EE 255 – SINGLE PHASE TRANSFORMER

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E/21/345

GROUP EE.21.B.23

SEMESTER 04

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PRELAB

255: ELECTRIC POWER

NGLE PHASE TRANSFORMER

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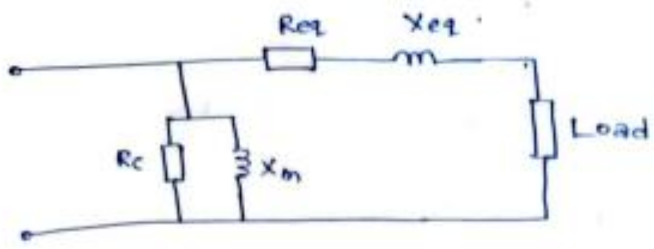
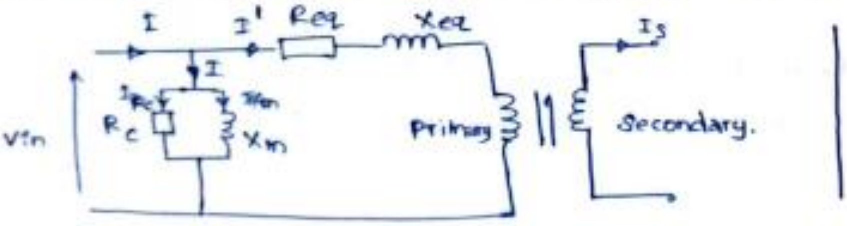


- Rc → core loss resistance. Represent losses in the core
- Xm → magnetization reactance. Represent the magnetizing current needed to establish flux in the core.
- Req → this is equivalent leakage resistance. This is because primary and secondary sides have some leakage flux in a practical transformer.
- Xeq → both flux losses in primary and secondary are transformed to the winding as Xeq.

Open circuit test is used to obtain Xm & Rc.



The secondary side is O:S! ,

$I_s = 0$

$I' = 0$

$N = \frac{V_{out}}{V_{in}}$

$P_n = \frac{V_{in}^2}{R_c}$

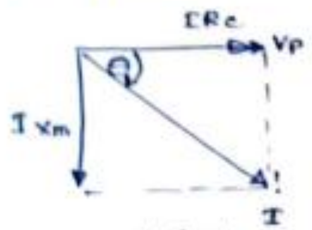
$Q = VI \sin\theta$

$|I_{Xm}| = I_{in} - I_{Rc}$

$|I_{Xm}| = \sqrt{I_{in}^2 - I_{Rc}^2}$

$X_m = \frac{|V_{in}|}{|I_{Xm}|}$ $\quad I_{Rc} = \frac{V_{in}}{R_c}$, $R_c = \frac{V_{in}^2}{P_n}$

$P = VI \cos\theta$



$\theta = \cos^{-1}(P/V_n)$

* Open circuit test is used to measure Xm and Rc.

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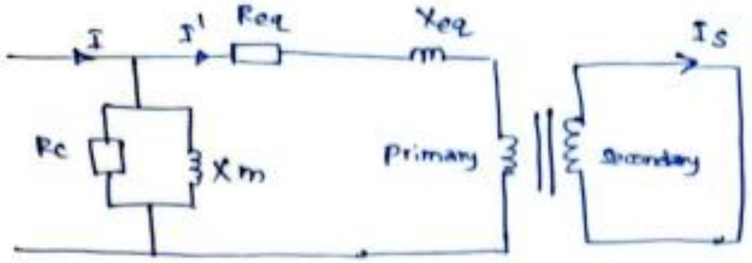
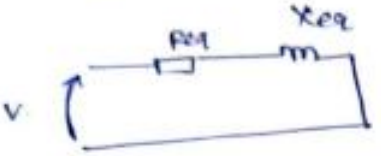


* short circuit test used to obtain Req & Xeq

Give $\frac{1}{10} \times V_{rated}$ as the input voltage.

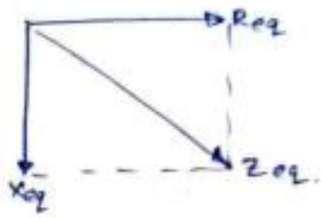


$P_{sc} = I_{sc}^2 R_{eq}$

$R_{eq} = \dfrac{P_{sc}}{I_{sc}^2}$

$Z_{eq} = \dfrac{V}{I}$

$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$



$$R_{eq} = \frac{P_{sc}}{I_{sc}^2}$$

$$\sqrt{P_{sc}} = \sqrt{R_{eq}} \cdot I_{sc}$$

$$y = m \cdot x$$

from the gradient of graph of $\sqrt{P_{sc}}$ Vs I_{sc}, R_{eq} can be found.

