Faculty of Engineering and Technology

Electrical and Computer Engineering Department

Machines Lab (ENEE3101)

Student's name: abed-Alrahman Hmedan

Student's number: 1161306

Report for Experiment #2

Single-phase Transformers

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Eng. Mostafa Helal

Dr. Ali Abdo

Partners name	partners ID:
Ahmed Nabeel	1160449
Ahmed Alkhateb	1161535

Abstract:-

The aim of experiment

1)The experiment was done to clarify the work mechanism for the single phase transformer and calculate the turns ratio between the primary stages and secondary stages.

2) Calculate the efficiency and voltage regulation for the transformer.

3) Measure the primary and secondary power factor.

4) calculate the internal impedances by doing open and short circuit test

Method used

1) Single phase transformer .
2) Single phase Toroidal core transformer.
3) Single phase autotransformer.
4) Resistive , inductive and capacitive loads .

5) Wattmeter

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Theory:

Part A: Single – phase Transformer

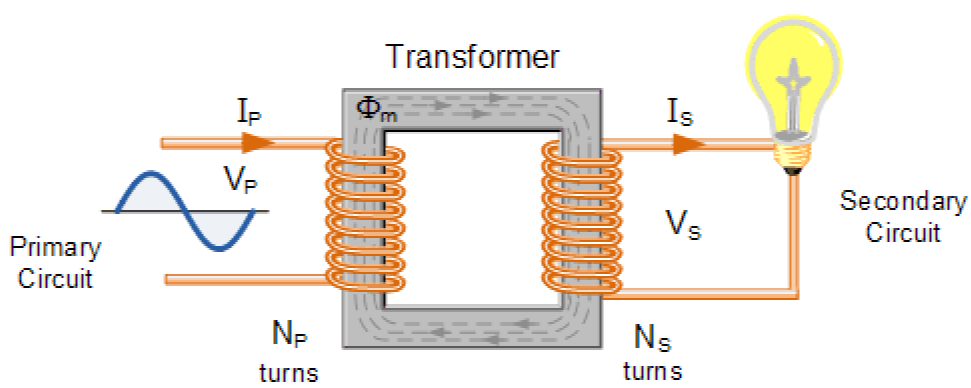


Figure 1

A single phase voltage transformer basically consists of two electrical coils of wire, one called the "Primary Winding" and another called the "Secondary Winding". For this tutorial we will define the "primary" side of the transformer as the side that usually takes power, and the "secondary" as the side that usually delivers power. In a single-phase voltage transformer the primary is usually the side with the higher voltage…..(1)

These two coils are not in electrical contact with each other but are instead wrapped together around a common closed magnetic iron circuit called the “core”. This soft iron core is not solid but made up of individual laminations connected together to help reduce the core’s losses….(1)

The two coil windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other. When an electric current passed through the primary winding, a magnetic field is developed which induces a voltage into the secondary winding …..(1)

The current drawn by primary windings from the AC supply produces an alternating flux which links all the coils . The voltage induced in the secondary can be measured directly but a voltage will also be induced in the primary winding , The and it depends on the ratio of the primary to secondary turns and magnetic flux . The induced voltage in the primary is referred to as the back emf it is almost equal in value to the AC supply voltage and will always act in opposite to it . The voltage in each turn of both the primary and the secondary windings will be the same . We call the transformer step up transformer , when the number of turns in the secondary more than the primary , else it step down one. For ideal transformer the ratio between the primary voltages to the secondary voltages is equal to the ratio between the numbers of turns in the primary to the secondary turns .

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = a\ .$$

The ratio between the primary current to the secondary current is equal to the ratio of turns a :

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} = a\ .$$

A real transformer with no load on its secondary may be represented as an ideal transformer with no core loss .

Open circuit test :

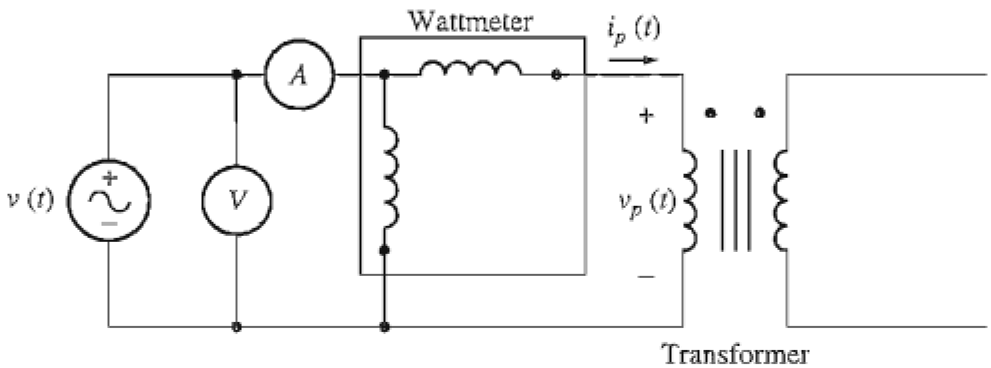


Figure 2

In the open-circuit test, one transformer winding is open-circuited, and the

other winding is connected to full rated line voltage. Look at the equivalent circuit in Figure 2. Under the conditions described, al1 the input current must be flowing through the excitation branch of the transformer. The series elements, Rp and Xp are too small in comparison to Rc and XM to cause a significant voltage drop, so essentially all the input voltage is dropped across the excitation branch…….(2)

The easiest way to calculate the values of Rc and XM is to look first at the

admittance of the excitation branch. The conductance of the core-loss resistor is

given by

$$G_C = \frac{1}{R_C}$$

and the susceptance of the magnetizing inductor is given by

$$B_M = \frac{1}{X_M}$$

Since these two elements are in parallel, their admittances add, and the total excitation admittance is

$$Y_E = G_C - jB_M$$

$$Y_E = \frac{1}{R_C} - j\frac{1}{X_M}$$

The magnitude of the excitation admittance (referred to the side of the transformer used for the measurement) can be found from the open-circuit test voltage and current:

$$|Y_E| = \frac{I_{OC}}{V_{OC}}$$

The angle of the admittance can be found from a knowledge of the circuit power factor. The open-circuit power factor (PF) is given by

$$\text{PF} = \cos\theta = \frac{P_{OC}}{V_{OC}I_{OC}}$$

The final equation is

$$Y_E = \frac{I_{OC}}{V_{OC}} \angle -\cos^{-1} \text{PF}$$

Short- circuit test:

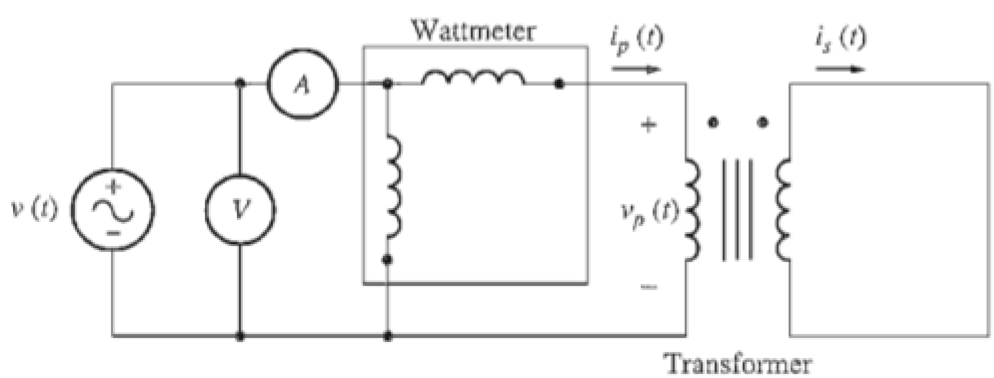


Figure 3

In the short-circuit test, the low-voltage terminals of the transformer are short-circuited, and the high-voltage terminals are connected to a variable voltage source ,as shown in Figure 3. (This measurement is normally done on the high-voltage side of the transformer, since currents will be lower on that side, and lower currents are easier to work with.) The input voltage is adjusted until the current in the short- circuited windings is equal to its rated value, The input voltage, current, and power are again measured….(2)

Since the input voltage is so low during the short-circuit test, negligible current flows through the excitation branch. If the excitation current is ignored, then all the voltage drop in the transformer can be attributed to the series elements in the circuit. The magnitude of the series impedances referred to the primary side of the transformer is

$$|Z_{SE}| = \frac{V_{SC}}{I_{SC}}$$

The power factor of the current is given by

$$PF = \cos\theta = \frac{P_{SC}}{V_{SC} I_{SC}}$$

Therefore,

$$Z_{SE} = \frac{V_{SC}\angle 0^\circ}{I_{SC}\angle -\theta^\circ} = \frac{V_{SC}}{I_{SC}}\angle \theta^\circ$$

The series impedance Z_{SE} is equal to

$$Z_{SE} = R_{eq} + jX_{eq}$$

$$Z_{SE} = (R_P + a^2R_S) + j(X_P + a^2X_S)$$

Part B :Single –Phase Autotransformer :-

Autotransformer has only one single voltage winding which is common to both sides. This single winding is “tapped” at various points along its length to provide a percentage of the primary voltage supply across its secondary load. Then the *autotransformer* has the usual magnetic core but only has one winding, which is common to both the primary and secondary circuits…(1)

Therefore in an autotransformer the primary and secondary windings are linked together both electrically and magnetically. The main advantage of this type of transformer design is that it can be made a lot cheaper for the same VA rating, but the biggest disadvantage of an autotransformer is that it does not have the primary/secondary winding isolation of a conventional double wound transformer….(1)

The section of winding designated as the primary part of the winding is connected to the AC power source with the secondary being part of this primary winding. An autotransformer can also be used to step the supply voltage up or down by reversing the connections. If the primary is the total winding and is connected to a supply, and the secondary circuit is connected across only a portion of the winding, then the secondary voltage is “stepped-down” as shown.

