European Journal of Technique

journal homepage: https://dergipark.org.tr/en/pub/ejt

Vol.12, No.2, 2022

Experimental Investigation of the Variation of Power and Iron-Copper Losses in the Loaded Operation of the Transformer

Mehmet Ali Özçelik[1*], Ahmet Aycan[2]

[1*]Gaziantep University, Technical Science, Electrical and Energy Department, Gaziantep, Turkey. (e-mail: ozcelik@gantep.edu.tr).
[2]Gaziantep University, Technical Science, Electrical and Energy Department, Gaziantep, Turkey. (e-mail: aycan@gantep.edu.tr).

ARTICLE INFO

Received: October, 31.2022
Revised: December, 22.2022
Accepted: December, 26.2022

Keywords:
Transformers
Iron losses
Copper losses
Hysteresis losses

Corresponding author: *M.Ali Özçelik*

ISSN: *2536-5010* | e-ISSN: *2536-5134*

DOI: https://doi.org/10.36222/ejt.1196829

ABSTRACT

Transformers are one of the vital equipment widely used in the transmission, distribution, and power systems of electrical energy. An equivalent circuit can be created, and losses can be calculated according to various operating experiments of the transformer. In the study, the variation of iron losses according to the voltage values applied to the primary circuit of the transformer was examined, and a non-linear change in iron losses was observed depending on the applied voltage. When a load is connected to the transformer's secondary, it has been observed that as the load increases, the iron losses do not change and remain constant depending on the load. The copper losses at various loads were calculated by increasing the load connected to the secondary transformer. It has been shown with experimental studies and calculations that copper losses show a non-linear variation depending on the load.

1. INTRODUCTION

Although the demand for electrical energy is increasing day by day, the alternating current (AC) voltage level must be increased to transmit electrical energy effectively [1-2]. Power transformers have been used to raise and lower the electrical energy at constant power and constant frequency [3]. In the operation of transformers, electrical energy has been transferred between two or more circuits by electromagnetic induction [4-5]. Although there are no moving parts in transformers, losses occur in transformers like in all electrical machines [6]. Energy losses due to hysteresis and eddy currents in the transformer core are called iron losses, and energy losses due to resistance in the winding are called copper losses [7].

As long as the transformer is connected to the energy system, apart from the power that draws power from the system and the load draws, the current-carrying part (conductor) and the magnetic flux-forming part (iron core) are the power losses [8-9]. Although mathematical expressions have been developed to include hysteresis and eddy current losses in the calculations, the experimentally measured core losses are greater than the value obtained by the calculations [10]. It is accepted that while iron losses are directly proportional to the square of the voltage value, copper losses are proportional to the square of the winding current [11].

In this study, the load operation of the transformer was made experimentally, and the power change and the change of iron and copper losses in the ohmic and inductive loads were examined and commented on.

2. MATERIAL AND METHOD

2.1. Loaded circuit of transformer and experimental setup

In the AC operation of transformers, the primary and secondary windings have effective resistance (R) and inductive reactance (X_L). Using the conversion ratio (a) between the primary and secondary windings, the primary circuit can be drawn by converting it to secondary terms. In Figure 1, the connection circuit of the transformer is loaded operation is given. Variable AC is applied to the Tr transformer with a regulated autotransformer (variac), the mains frequency is 50 Hz. The idle power of the transformer meets the iron losses. Resistive and inductive loads are used at the transformer's secondary output.

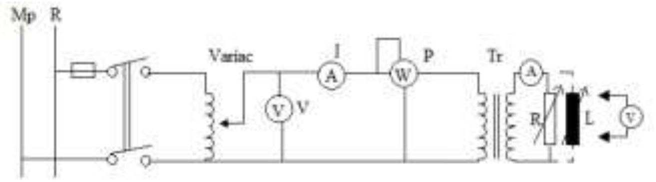

Figure 1. Loaded Operating Circuit of the Transformer

The experimental setup is shown in Figure 2. The power coefficient of the transformer was measured with a cosφ-meter. Incandescent lamps were used as ohmic load. The voltage applied to the transformer has been reduced by the autotransformer starting from high. The current drawn by the circuit at each voltage value, the power, and the power coefficient were measured and recorded in the tables.