EE 255: ELECTRIC POWER

Experiment: Single Phase Transformer

(3 hours)

DATE: 16/07/2025

REG. NO: E/21/345

INTRODUCTION:

Students are given hand on experience in determining the approximate equivalent circuit of a single phase transformer by using the results obtained from the open circuit test and the short circuit test.

Students can get an idea about the losses associate with a transformer at the same time typical variation of the efficiency and the voltage regulation of a single phase transformer for different loadings.

LEARNING OUTCOMES:

LO 1: Describe different magnetic circuits, their properties and appreciate losses associated with them.

LO 2: Perform the open circuit and short circuit tests on a single phase transformer.

LO 3: Estimate the parameters in the equivalent circuit of a single phase transformer.

LO 4: Calculate voltage regulation and efficiency of a transformer using the equivalent circuit.

LO 5: To perform the load test on a single phase transformer and determine its voltage regulation and efficiency at each of the loading level.

THEORY:

Approximate equivalent circuit of a single phase transformer is shown below.

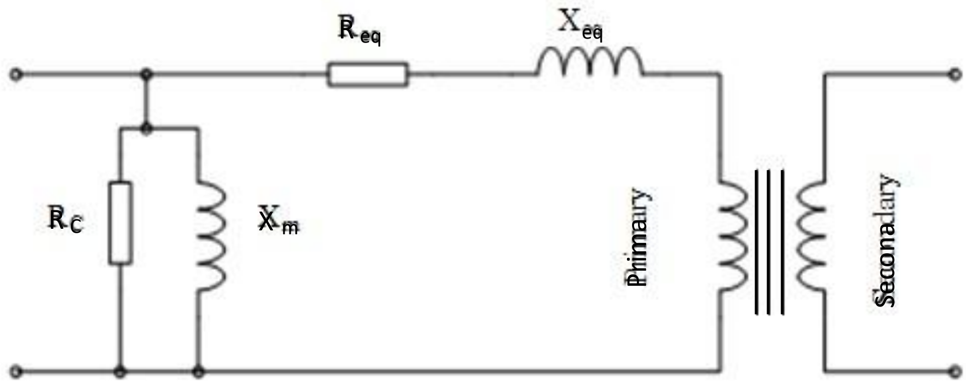


Figure 01: Approximate Equivalent Circuit of a Single Phase Transformer

Open Circuit Test

The purpose of this test is to determine the shunt branch parameters of the equivalent circuit of the transformer.

In this test one of the windings is connected to supply at rated voltage, while the other winding is kept open – circuited.

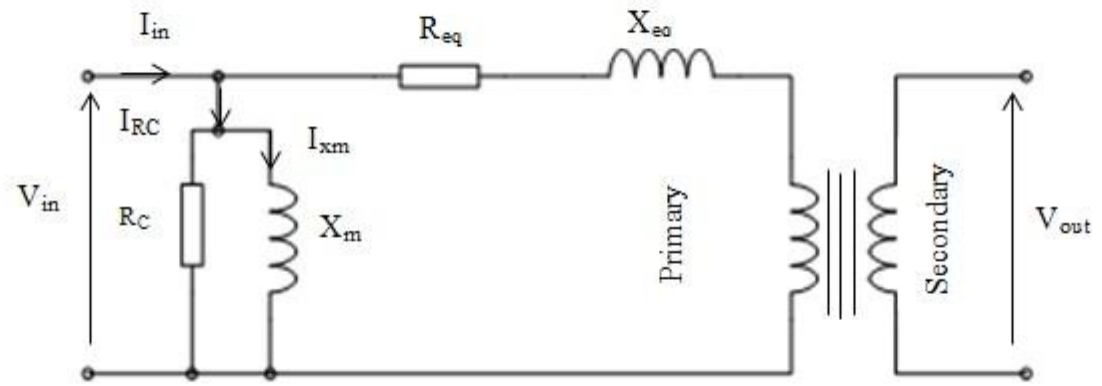


Figure 02: Open Circuit Test

As secondary is open circuited, the current through X_{eq} and R_{eq} can be neglected.

Turns ratio N,

$$N = V_{out} / V_{in}$$

$$P_{in} = V_{in}^2 / R_C$$

P_{in}, I_{in}, V_{in} and V_{out} can be measured in the practical. Therefore, R_C can be found using the above equation.

$$I_{RC} = V_{in} / R_C \qquad i_{xm} = i_{in} - i_{Rc}$$

$$|I_{xm}| = (I_{in}^2 - I_{Rc}^2)^{1/2}$$

$$|X_m| = |V_{in}| / |I_{xm}|$$

X_m can be found by using above equations.