Autotransformer Design

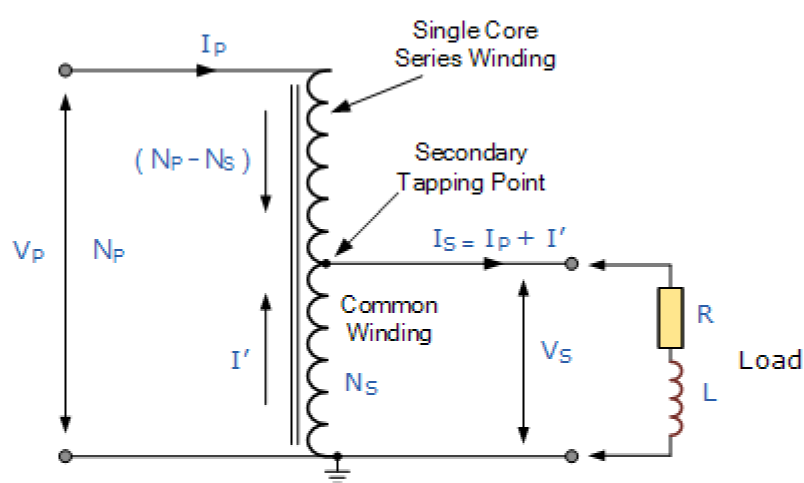


Figure 4

The *autotransformer* has many uses and applications including the starting of induction motors, used to regulate the voltage of transmission lines, and can be used to transform voltages when the primary to secondary ratio is close to unity……(1)

An autotransformer can also be made from conventional two-winding transformers by connecting the primary and secondary windings together in series and depending upon how the connection is made, the secondary voltage may add to, or subtract from, the primary voltage…..(1)

Procedure & data calculation :

Part A :Single-phase Transformer

Voltage and Current Transformation & Open Circuit Test

The circuit in the Figure 5 was connected as shown below

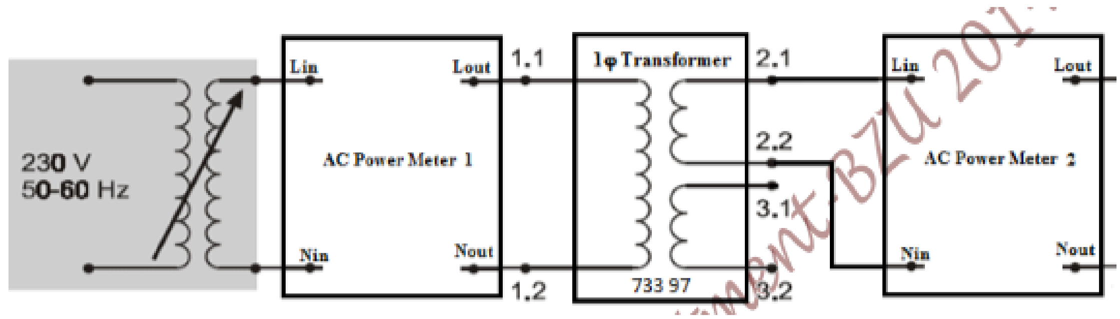


Figure 5

Nominal Data for the single phase Transformer Under Test was filled in the Table below

Table 1

Nominal voltage (Primary) V_1	230
Nominal voltage (Secondary) V_2:	115
Nominal voltage (Secondary) V_3	115
Nominal current (Secondary) I_2:	1.36
Nominal current (Secondary) I_3:	1.36
Number of Turns N_1	408
Number of Turns N_2:	214
Number of Turns N_3	214

The input voltage was set to 230 V and the load was set open circuit then the value of I_{oc} & P_{oc} was measured using wattmeter.

V_{oc} = 230 V P_{oc} = 10 W

I_{oc} = 182.5 mA

To calculate the value of excitation branch impedance ,the following equations will use(mentioned in theory)

$$|Y_E| = \frac{I_{OC}}{V_{OC}} \qquad \text{PF} = \cos\theta = \frac{P_{OC}}{V_{OC} I_{OC}}$$

$$|Y_E| = \frac{182.5*10^{-3}}{230} = 7.93 * 10^{-4}$$

$$\theta = \cos^{-1} 0.23 = 76.7^{\circ}$$

$$R_c = \frac{1}{7.93*10^{-4}*\cos 76.7} = 5.481 K\Omega$$

$$X_c = \frac{1}{7.93*10^{-4}*\sin 76.7} = 1.3\ K\Omega$$

The value of V_2,V_3 was calculated using the turns ratio

$V_2 = (N_2 / N_1) . V_1 = 120$ V

$V_3 = (N_3 / N_1) . V_1 = 120$ V

The circuit in the Figure 6 below was connected to determine the current transformation ratio

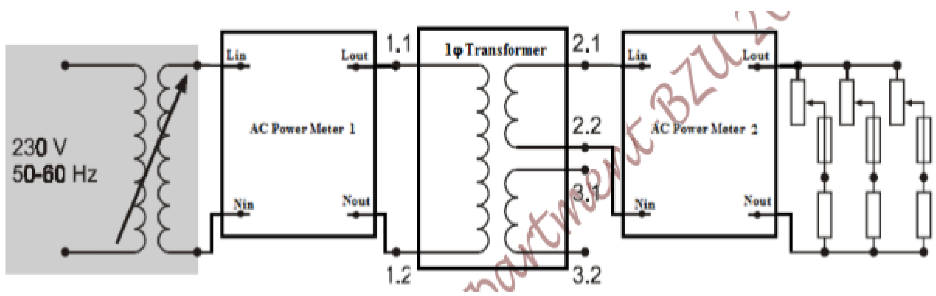


Figure 6

The input voltage was set to 230 V and the resistive load was set to 90% of its value then the value of the load was decreased until the current on the secondary reach the rated value ,then the value of the primary current was measured .

$I_{p,rated}$ =772 mA

$$\frac{N1}{N2} = \frac{Is}{Ip} = \frac{1.36}{0.772} = 2{:}1$$

Short-Circuit Test and Sustained Short-circuit Current:

The circuit in the Figure 7 was connected as shown :

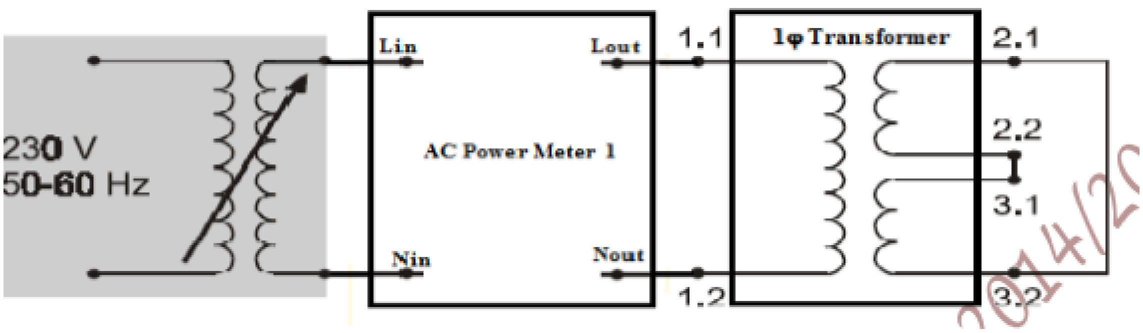


Figure 7

The input voltage was set to zero and the load was shorted ,then the input voltage was increased slowly until the primary current reach it rated value then the value of V_{sc} and P_{sc} was measured using Wattmeter to determine the transformer equivalent series impedance (Req1& Xeq1).

V_{sc} = 4.81 V P_{sc} = 3.719 W I_{sc} = 0.792 A

From the equations below

$$|Z_{SE}| = \frac{V_{SC}}{I_{SC}} \qquad \mathrm{PF} = \cos\theta = \frac{P_{SC}}{V_{SC} I_{SC}}$$

$Z_{SE} = \frac{4.81}{0.792} = 6.07$ $\Theta = \cos^{-1} 0.97 = 14°$

$R_{eq} = 6.07 * \cos 14 = 5.89\Omega$

$|X_{eq}| = 6.07 * \sin 14 = 1.46\Omega$

$(V_{sc})_{pu} = 4.81/230 = 0.02$

The transformer equivalent circuit shown below

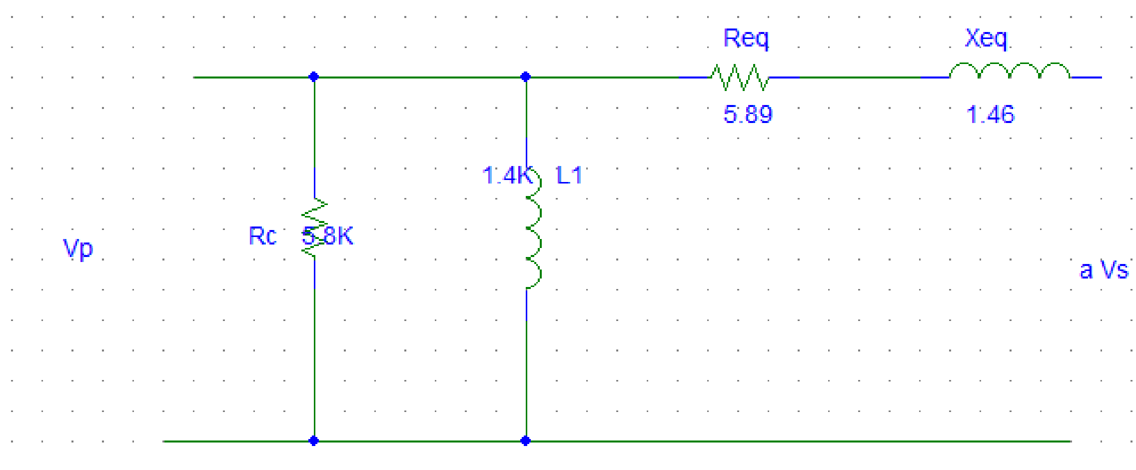


Figure 8

Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore, calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation.

