.I_{1n}^2 + P_{fcn} + R_{2n}.u_n^2.\frac{I_{2n}^2}{u_n^2} + R_{Ln}.u_n^2\frac{I_{2n}^2}{u_n^2} \quad (3)$$

$$R_{sn}.I_{1n}^2 = R_{1n}.I_{1n}^2 + P_{fcn} + R_{2n}.I_{2n}^2 + R_{Ln}.I_{2n}^2 \quad (4)$$

$$P_{fcn} = R_{sn}.I_{1n}^2 - R_{1n}.I_{1n}^2 - R_{2n}.I_{2n}^2 - R_{Ln}.I_{2n}^2 \quad (5)$$

$$P_{fcn} = (R_{sn} - R_{1n}).I_{1n}^2 - (R_{2n} + R_{Ln}).I_{2n}^2 \quad (6)$$

$$X_{sn}.I_{1n}^2 = X_{1n}.I_{1n}^2 + Q_{xmn} + X_{2n}.u_n^2.\frac{I_{2n}^2}{u_n^2} + X_{Ln}.u_n^2\frac{I_{2n}^2}{u_n^2} \quad (7)$$

$$X_{sn}.I_{1n}^2 = X_{1n}.I_{1n}^2 + Q_{xmn} + X_{2n}.I_{2n}^2 + X_{Ln}.I_{2n}^2 \quad (8)$$

$$Q_{xmn} = X_{sn}.I_{1n}^2 - X_{1n}.I_{1n}^2 - X_{2n}.I_{2n}^2 - X_{Ln}.I_{2n}^2 \quad (9)$$

$$Q_{xmn} = (X_{sn} - X_{1n}).I_{1n}^2 - (X_{2n} + X_{Ln}).I_{2n}^2 \quad (10)$$

$$tg\varphi_n = \frac{Q_{xmn}}{P_{fcn}} \quad (11)$$

According to equations (10) and (11),

$$\bar{V}_{cn} = \bar{V}_{sn} - (R_{1n} + jX_{1n})\bar{I}_{1n} \quad (12)$$

$$I_{extn} = \frac{P_{fcn}}{V_{cn}.\cos\varphi_n} \quad (13)$$

- *Examining The Cost Annual Losses Of Four Different Conditions*

A 2 kVA, 220 / 110 V, 50 Hz transformer was used. Its operation under 4 different conditions was examined. The four conditions mentioned total loses and efficiency are given below:

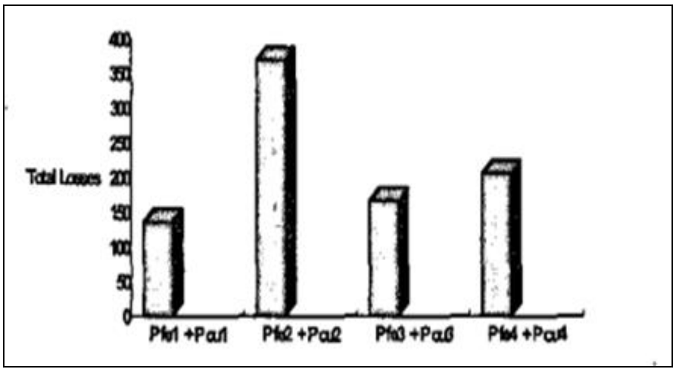

Fig 2: Total Losses

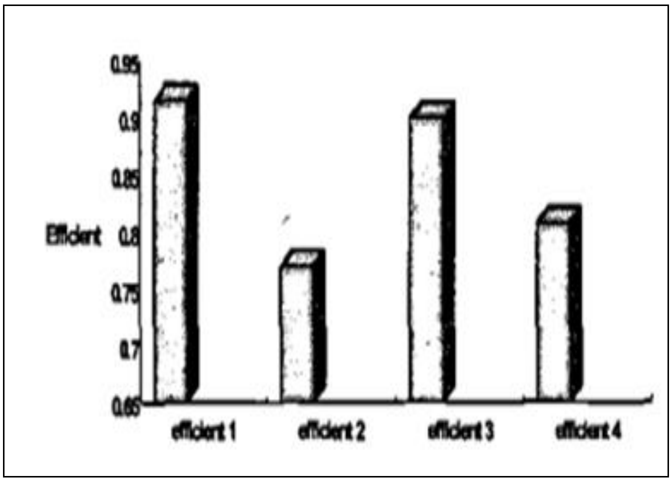

Fig 3: Efficiency

Table 1: Outputting the Values Taken in Four Different Studies on a Table.

	Sinusoidal Voltage Supply / Loaded With Linear Loa	Sinusoidal Voltage Supply / Loaded With Non-Linear Load	Non-Sinusoidal Voltage Supply / Loaded with Linear Load	Non-Sinusoidal Voltage Supply Loaded with Non-Linear Load
Total Losses $P_{fe}+P_{Cu1}+P_{cu2}$	136	369	166	205
Efficiency	% 91.5	% 77	% 90	% 81

IV. EXPERIMENTAL RESULTS

Transformer rating 2 kVA, 220 V / 110 V, 50 Hz, Harmonic Analyzer, Fluke 43 B, Load 10 Ohm, Diode IX 45 DS 39- 12A, 820 L. [5].

In this study the effects of harmonic on transformer parameters, such as core losses are investigated for non-distorted and distorted current loaded transformer under non-distorted and distorted voltage supply. When Fig. 4, Fig. 5, Fig. 6, and Fig. 7, are examined, the results obtained show the annual cost of transformer losses for 4 operating conditions is examined.

The reason why annual costs seem low is that the transformer is small and powerful. In places where higher power transformers are used, such as workplaces and factories, the annual costs of losses also increase to higher figures.

Harmonics also reduce efficiency. The choice of core material is very important for efficiency. If materials that enter saturation later are used in the core of the transformer, the efficiency increases proportionally.

The amount of loss resulting from harmonic current can reach very high levels. High harmonic current may damage the elements and transformers connected to the network. Apart from harm, harmonic currents cause heating and decrease in efficiency.

Harmonic currents depend on the type of load. Voltage harmonic distortion in energy distribution systems should not exceed 5%. Current distortion is several times higher than voltage distortion. Harmonics can be reduced with filtering systems.

V. CONCLUSION

➢ *According to the Analysis,*

- The annual loss of the non-distorted voltage supply and with non-distorted current load is 4807 TL;
- The annual loss of the non-distorted voltage supply and with distorted current load is 13042 TL;
- The annual loss of the distorted voltage supply and with non-distorted current load.is 5867 TL;
- The annual loss of the distorted voltage supply and with distorted current load is 7246 TL.