Short Circuit Test

This test serves the purpose of determining the series parameters of a transformer.

For convenience of supply arrangement and voltage and current to be handled, the test is usually conducted from the HV side of the transformer while the LV side is short-circuited.

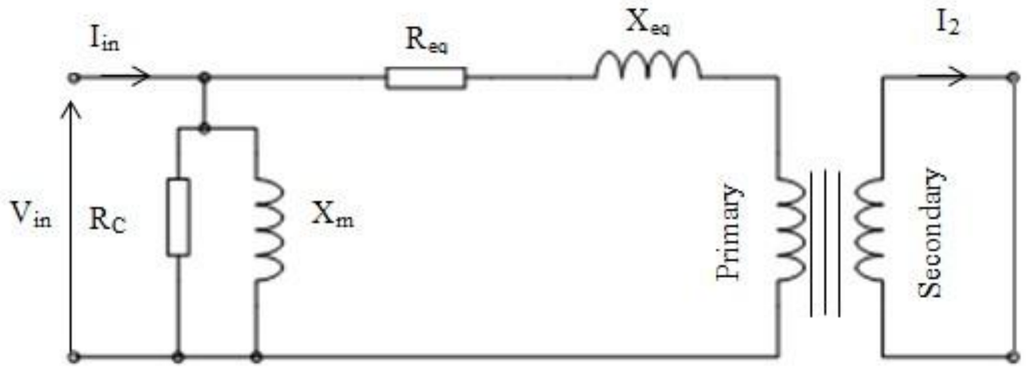


Figure 03: Short Circuit Test

R_C and X_m can be neglected as a lower voltage are applied.

PSC = ISC^2 * Req

(PSC)1/2 = (Req)1/2. ISC

Y = m_1. X

From the gradient m_1 of the graph of $(P_{SC})^{1/2}$ Vs. I_{SC}, R_{eq} can be found.

Zp = |VSC |/ |ISC|

VSC =Zp .ISC

Y = m_2. X

From the gradient m_2 of the graph V_{SC} Vs. I_{SC}, Z_p can be found.

Zp = (Req2 +Xeq2)1/2

From the above equation X_{eq} can be found.

PROCEDURE:

(a). Open Circuit Test

Apparatus

1. Single phase transformer (230/115V, 1.1 kVA,50 Hz)
2. Variac (230V, 50 Hz)
3. Rheostats – 2 Nos (1030Ω/1A & 1Ω/13A)
4. Wattmeter (240V/1A)
5. Voltmeters – 2 Nos(0-300V & 0- 150V)
6. Ammeter (0-1A)

Procedure

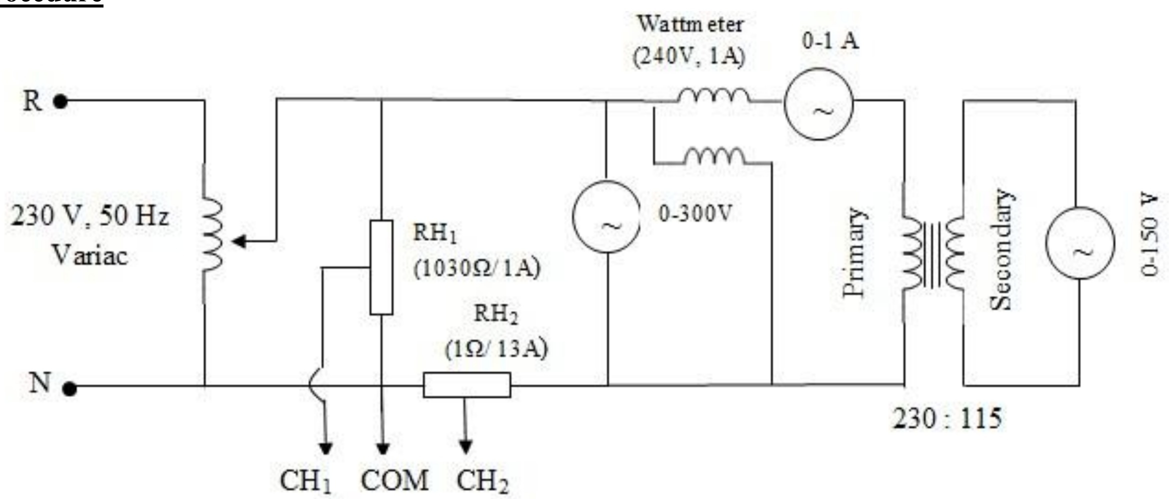


Figure 04: Open Circuit Test Circuit Diagram

1. Connect the circuit as shown in Figure 04. (Do not connect the C.R.O. probes to the circuit until the instructor checks the circuit.)
2. Show the connected circuit to the instructor.
3. Set the **Variac to zero position** and Rheostat 1 (RH_1) and Rheostat 2 (RH_2) to the minimum position.
4. Power on the AC voltage supply.
5. Adjust the Variac and set the secondary voltage to 115V.
6. Record the readings of Wattmeter, ammeter and Voltmeters.
7. Connect the C.R.O. probes and adjust the rheostats (RH_1 and RH_2) slightly to get the full waveform on the screen.
8. Record the voltage and magnetizing current waveforms.
9. Now bring the Variac to zero volts and Switch off the power supply.