$Iss = I_{2N} / (V_{sc})_{pu} = 1.36/0.02 = 68$ A

Voltage Behavior with Resistive Load, Evaluating Efficiency:

The circuit in the Figure 9 was connected as shown :

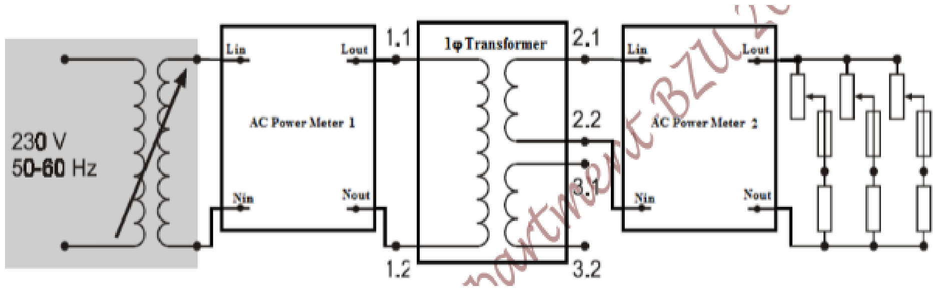


Figure 9

The input voltage was set 230 V and the resistive load was set to 90% of it's value ,then the value of the load was decreased sequentially until reach 20% of it's value ,In each case the value of I_1,V_2,I_2,P_1,P_2,cosϴ was measured and recorded in Table 2

Table 2

setting	R/[%]	90	80	70	60	50	40	30	20
Measure	I_1(mA)	228	229	241	259	288	345	550	570
	Cosϴ	0.65	0.66	0.68	0.73	0.79	0.86	0.93	0.95
	V_2	120	119.7	119.5	119.4	119.2	118.7	118	117.5
	I_2	196	198	234	281	355	485	840	881
	P_1	33.3	33.6	37.7	43.6	52.4	68.2	107	115
	P_2	23.4	23.7	27.9	33.5	42.2	52.8	96	103
	P_1	33	34.7	37.7	43.4	52.3	68.2	117	124

calculated	P_2	23.5	23.7	27.9	33.5	42.3	57.5	99	103.5
	Ŋ[%]	70.5	70.5	74	76.8	80.5	84.3	89.7	89.5
	V_R[%]	0	0.25	0.41	0.5	0.66	1.08	1.66	2.08

$P_1 = V_1 * I_1 * \cos\Theta = 230 * 0.228*0.63 = 33$ w

$P_2 = V_2 * I_2 = 120 * 196.2 = 23.5$ w

$Ŋ = \frac{Pout}{Pin} *100\% = 23.4/33.3 = 70.2\%$

$V_R = V_{nl} – V_{Fl} / V_{nl} = 120 – 120 /120 = 0\%$

The following diagram shown the relation between the secondary current and the efficiency and secondary voltage

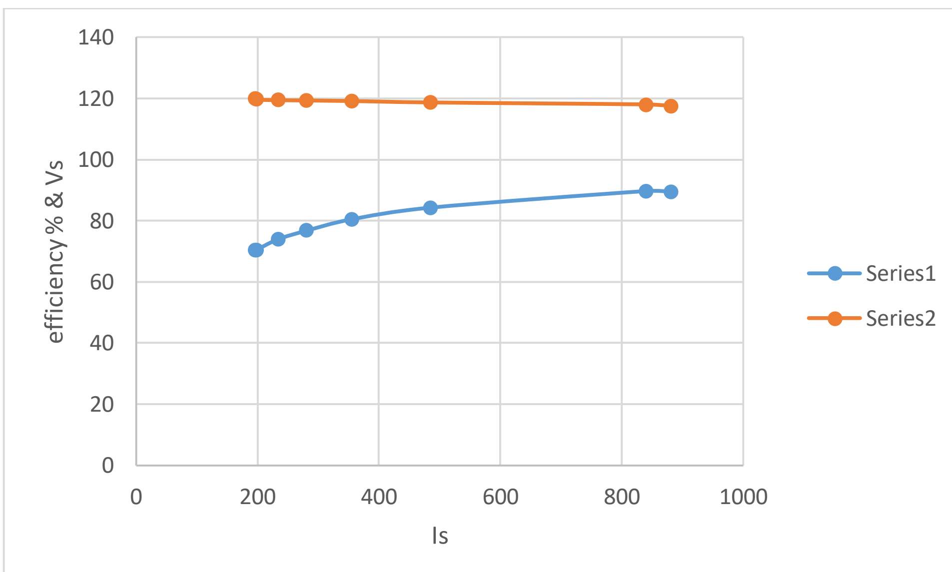


Figure 10

From the diagram above, noticed that the efficiency increased as the secondary current increase until reach 850 mA then the efficiency starting to decrease ,in terms of secondary voltage Vs secondary current ,the voltage will decrease as the current increase as a result of the internal voltage drop (R_{eq} & X_{eq}) .

Voltage Behavior With Inductive or Capacitive Load:

L_{indi}	open	6	4.8	2.4	1.2
L_{tot}	open	2	1.6	0.8	0.4
I_2[mA]	0	289	358	700	1434
V_2[v]	240	239.7	238.4	236	232.5
P_1	10	20.1	22.4	35.2	61.5
P_2	0	9.4	11.5	21	36
Ŋ[%]	0	46.6	51.3	59.6	58.5
V_R[%]	0	0.12	0.66	1.66	3.1

The circuit in the Figure 11 was connected as shown:

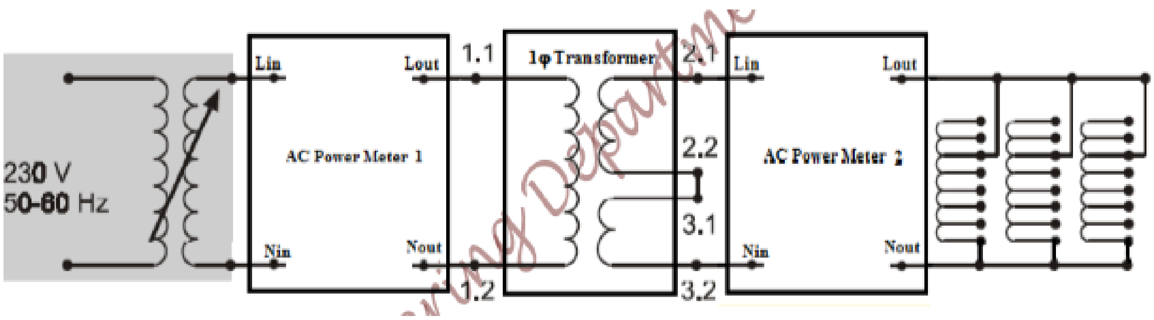


Figure 11

The input voltage was set 230 V and the inductive load was set to 2H ,then the value of the load was decreased sequentially until reach 0.4H ,In each case the value of I_1,V_2,I_2,P_1,$P_2$was measured and recorded in Table 3

Table 3

Repeating the previous connection and change the load to be capacitive after that recorded the measured value in table 4.