➢ *The Results Obtained from Measurements and Calculations are Given Below*

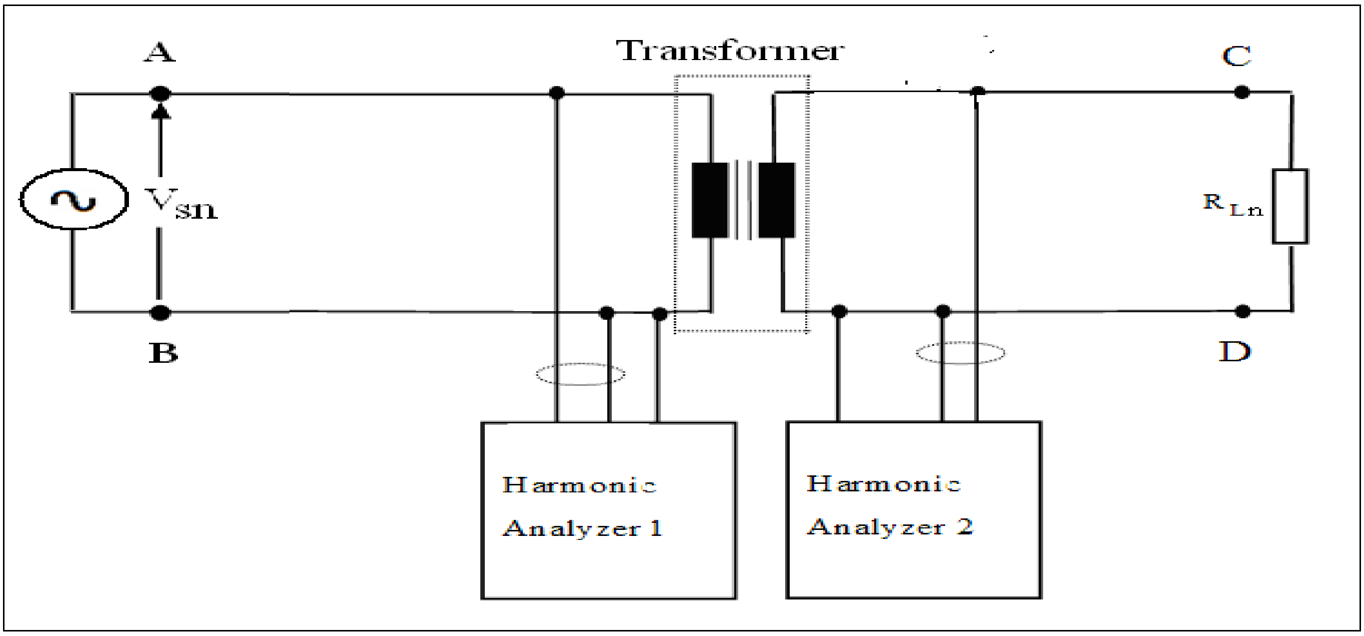

Fig 4: Experimental Connection Diagram of the Transformer Fed by Non-Distorted Voltage Supply and with Non-Distorted Current Load

When Annual cost analysis for a transformer fed with a non-distorted voltage supply and with non-distorted current load is calculated one year electrical price lost. $P_{cu} + P_{fe} + P_{cu2} = 136\ W$.

We see that it is equal for 24 hours $136 \times 24 = 3264\ W$h.

It is possible for one year $3264 \times 365 = 1191{,}36\ kW$h.

It is possible the electricity unit price is 4,03499 TL on 01.04.2024. One year lost electricity cost $1191{,}360 \times 4{,}03499 = 4807$ TL.

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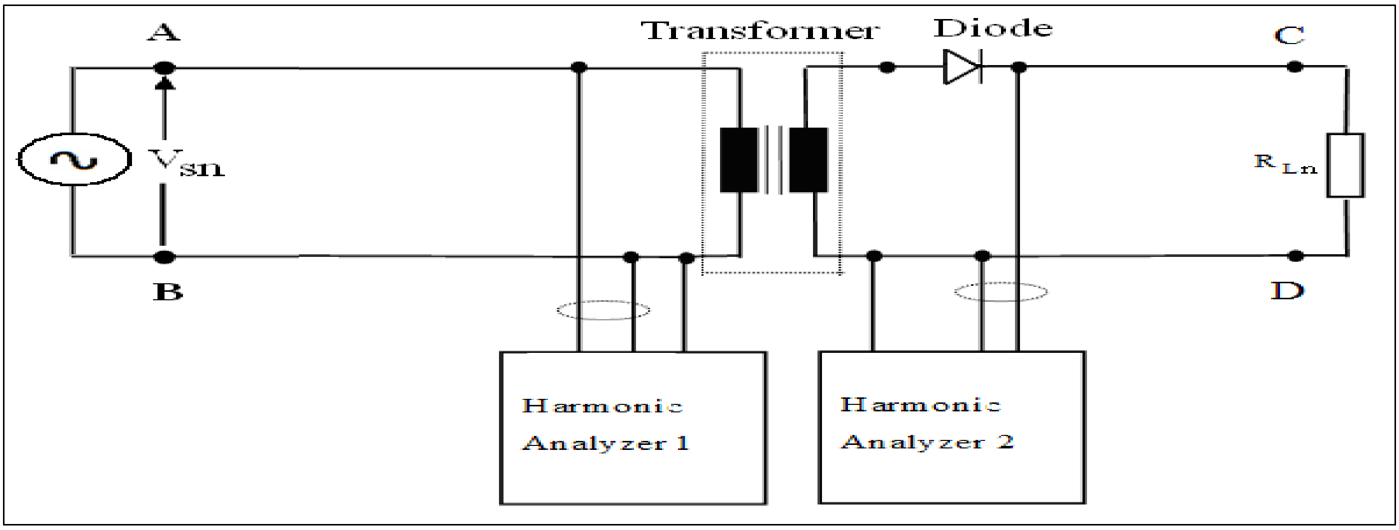