Observations

Table 1: Observations

Voltmeter reading	Ammeter reading	Wattmeter reading
230 V	0.11 A	14 W

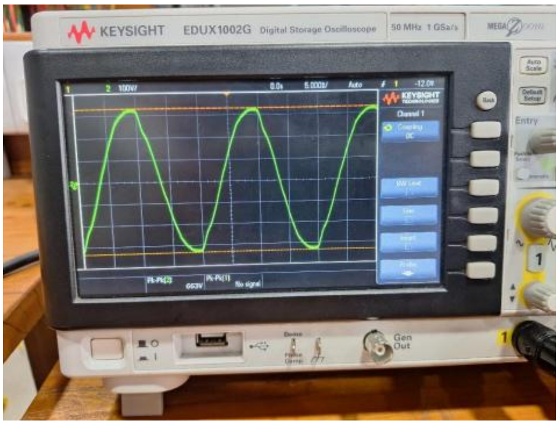


Figure 05: Open circuit voltage waveform

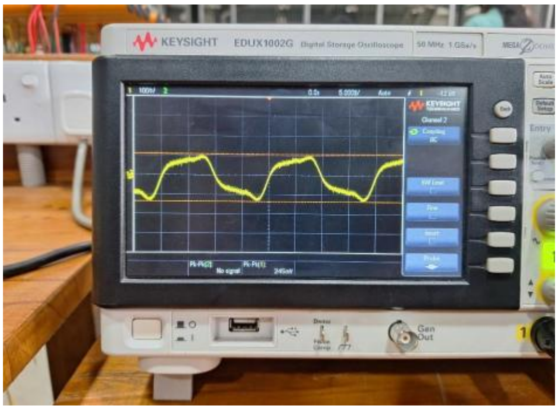


Figure 06: Magnetization current waveform

Calculations

• Calculate R_C and X_m referred to the primary side of the transformer by using Open Circuit Test results.

(b). Short Circuit Test

Apparatus

1. Single phase transformer (230/115V, 1.1 kVA,50 Hz)
2. Variac (230V, 50 Hz)
3. Wattmeter (120V/1A)
4. Voltmeter (0-75V)
5. Ammeter (0-5A)

Procedure

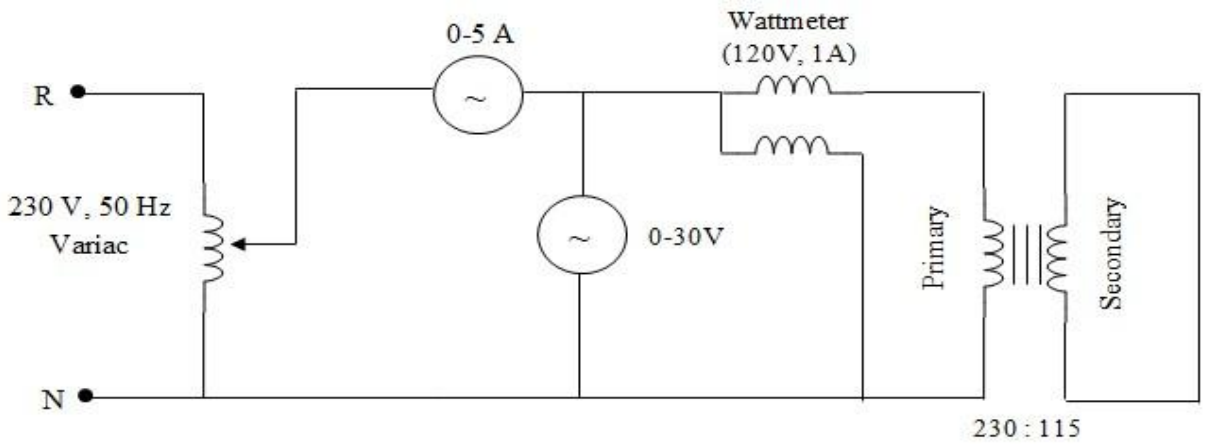


Figure 07: Short Circuit Test Circuit Diagram

1. Connect the circuit as shown in Figure 05.
2. Show the connected circuit to the instructor.
3. Make sure the **Variac is at Zero volt position**.
4. Power on the AC supply.
5. Adjust the Variac and record the readings of the voltmeter, ammeter and wattmeter for ammeter readings from 0 to 4 A by 0.5 A steps. (**Do not exceed the current beyond 4 A.**)
6. Rotate the Variac to zero and switch off the power supply after the experiment.