Table 4

C[uF]	Open	4	8	12	16	20
I_2[mA]	0	289	358	700	1.434	1.58
V_2[v]	240	241	241.4	241.6	242.1	242.8
P_1	10	10.3	11.9	15	19	25
P_2	0	0	0	0	0	0
Ŋ[%]	0	0	0	0	0	0
V_R[%]	0	-0.41	-0.53	-0.66	-0.87	-1.1

The following diagram shown the relation between the secondary current Vs the secondary voltage in case the load was inductive and capacitive

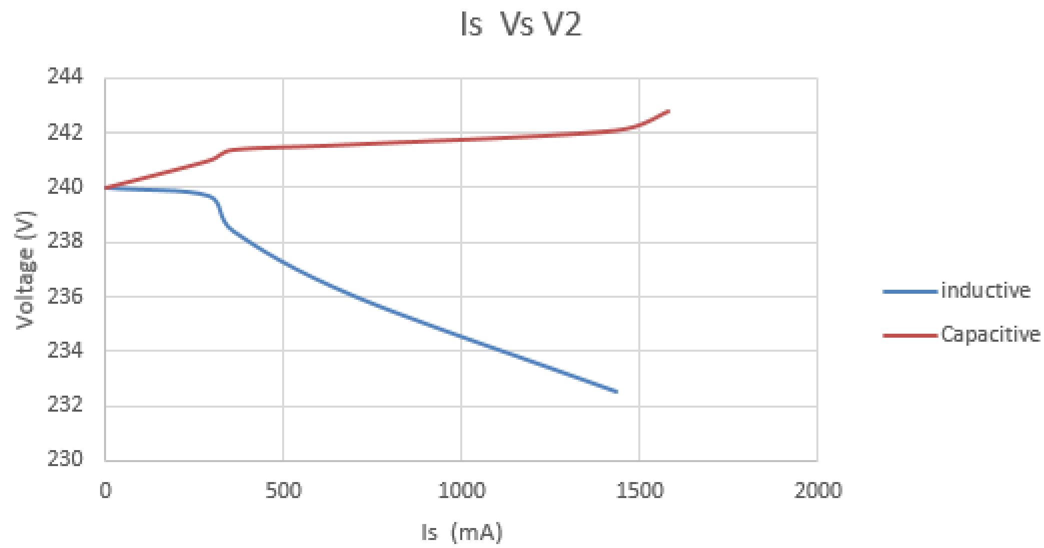


Figure 12

from the diagram above, noticed that the inductive load voltage will decrease as the current increase as a result of the internal voltage drop (R_{eq} & X_{eq}) .In terms of capacitive load , noticed that the voltage will increase as the current increase as a result of decreasing the capacitive load impedance .

The following diagram shown the relation between the secondary current and the efficiency

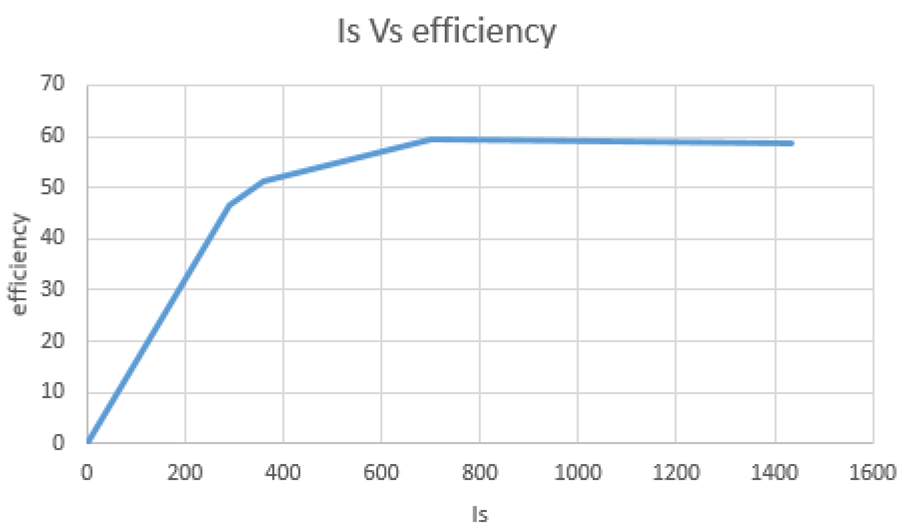


Figure 13

From the diagram above, noticed that the efficiency increased as the secondary current increase until reach 800 mA then the efficiency starting to decrease.

PART B: Single-phase Autotransformer

Voltage and Current Transformation:

The circuit in the Figure14 was connected as shown below

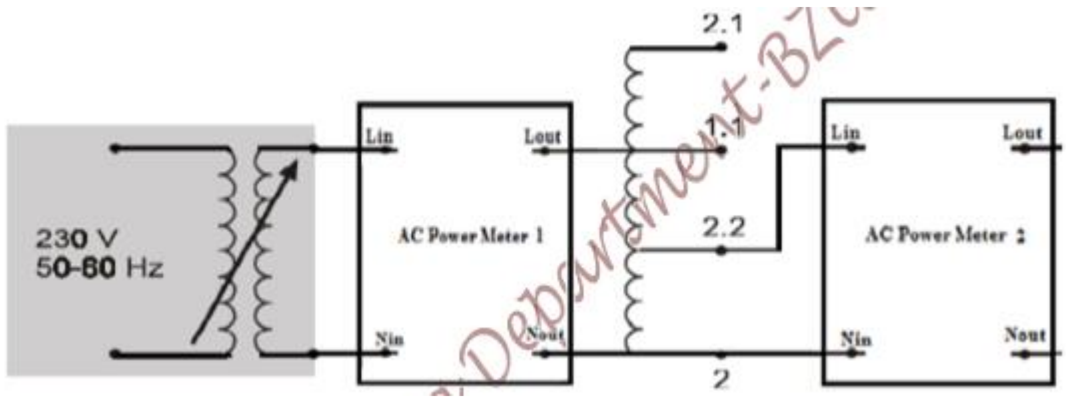


Figure 14

Nominal Data for the single phase Transformer Under Test was filled in the Table below

Table 5

Nominal voltage $V_{1.1}$	230
Nominal voltage $V_{2.1}$	240
Nominal voltage $V_{2.2}$	115
Nominal current $I_{1.1}$	1.36
Nominal current $I_{2.1}$	1.25
Nominal current $I_{2.2}$	2.72
Number of Turns N_1	327
Number of Turns N_2:	327
Number of Turns N_3	29

The input voltage was set to 230 V and the load was set open circuit then the value of I_{oc} & P_{oc} was measured using wattmeter.

V_{oc} = 230 V $\quad$ P_{oc} = 7.5 W

I_{oc} = 112 mA

To calculate the value of excitation branch impedance ,the following equations will use(mentioned in theory)

$$|Y_E| = \frac{I_{OC}}{V_{OC}} \qquad \text{PF} = \cos\theta = \frac{P_{OC}}{V_{OC} I_{OC}}$$

$$|Y_E| = \frac{112*10^{\wedge}-3}{230} = 4.86 * 10^{-4}$$

$$\Theta = \cos^{-1} 0.29 = 73^{\circ}$$

$$R_c = \frac{1}{4.86*10^{-4}*\cos 73} = 7.037 K\Omega$$

$$X_c = \frac{1}{4.86*10^{-4}*sin73} = 2.151\ K\Omega$$

The circuit in the Figure 15 below was connected to determine the current transformation ratio

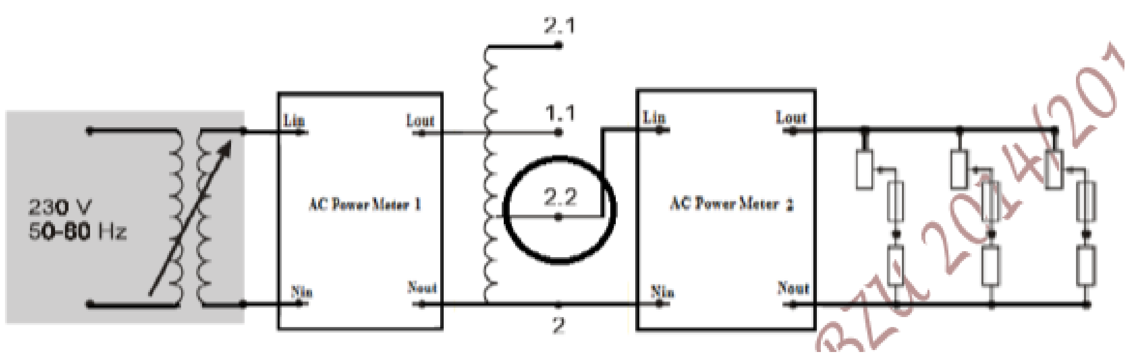


Figure 15

The input voltage was set to 230 V and the resistive load was set to 90% of its value then the value of the load was decreased until the current on the secondary reach the rated value ,then the value of the primary current was measured .

$I_{p,rated}$ =1.36A

$$\frac{N1+N2}{N2} = \frac{Is}{Ip} = \frac{2.72}{1.3} = 1:1$$

Short-Circuit Test and Sustained Short-circuit Current:

The circuit in the Figure 16 was connected as shown :

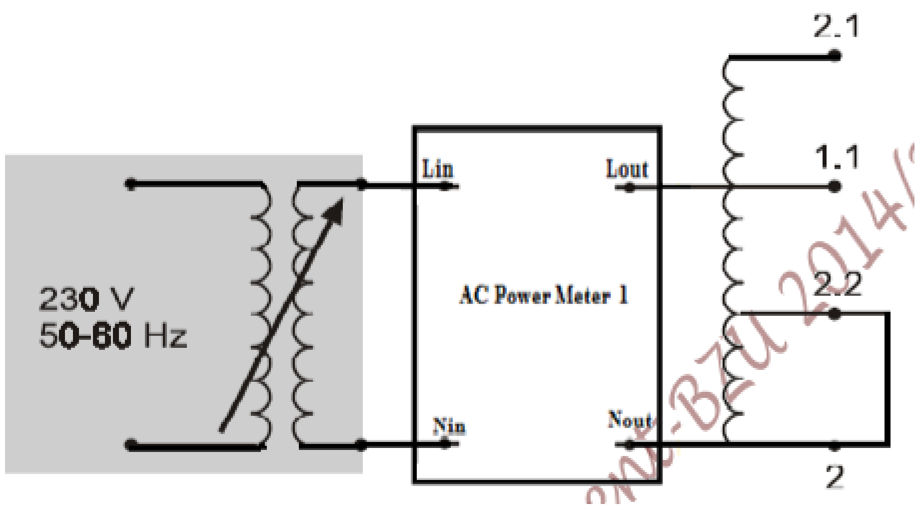


Figure 16

The input voltage was set to zero and the load was shorted ,then the input voltage was increased slowly until the primary current reach it rated value then the value of V_{sc} and P_{sc} was measured using Wattmeter to determine the transformer equivalent series impedance (Req1& Xeq1).