Fig 5: Experimental Connection Diagram of the Transformer Fed by non-distorted voltage supply and with distorted current load.

When Annual cost analysis for a transformer fed with a non-distorted voltage supply and with distorted current load is calculated one year electrical price lost. $P_{cu} + P_{fe} + P_{cu2} = 369\ W$
.
We see that it is equal for 24 hours $369 \times 24 = 8856\ W$h.

It is possible for one year 8856x365=3232,44 kWh

It is possible the electricity unit price is 4,03499 TL on 01.04.2024. One year lost electricity cost $3232{,}440 \times 4{,}03499 = 13042$ TL.

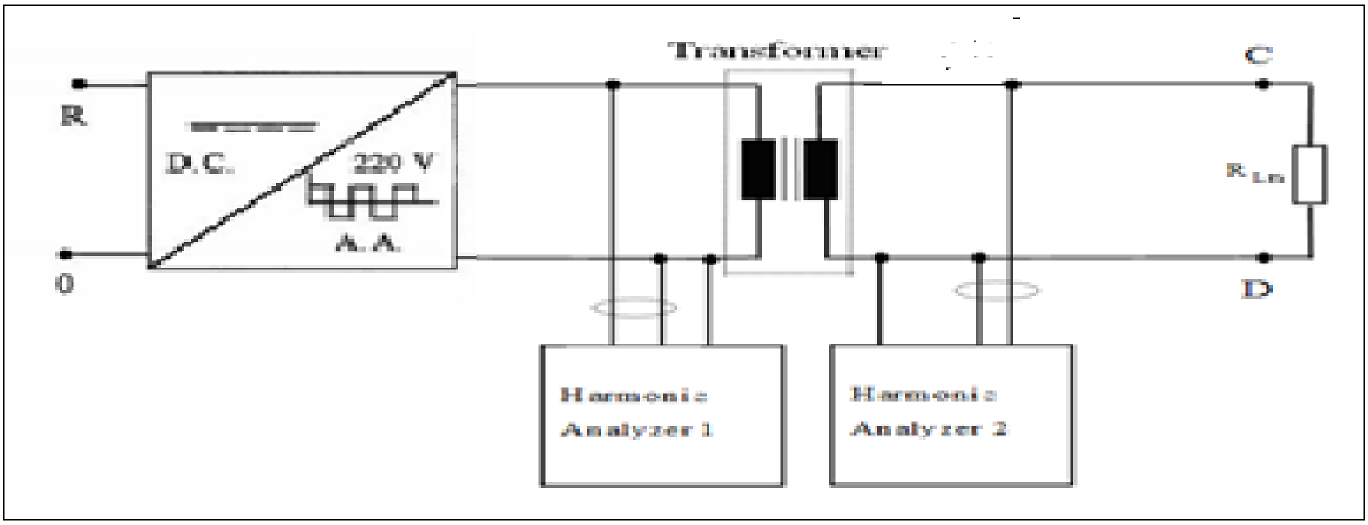

Fig 6: Experimental Connection Diagram of the Transformer Fed by Distorted Voltage Supply and with Non-Distorted Current Load

When Annual cost analysis for a transformer fed with a distorted voltage supply and with non-distorted current load is calculated one year electrical price lost. $P_{cu} + P_{fe} + P_{cu2} = 166\ W$.