Observations

Table 2: Observation

Ammeter Reading	Voltmeter Reading	Wattmeter Reading
0.0	0.0	0
0.5	2.0	2
1.0	5.0	5
1.5	7.0	10
2.0	10.0	17
2.5	12	26
3.0	14.5	40
3.5	16.5	54
4.0	19.0	71

Calculations

- Plot the following graphs.
  - **i.** Voltage Vs. Current
  - **ii.** $(\text{Power})^{1/2}$ Vs. Current
- Calculate R_{eq} and X_{eq} referred to the primary side of the transformer by using Short Circuit Test results.

RESULTS

Table 3: Results of transformer approximation model parameters

R_C	3778.571 Ω
X_m	2510.970 Ω
Req	4.24 Ω
X_{eq}	2.207Ω

- Draw the approximate equivalent circuit of the single phase transformer referred to primary side with mentioning calculated parameter values.

(c). Load Test

Apparatus

1. Single phase transformer (230/115V, 1.1 kVA,50 Hz)
2. Variac (230V, 50 Hz)
3. Wattmeters – 2 Nos (240V/25A)
4. Voltmeters – 2 Nos (0-300V & 0-150V)

5. Ammeters – 2 Nos (0-5A & 0-25A)
6. Water Load

Procedure

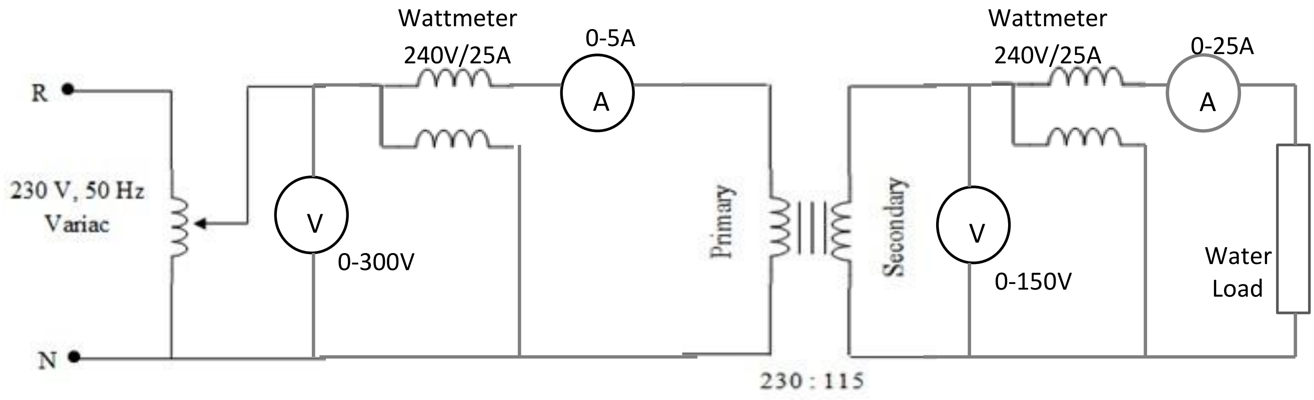


Figure 08: Load test circuit diagram

1. Connect the circuit as shown in figure 6 and set the variac to zero position.
2. Set water load positions to "Low".
3. Adjust the variac and set the primary voltage to 230V.
4. Record the readings of Wattmeters, ammeters and voltmeters for different water load positions.

Observations

Table 4: Primary side and Secondary side readings against percentage full load

Water Load position	Percentage full load(%)	Primary Side			Secondary Side		
		Voltmeter/V	Ammeter/A	Wattmeter/W	Voltmeter/V	Ammeter/A	Wattmeter/W
LLL	30	230	1.9	430	112	3.6	420
LLM	40	230	2.5	570	112	4.9	540
LMM	50	230	1.55	350	114	2.9	340
MMM	60	230	2.00	460	112	3.9	440
MMH	80	230	2.95	680	110	5.8	650

Calculations

Considering the 5th data set of the table,

$P_P = V_P.I_P.Cos(\theta)$,

Power Factor, $Cos(\theta) = P_P / (V_P.I_P)$

$= 680/(230*2.95)$

$= \underline{1.002}$

Voltage regulation $= \frac{(V_{NL} - V_{FL}) \times 100}{V_{FL}}$

$=((115-110)*100)/110$

$= \underline{4.55\ \%}$

Efficiency $= \frac{P_{OUT}}{P_{IN}} \times 100$

$=(650/680)*100$

$= \underline{95.59\%}$

Results

Table 5: Results

Percentage full load (%)	Power Factor	Voltage Regulation (%)	Efficiency (%)
30	0.984	2.68	97.67
40	0.991	2.68	94.74
50	0.982	0.877	97.14
60	1.000	2.68	95.65
80	1.002	4.55	95.59