V_{sc} = 4.6 V P_{sc} = 6.24 W I_{sc} = 1.37 A

From the equations below

$$|Z_{SE}| = \frac{V_{SC}}{I_{SC}} \qquad \qquad \mathrm{PF} = \cos\theta = \frac{P_{SC}}{V_{SC} I_{SC}}$$

$Z_{SE} = \frac{4.6}{1.37} = 3.35$ $\qquad \Theta = \cos^{-1}0.99 = 8°$

$R_{eq} = 3.35 * \cos 8 = 3.3\Omega$

$|X_{eq}| = 3.35 * \sin 8 = 0.46\Omega$

$(V_{sc})_{pu} = 4.6/230 = 0.02$

The transformer equivalent circuit shown below

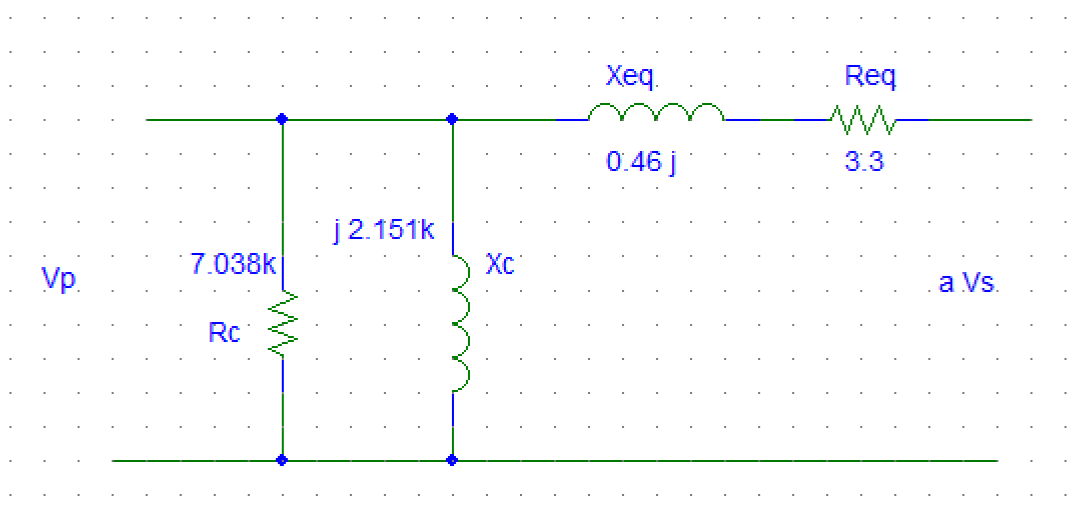


Figure 17

Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore, calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation.

$I_{ss} = I_{2N} / (V_{sc})_{pu} = 2.72/0.02 = 136$ A

Voltage Behavior with Resistive Load, Evaluating Efficiency:

The circuit in the Figure 19 was connected as shown :

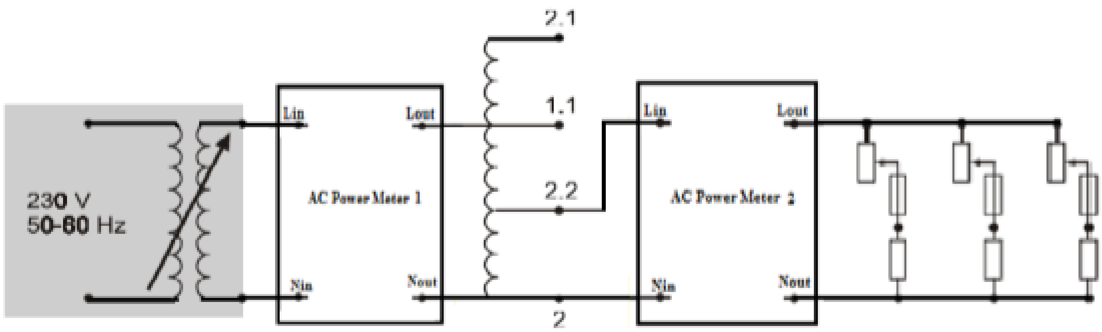


Figure 18

The input voltage was set 230 V and the resistive load was set to 90% of it's value ,then the value of the load was decreased sequentially until reach 20% of it's value ,In each case the value of I_1,$V_{2.2}$,$I_{2.2}$,P_1,P_2,cosϴ was measured and recorded in Table 6

Table 6

setting	R/[%]	90	80	70	60	50	40	30	20
Measure	I_1(mA)	165	166	179	199	228	297	441	472
	Cosϴ	0.75	0.78	0.82	0.85	0.89	0.90	0.93	0.98
	$V_{2.2}$	115	115	115	115	115	115	114.6	114.5
	$I_{2.2}$	188	191	222	271	335	475	790	855
	P_1	29.4	29.4	33.2	38.6	46.3	62.3	98.5	106
	P_2	21.7	22	25.7	31.15	38.7	55.5	90	98
calculated	P_1	28.4	29.7	33.7	38.9	46.9	63	99	107
	P_2	21.6	21.9	27.9	31.5	38.3	55.5	90.3	97.8

	Ŋ[%]	73.8	74.8	77.4	80.6	83.5	89	91.3	90.3
	V_R[%]	0	0	0	0	0	0	0.34	0.43

$P_1 = V_1 * I_1 * \cos\Theta = 230 * 0.165*0.75 = 28.4$ w

$P_2 = V_2 * I_2 = 115 * 191 = 22$ w

Ŋ $= \frac{Pout}{Pin} *100\% = 22/29.4 = 74.8\%$

$V_R = V_{nl} – V_{Fl} / V_{nl} = 115 – 115 /115 = 0\%$

The following diagram shown the relation between the secondary current and the efficiency and secondary voltage

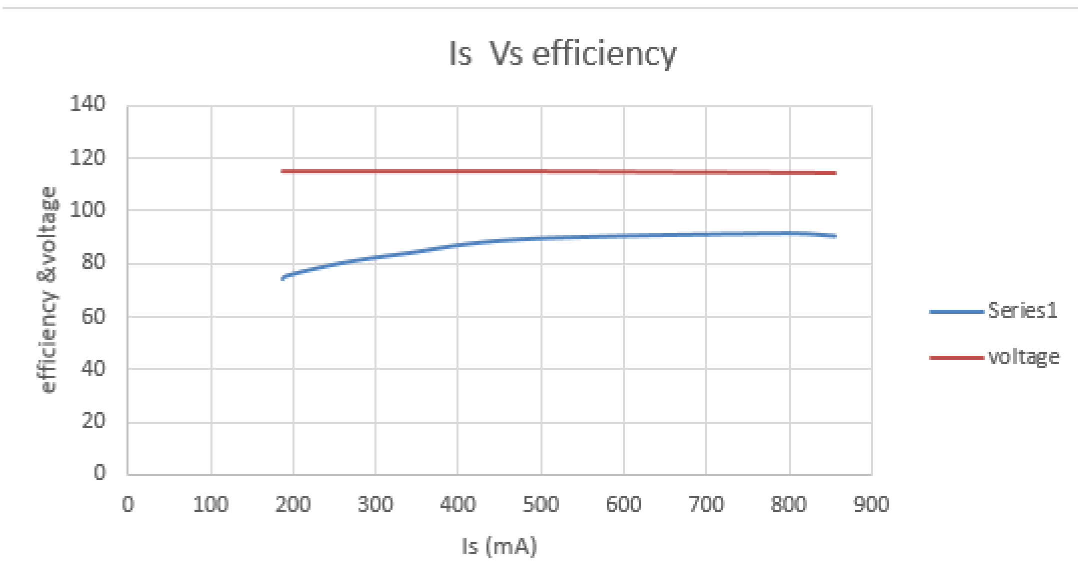


Figure 19

From the diagram above, noticed that the efficiency increased as the secondary current increase until reach 800 mA then the efficiency starting to decrease ,in terms of secondary voltage Vs secondary current ,the voltage almost has a fixed value 115 V at any value of current

There is some error between the calculated and measured value of the power

Error in the first case = 29.4-28.4/28.4 = 3.5 % ,this error resulted of uncelebrated equipment or human's error.