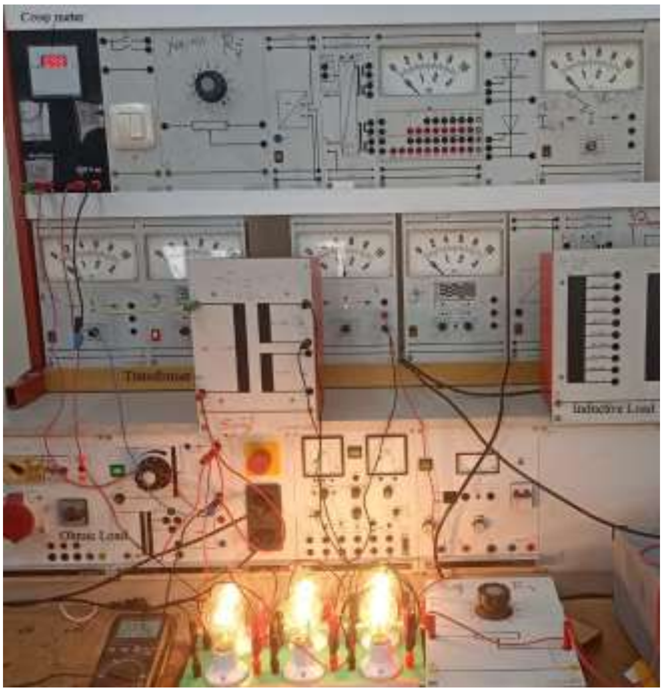

Figure 2. Experimental Setup

Core losses due to fuco-hysteresis losses are constant at all working loads. These losses are found by the no-load test of the transformer. Fuko losses are minimized by making the core from thin hair. Hysteresis losses are also reduced by adding silicon to the iron.

2.2. Values taken in the loaded operation of the transformer

The values in Table 1 were taken by loading a single-phase transformer with an ohmic load. The transformer is loaded up to 1.2 times the rated secondary current.

TABLE I
CURRENT VARIATION AT OHMIC LOAD

U_1 (V)	U_2 (V)	I_2 (A)
220	115	0 (idle)
220	114	0,215
220	113	0,430
220	112	0,650
220	111	1,22
220	110	1,45
220	109	1,65

The difference between the voltage values when the secondary voltage of the transformer is empty and loaded is called voltage regulation. Transformer voltage regulation, the rate of change of output terminal voltage of a transformer as a result of changes in connected load current is given below. Here, U20 is the no-load secondary voltage and U2 is the loaded secondary voltage.

$$\%Reg = \frac{U_{20}-U_2}{U_2}100 = \frac{115-110}{110}100 = \%4{,}5 \quad (1)$$

Current and power changes in inductive load are given in Table 2.

TABLE II
CURRENT AND POWER VARIATION IN INDUCTIVE LOAD

U_1 (V)	P_{fe} (W)	Q_1 (VAR)	V_2(V)	I_2(A)	Load (Henry)
220	15	32	115,7	0	0
220	15	60	115,5	0,264	1,2
220	15	65	115,4	0,32	1
220	15	75	115,2	0,4	0,8
220	15	90	115,1	0,54	0,6
220	15	120	114,6	0,81	0,4
220	15	205	113	1,64	0,2

In inductive load, as the current value increased, the reactive power drawn from the grid increased significantly. This shows us that in the case of inductive load, the reactive component of the current drawn from the grid increases significantly. The inductance-reactive power change is seen in Figure 3.

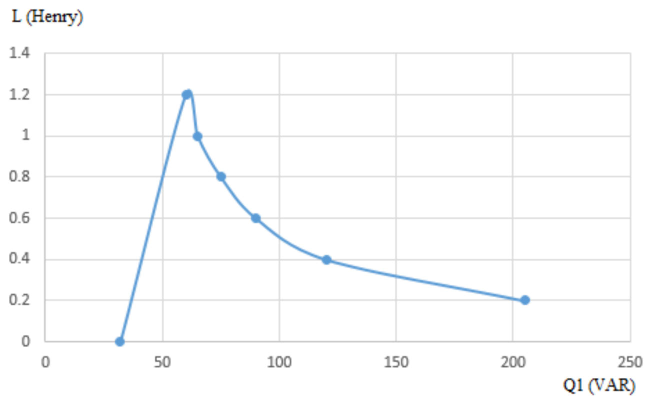

Figure 3. Inductance-Reactive Power Change

The regulation value in the inductive load shows a decreasing value according to the ohmic load.

$$\%Reg = \frac{U_{20}-U_2}{U_{20}}100 = \frac{115{,}7-113}{115{,}7} = \%2{,}33 \quad (2)$$

The transformer is loaded 1.2 times the rated current. The transformer was loaded with an ohmic load of 1.2 times the rated current and the values in the table below were taken.

TABLE III
CURRENT AND REACTIVE POWER VALUES ACCORDING TO OHMIC LOAD

U_1 (V)	U_2 (V)	I_2 (A)	Q_1 (VAR)
220	115	0	25
220	114	0,215	25
220	113	0,43	25
220	112	0,65	24
220	110	1,45	21
220	109	1,65	20

At the ohmic load, the reactive power drawn by the transformer from the grid did not change much. The variation of reactive power according to the ohmic load is given in Figure 4.