We see that it is equal for 24 hours $166 \times 24 = 3984\ W$h.

It is possible for one year $3984 \times 365 = 1454{,}16\ kW$h.

It is possible the electricity unit price is 4,03499 TL on 01.04.2024. One year lost electricity cost $1454{,}16 \times 4{,}03499 = 5867$ TL.

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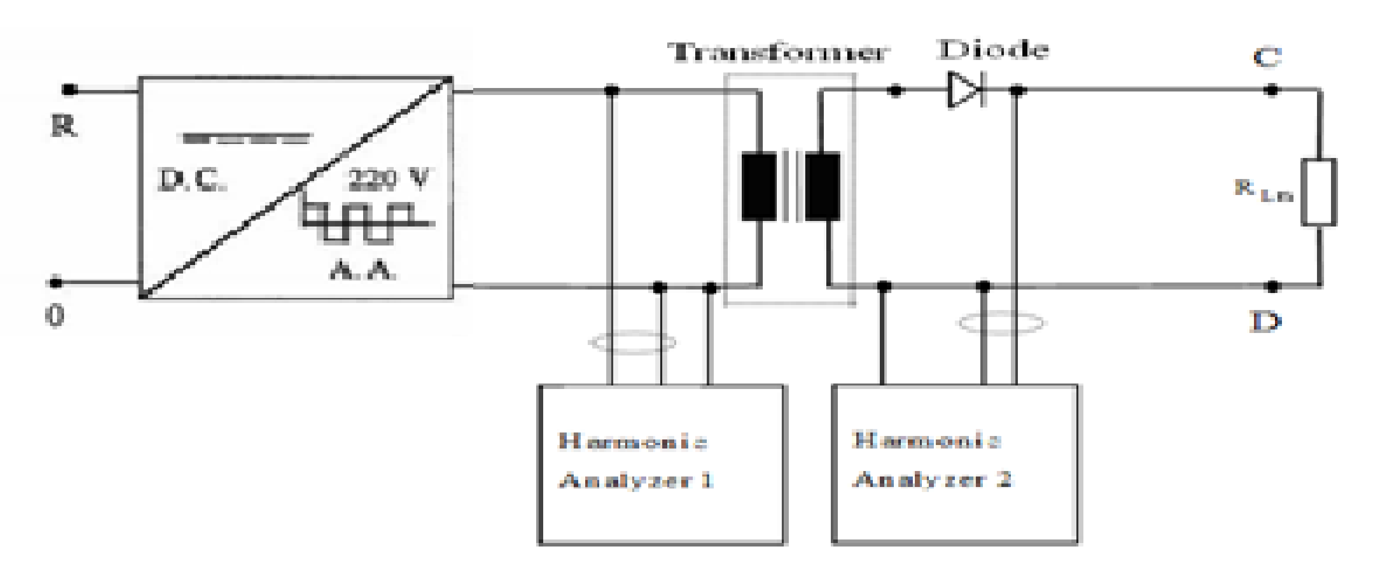

Fig 7: Experimental Connection Diagram of the Transformer Fed by by distorted Voltage Supply and with Distorted Current Load

When Annual cost analysis for a transformer fed with distorted voltage supply and with distorted current load is calculated one year electrical price lost. $P_{cu} + P_{fe} + P_{cu2} = 205\ W$.

We see that it is equal for 24 hours $205 \times 24 = 4920\ W$h.

It is possible for one year $920 \times 365 = 1795{,}8\ kW$h.

It is possible the electricity unit price is 4,03499 TL on 01.04.2024. One year lost electricity cost $1795{,}800 \times 4{,}03499\ = 7246$ TL.

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