Voltage Behavior With Inductive or Capacitive Load:

The circuit in the Figure 21 was connected as shown:

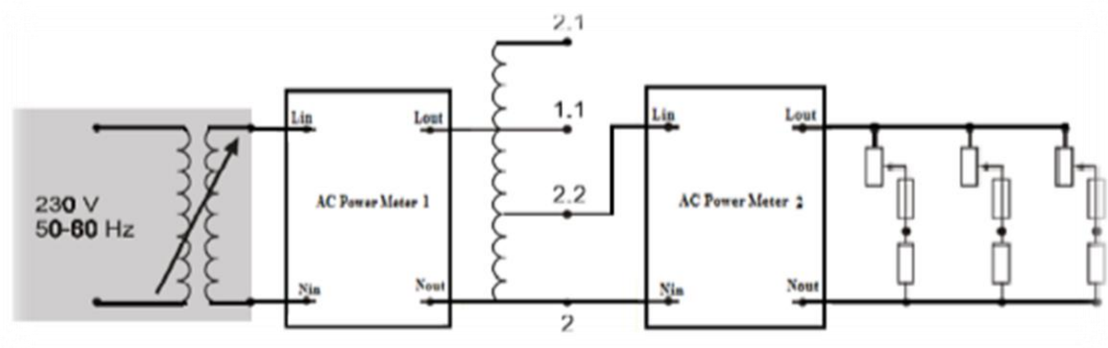


Figure 20

The input voltage was set 230 V and the inductive load was set to 2H ,then the value of the load was decreased sequentially until reach 0.4H ,In each case the value of I_2,$V_{2.2}$,,$P_{1.1}$,$p_{2.2}$ was measured and recorded in Table 7

Table 7

L_{indi}	open	6	4.8	2.4	1.2	1
L_{tot}	open	2	1.6	0.8	0.4	0.33
I_2[mA]	0	140	174.8	337	678	804
V_2[v]	115	115	115	115	114.7	114.7
P_1	7.36	9.7	10.3	13.1	18.3	20.2
P_2	0	2.27	2.9	5.6	10.5	12.2
Ŋ[%]	0	23.4	28.1	42.7	57.3	60.3
V_R[%]	0	0	0	0	0.66	0.66

Repeating the previous connection and change the load to be capacitive after that recorded the measured value in table 8.

Table 8

C[uF]	Open	2	4	8	12	16
I_2[mA]	0	73.5	147.5	300	448	590
V_2[v]	115	115	115	115	115.2	115.2
P_1	7.36	7.37	7.4	7.4	7.6	7.7
P_2	0	0	0	0	0	0
Ŋ[%]	0	0	0	0	0	0
V_R[%]	0	0	0	0	-0.17	-0.17

The following diagram shown the relation between the secondary current Vs the secondary voltage in case the load was inductive and capacitive

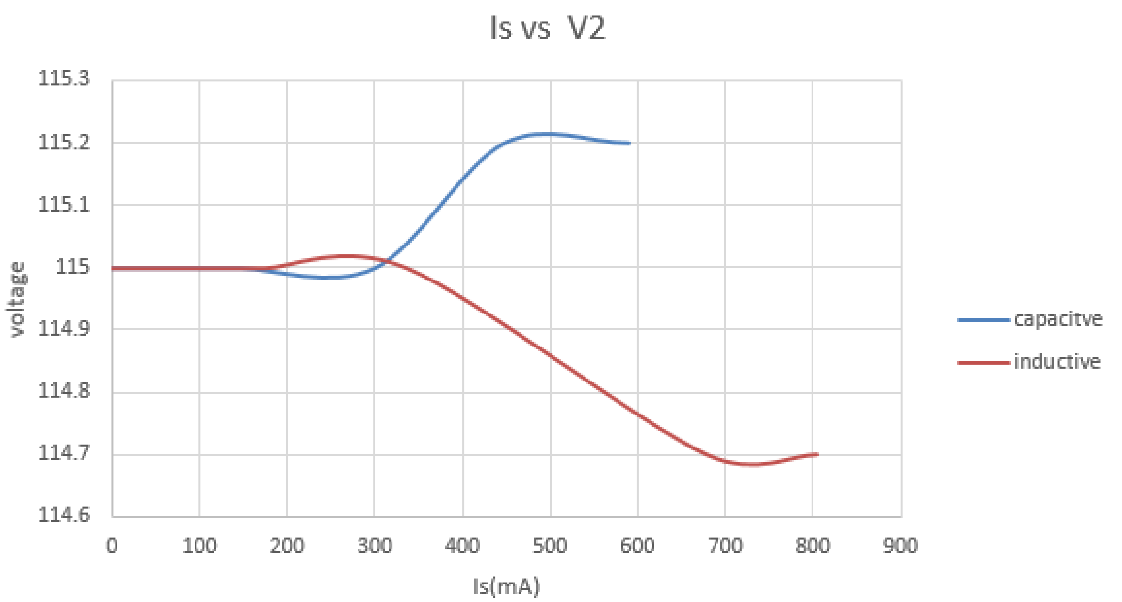


Figure 21

From the diagram above, noticed that the voltage has a slightly variation (i.e. decreasing) when the current increase above 400 mA and the voltage regulation can be negligible, In terms of capacitive load noticed that the voltage has a slightly increasing when the current increase above 300 mA and the voltage regulation can be negligible .

From the diagram above, The following diagram shown the relation between the secondary current and the efficiency

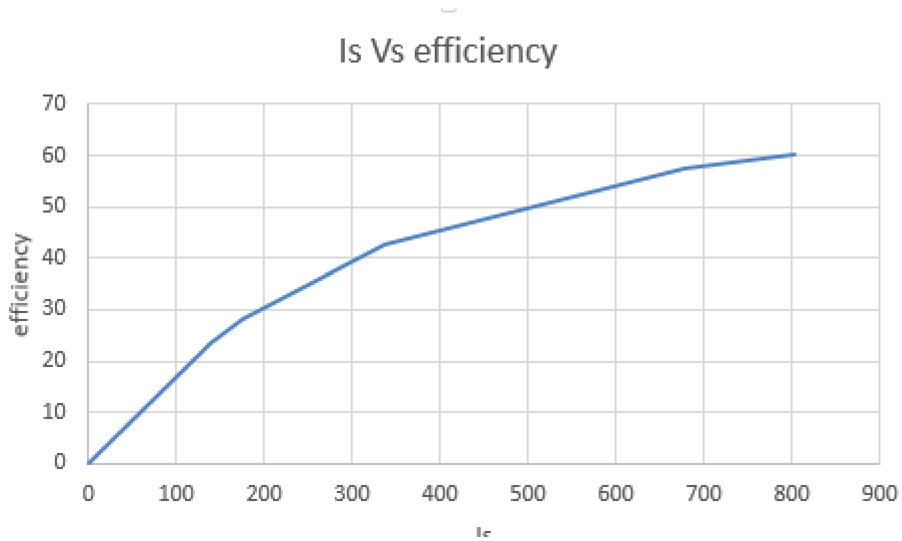


Figure 22

From the diagram above, noticed that the efficiency increased as the secondary current increase

PART C: Single-phase Toroidal Core Transformer:

Voltage and Current Transformation:

The circuit in the Figure25 was connected as shown below

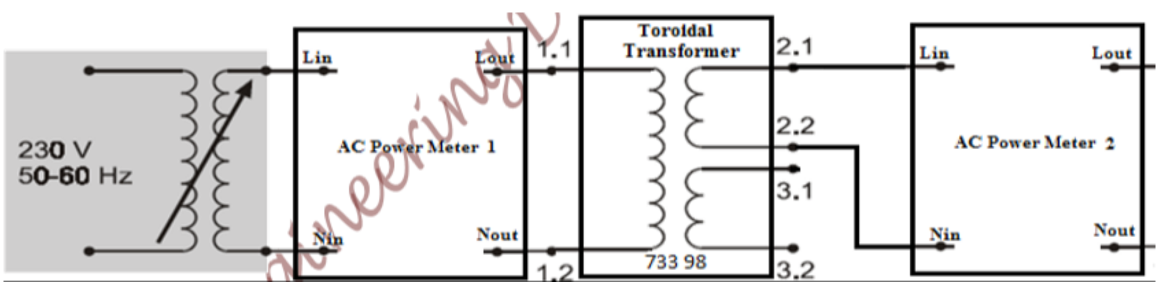


Figure 23

Nominal Data for the single phase Transformer Under Test was filled in the Table below

Table 9

Nominal voltage (Primary) V_1	230
Nominal voltage (Secondary) V_2:	115
Nominal voltage (Secondary) V_3	115
Nominal current (Secondary) I_2:	1.36
Nominal current (Secondary) I_3:	1.36
Number of Turns N_1	874
Number of Turns N_2:	456
Number of Turns N_3	456

The input voltage was set to 230 V and the load was set open circuit then the value of I_{oc} & P_{oc} was measured using wattmeter.

V_{oc} = 230 V P_{oc} = 2W

I_{oc} = 14.5 mA

To calculate the value of excitation branch impedance ,the following equations will use(mentioned in theory)

$$|Y_E| = \frac{I_{OC}}{V_{OC}} \qquad \mathrm{PF} = \cos\theta = \frac{P_{OC}}{V_{OC} I_{OC}}$$

$$|Y_E| = \frac{14.5*10\text{^}-3}{230} = 6.3 * 10^{-5}$$

$$\Theta = \cos^{-1} 0.6 = 53^{o}$$

$$R_c = \frac{1}{6.3*10^{-5}*\cos 53} = 26.375 K\Omega$$

$$X_c = \frac{1}{6.3*10^{-5}*sin 53} = 19.875\ K\Omega$$

The circuit in the Figure 24 below was connected to determine the current

transformation ratio

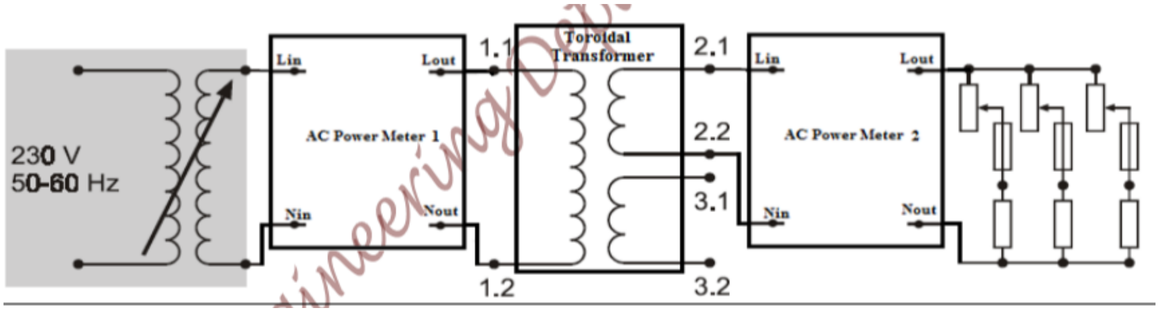


Figure 24

The input voltage was set to 230 V and the resistive load was set to 90% of its value then the value of the load was decreased until the current on the secondary reach the rated value ,then the value of the primary current was measured .