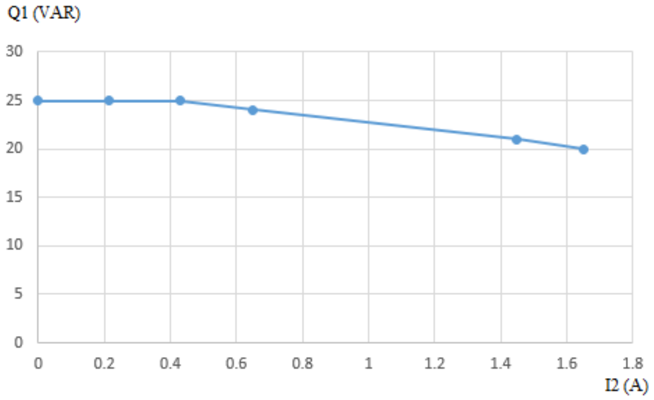

Figure 4. Variation of reactive power according to ohmic load

Copper losses are the losses caused by the currents passed in the Primary-Secondary windings. It occurs due to the winding resistances. They increase with the increase of the current passing through the windings. Copper losses P'cu occurring at various load values, including P_{TCU} total copper losses, have been given below.

$$P'_{cu} = P_{TCU}\left(\frac{I'_2}{I_2}\right)^2=6{,}2\left(\frac{0{,}215}{1{,}65}\right)^2=0{,}104\ \text{W} \qquad (3)$$

The finding of copper losses at any load and the change values of copper losses according to the load is given in Table 4.

TABLE IV

VARIATION VALUES OF COPPER LOSSES ACCORDING TO LOAD

P_{TCU} (W)	I_2 (A)	I_2' (A)	P'cu (W)
6,2	1,65	0,215	0,104
6,2	1,65	0,43	0,419
6,2	1,65	0,65	0,957
6,2	1,65	1,45	4,77
6,2	1,65	1,65	6,2

The variation of copper losses according to the load is shown in Figure 5.

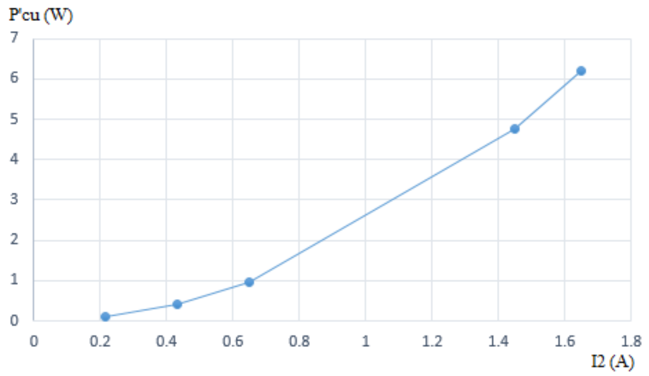

Figure 5. Variation of copper losses with load

As seen in Figure 5, it is seen transformer copper losses increase as the load increases.The variation of iron losses depending on the voltage at idle and the iron loss at any voltage are given in the expression in (4).

$$P'_b = \left(\frac{U'_1}{U_1}\right)^2 P_b = \left(\frac{30}{220}\right)^2 16=0{,}295\ W \qquad (4)$$

TABLE V

VARIATION VALUES OF STRESS-DEPENDENT IRON LOSSES

U_1(V)	U_1'(V)	P_b (W)	P_b' (W)
220	30	16	0,295
220	70	16	1,617
220	150	16	7,42
220	190	16	11,87
220	220	16	16

The variation of the voltage-related iron losses can be seen in Figure 6.

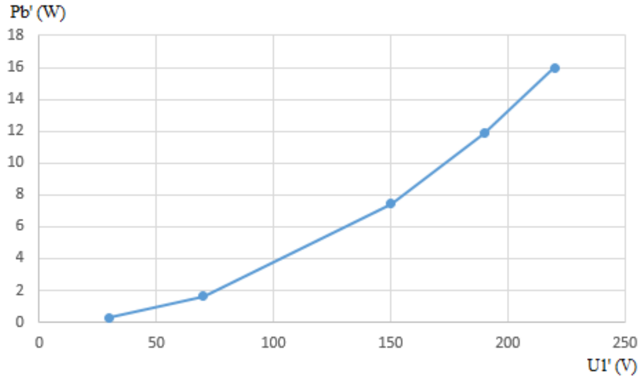

Figure 6. Variation of voltage-related iron losses

In Figure 6, it is seen that as the voltage applied to the transformer increases, the iron losses increase, that is, the iron loss increases depending on the voltage and the change is not linear. The variation of the power factor according to the current drawn by the ohmic load is shown in Table 6 and Fig.7

TABLE VI

VARIATION OF THE POWER FACTOR ACCORDING TO THE CURRENT DRAWN BY THE OHMIC LOAD

Cosφ meter	I_2 (mA)
0.22	0
0.78	285
0.91	540
0.97	790
0.98	1010

The power factor increases when the transformer is loaded. Since the energy component of the current drawn in its no-load operation is small, the reactive component is large, the power coefficient cosα will be low in the no-load condition.