• Plot the variation of Voltage regulation Vs. percentage full load and Efficiency Vs. Full load

PROBLEM

Using the approximate equivalent circuit shown in Figure 01 and equivalent parameters calculated from Open circuit and Short circuit test, calculate the **Voltage Regulation** and **Efficiency** of the transformer for 30%, 40%, 50%, 60% and 80% of full load. Assume a unity power factor. Tabulate the results.

DISCUSSION

1. Does the core loss vary with the load? Why?
2. In the open circuit test, why the copper loss in the primary can be neglected?
3. In the short circuit test, why can the core loss be neglected?
4. Discuss any three points, which you have gained from this experiment. If any practical problems observed that can also be included in this discussion.
5. Compare voltage regulation and efficiency obtained during load test with theoretically calculated values in PROBLEM.

CALCULATIONS

Part a)

Calculate R_C and X_m referred to the primary side of the transformer by using Open Circuit Test results.

$$P_{in} = \frac{V_{in}^2}{R_C}$$

$$R_C = \frac{230^2\ V^2}{14\ W}$$

$$R_C = 3778.571\ \Omega$$

$$I_{RC} = \frac{V_{in}}{R_C}$$

$$= \frac{230\ V}{3778.571\ \Omega}$$

$$I_{RC} = 60.869\ mA$$

$$I_{Xm} = \sqrt{I_{in}^2 - I_{RC}^2}$$

$$= \sqrt{0.11^2 - 0.060869^2}\ A$$

$$I_{Xm} = 91.60\ mA$$

$$|X_m| = \frac{|V_{in}|}{|I_{Xm}|}$$

$$= \frac{230\ V}{91.60\ mA}$$

$$X_m = 2510.970\ \Omega$$

Part b)

<u>TABULATION</u>

Table 6: Variation of voltage with current

Current (A)	Voltage (V)
0.0	0.0
0.5	2.0
1.0	5.0
1.5	7.0
2.0	10.0
2.5	12.0
3.0	14.5
3.5	16.5
4.0	19.0