$I_{p,rated}$ =0.707A

$$\frac{N1}{N2} = \frac{Is}{Ip} = \frac{1.36}{0.707} = 2{:}1$$

Short-Circuit Test and Sustained Short-circuit Current:

The circuit in the Figure 25 was connected as shown :

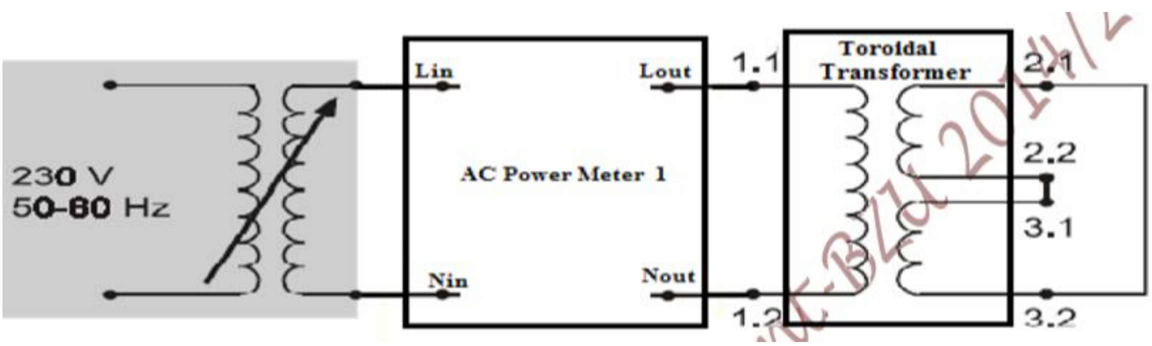


Figure 25

The input voltage was set to zero and the load was shorted ,then the input voltage was increased slowly until the primary current reach it rated value then the value of V_{sc} and P_{sc} was measured using Wattmeter to determine the transformer equivalent series impedance (Req1& Xeq1).

V_{sc} = 5.6 V P_{sc} = 3.82 W I_{sc} = 0.707 A

From the equations below

$$|Z_{SE}| = \frac{V_{SC}}{I_{SC}} \qquad \text{PF} = \cos\theta = \frac{P_{SC}}{V_{SC} I_{SC}}$$

$$Z_{SE} = \frac{5.6}{0.707} = 7.92 \qquad \Theta = \cos^{-1} 0.96 = 15.2°$$

R_{eq} = 7.92* cos 15.2 = 7.64Ω

$|X_{eq}|$ = 7.92* sin15.2 = 2.07Ω

$(V_{sc})_{pu}$ = 5.6/230 = 0.024

The transformer equivalent circuit shown below

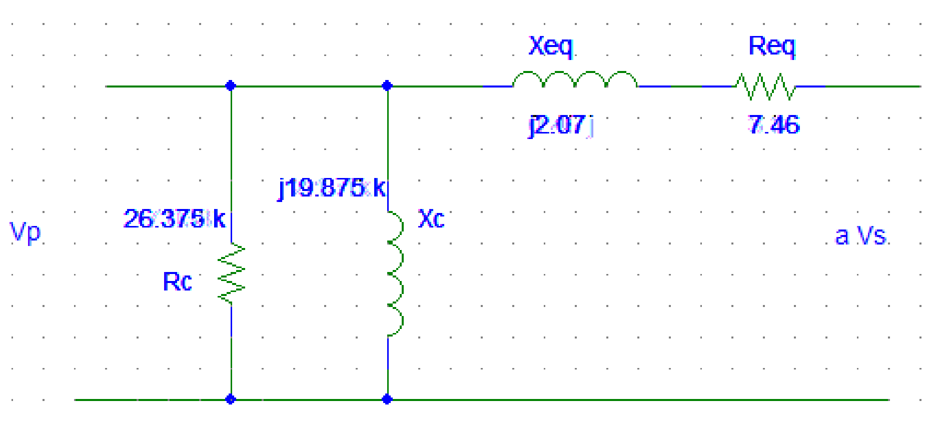


Figure 26

Sustained short-circuit current is that current which flows after transient reaction has died out when nominal voltage is applied to the primary side. Since this has a very high value it cannot be measured directly. Therefore, calculate its value from the secondary side's rated current and the relative short-circuit voltage with the help of the equation.

$Iss=I_{2N} /(V_{sc})_{pu} = 1.36/0.024 = 56.6$ A

Voltage Behavior with Resistive Load, Evaluating Efficiency:

The circuit in the Figure 27 was connected as shown :

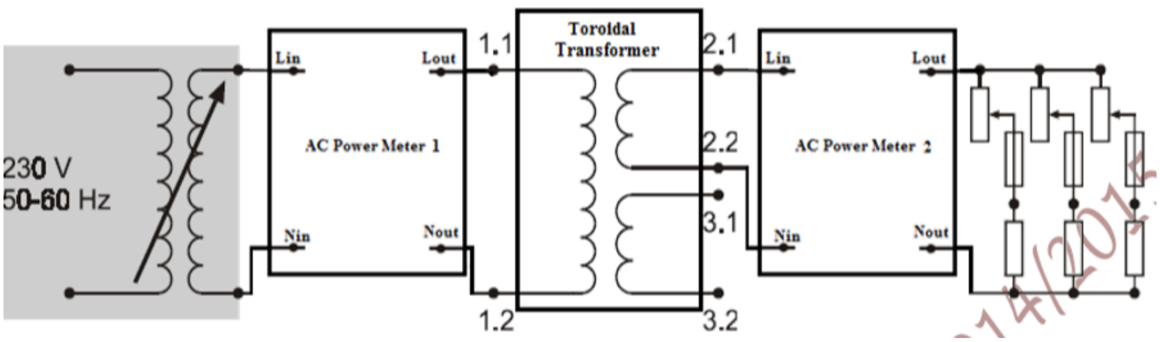


Figure 27

The input voltage was set 230 V and the resistive load was set to 90% of it's value ,then the value of the load was decreased sequentially until reach 20% of it's value ,In each case the value of I_1,$V_{2.2}$,$I_{2.2}$,P_1,P_2,cosϴ was measured and recorded in Table 10

Table 10

setting	R/[%]	90	80	70	60	50	40	30	20
Measure	I_1(mA)	112	113	133	157	190	256	442	470
	Cosϴ	0.9	0.92	0.93	0.93	0.94	0.95	0.95	0.98
	V_2	119.8	119.7	119.6	119.6	119	118.6	117.8	117

	I_2(mA)	196	198	237	282	345	547	806	878
	P_1	25.6	26	30.6	36.1	43.6	59.2	99	108
	P_2	23.4	23.8	28.4	33.8	41.3	56.3	95.1	103.3
calculated	P_1	25.1	26.2	30.1	36.5	43.1	59.9	99.3	107
	P_2	23.1	23.1	27.4	32.8	41.1	56.9	95.8	103
	Ŋ[%]	91.4	91.5	92.8	93	96	95.1	96	95.6
	V_R[%]	0.16	0.25	0.33	0.33	0.83	1.16	1.83	2.5

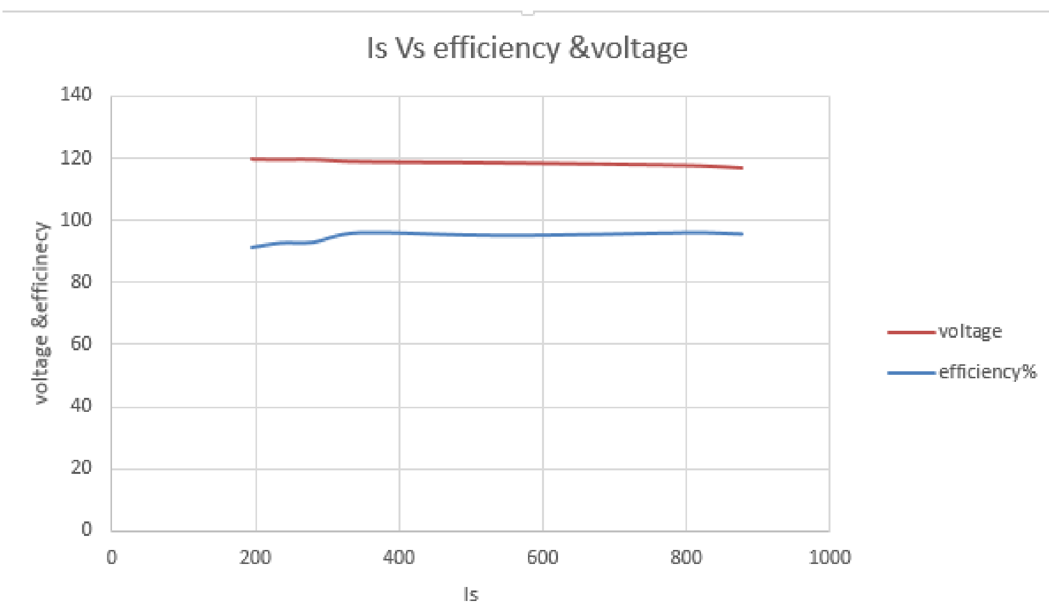
$P_1 = V_1 * I_1 * \cos\Theta = 230 * 0.112*0.75 = 25.1$ w