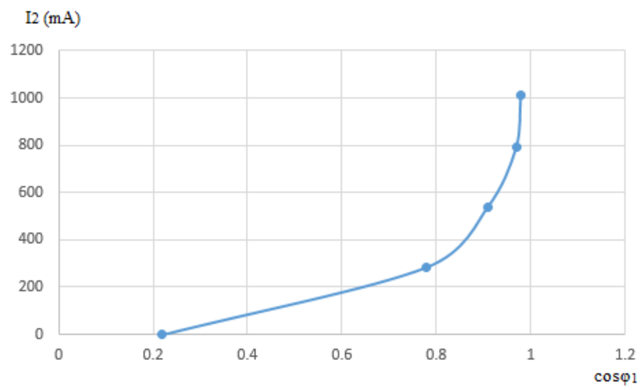

Figure 7. Variation of the power factor according to the current drawn by the ohmic load

The variation of the power factor according to the current drawn by the ohmic load is shown in Table 6 and Figure 7.

 ISSN 2536-5010 | **e-ISSN** 2536-5134 https://dergipark.org.tr/en/pub/ejt

Variation values of the power factor according to inductive load have been given in Table 7.

In the inductive case, it is observed that the power coefficient Cosφ1 remains constant as the load current I_2 increases.

Variation of power factor according to inductive load

TABLE VII
VARIATION VALUES OF STRESS-DEPENDENT IRON LOSSES

Cosφ1	I_2 (mA)	L (Henry)
0.16	125	2.4
0.16	255	1
0.16	380	0.8
0.16	520	0.6
0.16	790	0.4

The variation of the power factor according to the inductive load is seen in Figure 8.

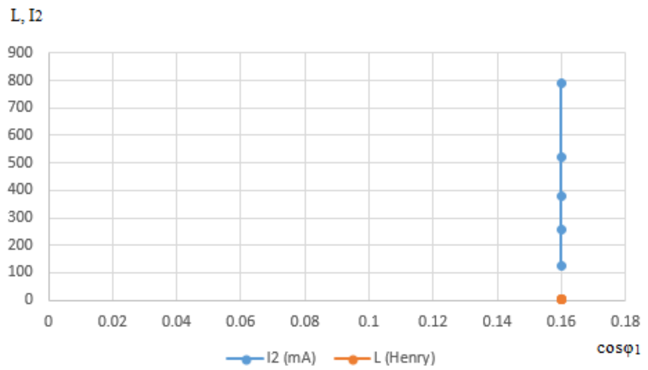

Figure 8. Change of power factor according to inductive load

In Figure 8, it is seen that the inductance load current does not change the power factor.

3. CONCLUSION

In this study, the iron losses from the unloaded test of the transformer and the copper losses in the loaded operation were found experimentally according to various load values. Copper losses and iron losses were also calculated, and it was determined that the occurring iron losses showed a non-linear increase according to the applied voltage. It has been observed that the reactive power drawn from the grid remains almost constant as the load current increases, while the power coefficient increases as the load increase at the ohmic load. In inductive load, as the load current increased, the reactive power drawn from the grid increased significantly. In inductive load, it has been observed that the power coefficient remains constant as the load current increases. It was observed that the reactive power drawn from the grid remained almost endless as the load current increased at no-load and ohmic load, while the power coefficient increased as the load increased at the ohmic load. In inductive load, as the load current increased, the reactive power drawn from the grid increased significantly. In inductive load, it has been observed that the power coefficient remains constant as the load current increases.

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BIOGRAPHIES

Mehmet Ali Özçelik received B.S., M.S., and PhD Degrees in Electrical Education/Electrical and Electronics Engineering from Marmara University/Harran University, Istanbul/Şanlıurfa and Electrical & Electronics Engineering, Kahramanmaras Sutcu Imam University, Turkey, in 1999, 2006, and 2015 respectively. He has been in Center for Future Energy Systems at the Rensselaer Polytechnic Institute, New York as a visiting/post-doc researcher from 2018 to 2020. He is currently an Assoc.Prof.Dr at the Department of Electric and Energy, Gaziantep University, Turkey. His field of interest includes PV systems, Microgrids and Smart lighting systems. He is an IEEE Senior Member.

Ahmet Aycan received B.S., and M.S. degrees in Electrical Education from Gazi University, Ankara, Türkiye, in 1990 and 1996, respectively. He is currently an Instructor at the department of Electric and Energy, Gaziantep University, Turkey. His field of interest includes Power Electronics and Electrical Machines.