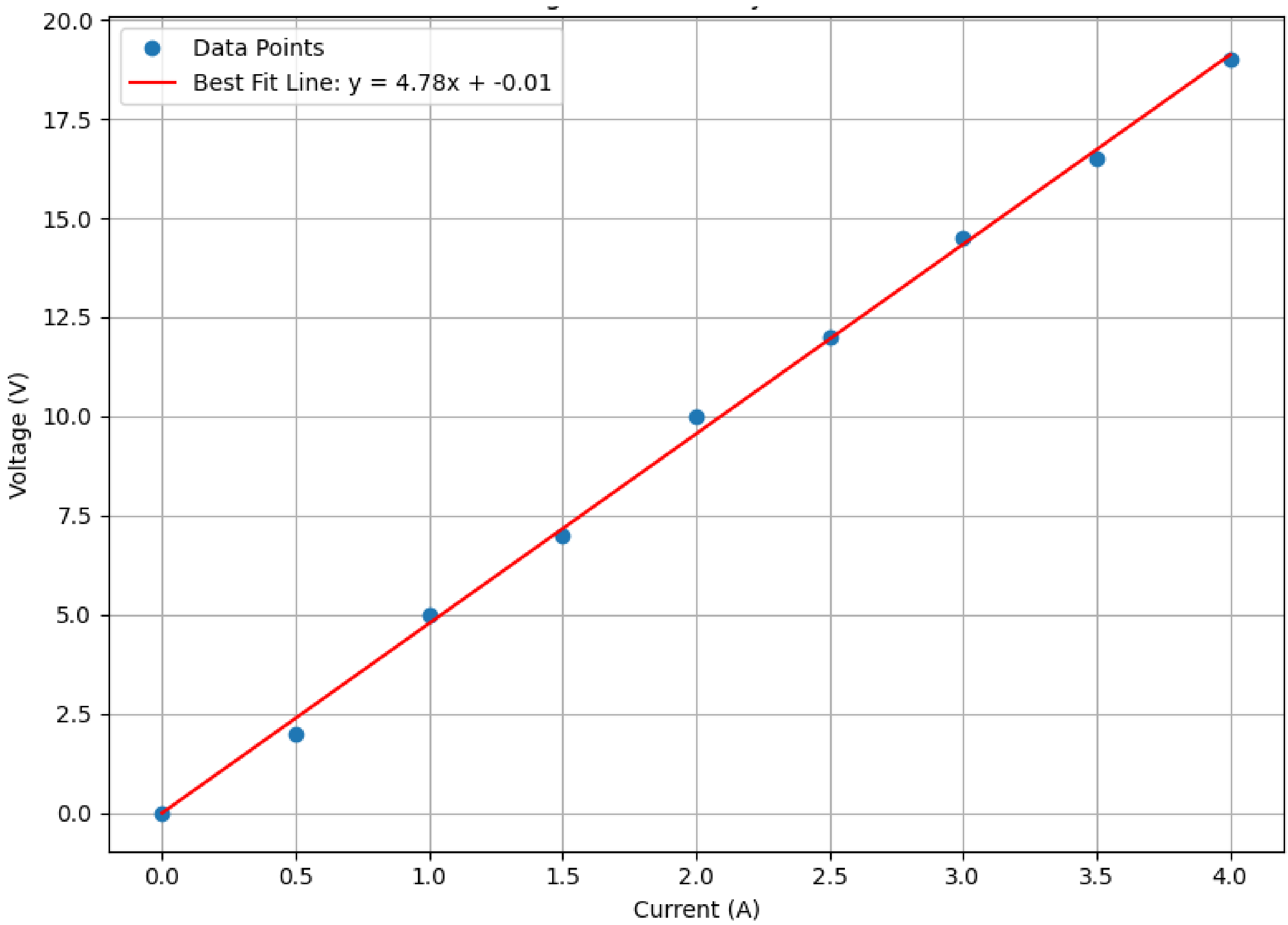


Figure 09: Variation of voltage with current

TABULATION

Table 7: Variation of $(\text{Power})^{1/2}$ with current

Current (A)	$\text{Power}^{1/2}$ $(^{W1/2})$
0.0	0.00
0.5	1.41
1.0	2.24
1.5	3.16
2.0	4.12
2.5	5.39
3.0	6.32
3.5	7.35
4.0	8.43