$P_2 = V_2 * I_2 = 119.7 * 0.196 = 23.1$ w

Ŋ $= \frac{Pout}{Pin} *100\% = 23.4/25.6 = 91.4\%$

$V_R = V_{nl} – V_{Fl} / V_{nl} = 120 – 119.8 /120 = 0.166\%$

The following diagram shown the relation between the secondary current and the efficiency and secondary voltage



From the diagram above, noticed that the efficiency have a good improvement comparing with the previous transformers , in terms of secondary voltage ,the voltage almost has a fixed value 120 V at a small value of secondary current ,at a large value of current there is a small variation in the secondary voltage and it may be negligible

Voltage Behavior With Inductive or Capacitive Load:

The circuit in the Figure 28 was connected as shown:

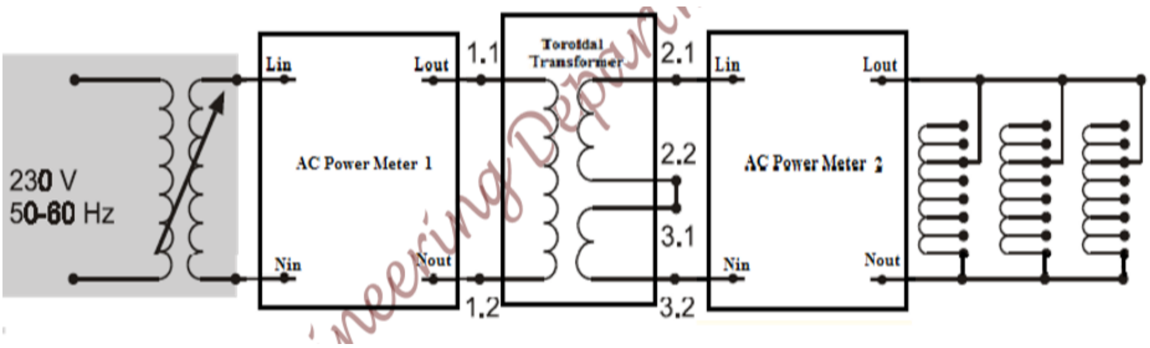


Figure 28

The input voltage was set 230 V and the inductive load was set to 2H ,then the value of the load was decreased sequentially until reach 0.2H ,In each case the value of I_2,$V_{2.2}$,,P_1,$P_2$was measured and recorded in Table 11

Table 11

L_{indi}	open	6	4.8	2.4	1.2	1	0.8	0.6
L_{tot}	open	2	1.6	0.8	0.4	0.33	0.27	0.2
I_2[mA]	0	290.3	362.5	707	1400	1700	2210	2950
V_2[v]	241.5	241.5	241	240	238.8	238.7	237	235
P_1	2.03	12.3	15	27.9	56.1	68.5	98	147
P_2	0	9.5	12	21.5	36.5	43.3	54	70
Ŋ[%]	0	77.2	80	77	65	63.2	55.1	47.6
V_R[%]	0	0	0.2	0.62	1.1	1.15	1.86	2.69

Repeating the previous connection and change the load to be capacitive after that recorded the measured value in table 12.

Table 12

C[uF]	Open	2	4	8	12	16
I_2[mA]	0	154	464	788	1090	1260
V_2[v]	241.5	242	241.7	242	243.5	243.7
P_1	2.03	2.3	3.7	7	12	15.2
P_2	0	0	0	0	0	0
Ŋ[%]	0	0	0	0	0	0
V_R[%]	0	-0.2	-0.08	-0.2	-0.8	-0.91

The following diagram shown the relation between the secondary current Vs the secondary voltage in case the load was inductive and capacitive

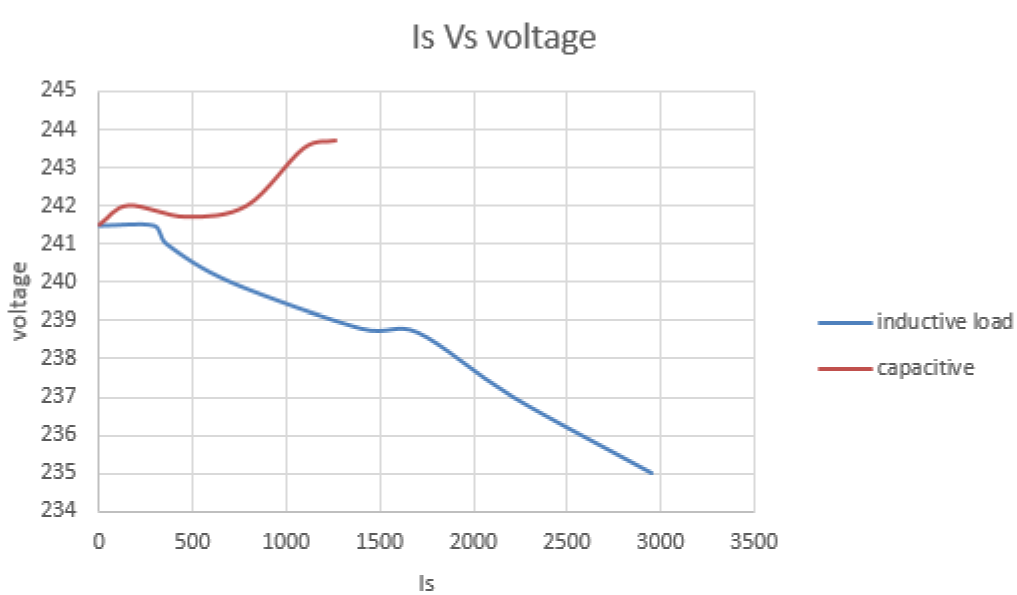


Figure 29

From the diagram above, noticed that in case of inductive load the secondary voltage will decrease as the current increase hence there is a large voltage regulation comparing with previous case(resistive load), in term of capacitive load, the voltage will increase as the current increase hence, there is a negative voltage regulation.

*Note :when the value of the capacitor increase the impedance of the capacitive load will decrease

The following diagram shown the relation between the secondary current and the efficiency

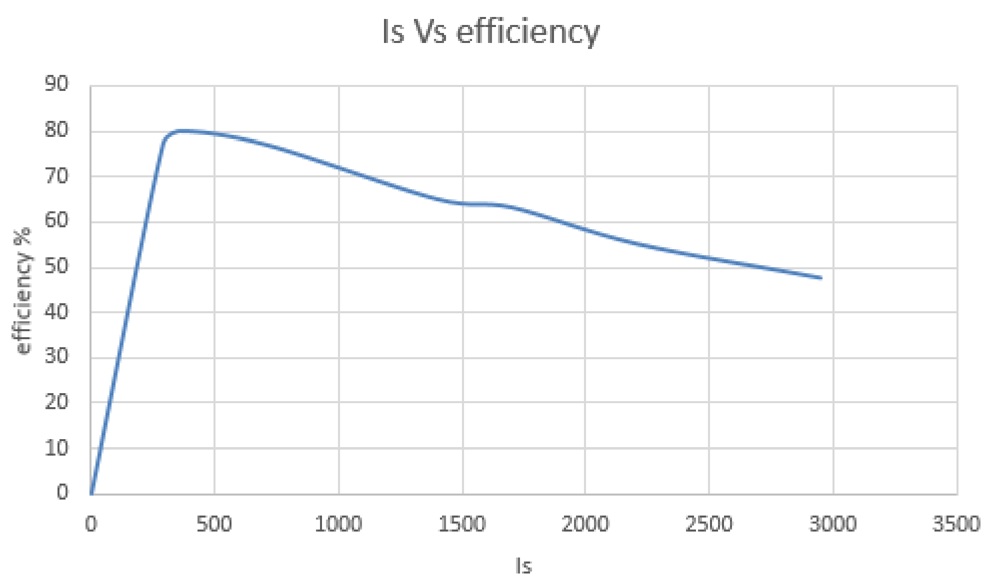


Figure 30

From the diagram above, noticed that the efficiency reach it maximum value at small value of current ,then the efficiency decrease as the load current increase.

In this case, the efficiency is worse than the previous case(resistive load) .

Conclusion :

The experiment was done, three type of transformers was used (Single-phase Transformer, Single-phase Autotransformer, Single-phase Toroidal Core Transformer),these three transformers was put under test using variable types of load(resistive, inductive, capacitive) ,after test it became clear that the Autotransformer is the best in term of voltage variation but, In term of efficiency the Toroidal Core Transformer is the best.

References :

[1] : electronics tutorial website

[2]:Electrical Machinery Fundamental "fifth edition"