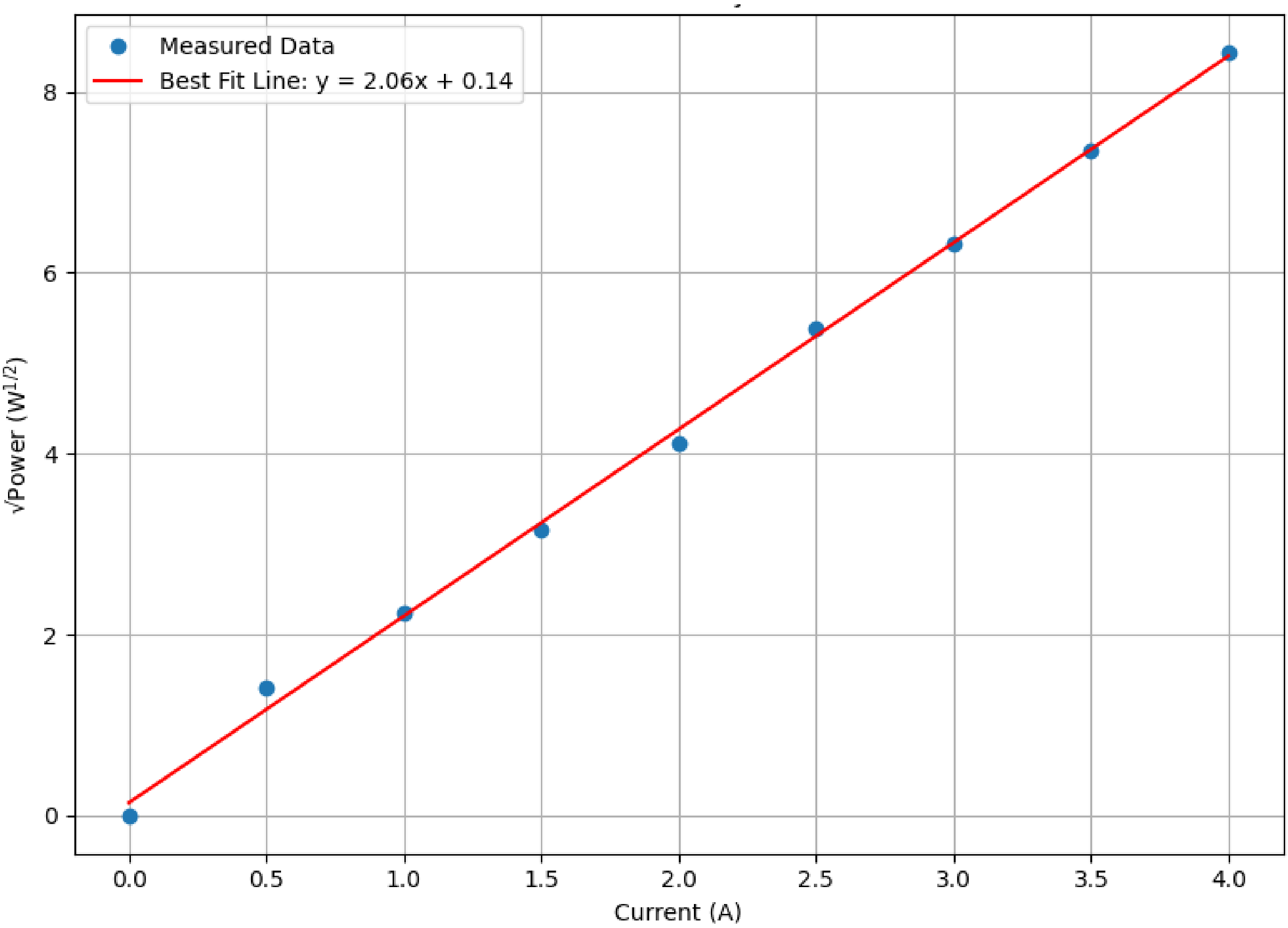


Figure 10: Variation of Power$^{1/2}$ with current

Let,

$$m_1 = gradient\ of\ figure\ 7$$

$$m_2 = gradient\ of\ figure\ 8$$

$$m_1 = 4.78\ V/A$$

$$m_2 = 2.06\ W^{\frac{1}{2}}/A$$

From figure 8,

$$P_{SC} = I_{SC}^2 \times R_{eq}$$

$$(P_{SC})^{\frac{1}{2}} = (R_{eq})^{\frac{1}{2}} \times I_{SC}$$

$$y = m_2 \times x$$

$$(R_{eq})^{\frac{1}{2}} = m_2$$

$$= 2.06$$

$$\underline{\underline{R_{eq} = 4.24\ \Omega}}$$

From figure 7,

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

$$V_{SC} = Z_{eq} \times I_{SC}$$

$$y = m_1 \times x$$

$$Z_{eq} = m_1$$

$$= 4.78$$

$$X_{eq} = \sqrt{(Z_{eq})^2 - (R_{eq})^2}$$

$$= \sqrt{4.78^2 - 4.24^2}$$

$$\underline{\underline{X_{eq} = 2.207\ \Omega}}$$

Part c)

Considering the 1st data set of the table,

$$P_P = V_P . I_P . \mathrm{Cos}(\theta)$$

$$Power\ factor, Cos(\theta) = \frac{P_P}{V_P . I_P}$$

$$= \frac{450\ W}{230\ \times 1.9\ VA}$$

$$= 1.03$$

$$Voltage\ regulation = \frac{(V_{NL} - V_{FL})}{V_{FL}} \times 100$$

$$= \frac{(115 - 112)}{112} \times 100$$

$$= 2.68\%$$

$$Efficiency = \frac{P_{OUT}}{P_{IN}} \times 100$$

$$= \frac{410}{450} \times 100$$

$$= 91.11\%$$

RESULTS

Part a), b)

R_C	3778.571 Ω
X_m	2510.970 Ω
Req	4.24 Ω
X_{eq}	2.207Ω

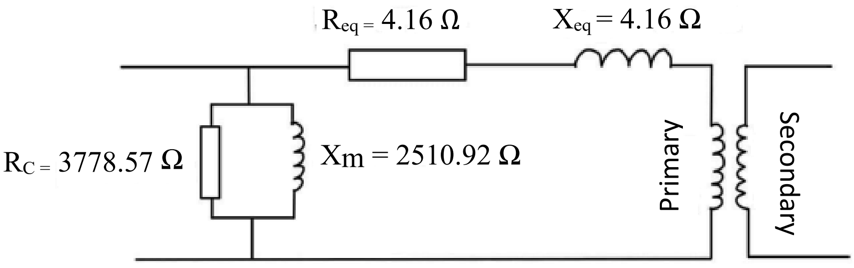


Figure 11: Approximate equivalent circuit referred to primary side

Part c)

Percentage full load (%)	Power Factor	Voltage Regulation (%)	Efficiency (%)
30	0.984	2.68	97.67
40	0.991	2.68	94.74
50	0.982	0.877	97.14
60	1.000	2.68	95.65
80	1.002	4.55	95.59

TABULATION

Table 8: Variation of voltage regulation with percentage full load

Percentage full load (%)	Voltage regulation (%)
30	2.68
40	2.68
50	0.877
60	2.68
80	4.55

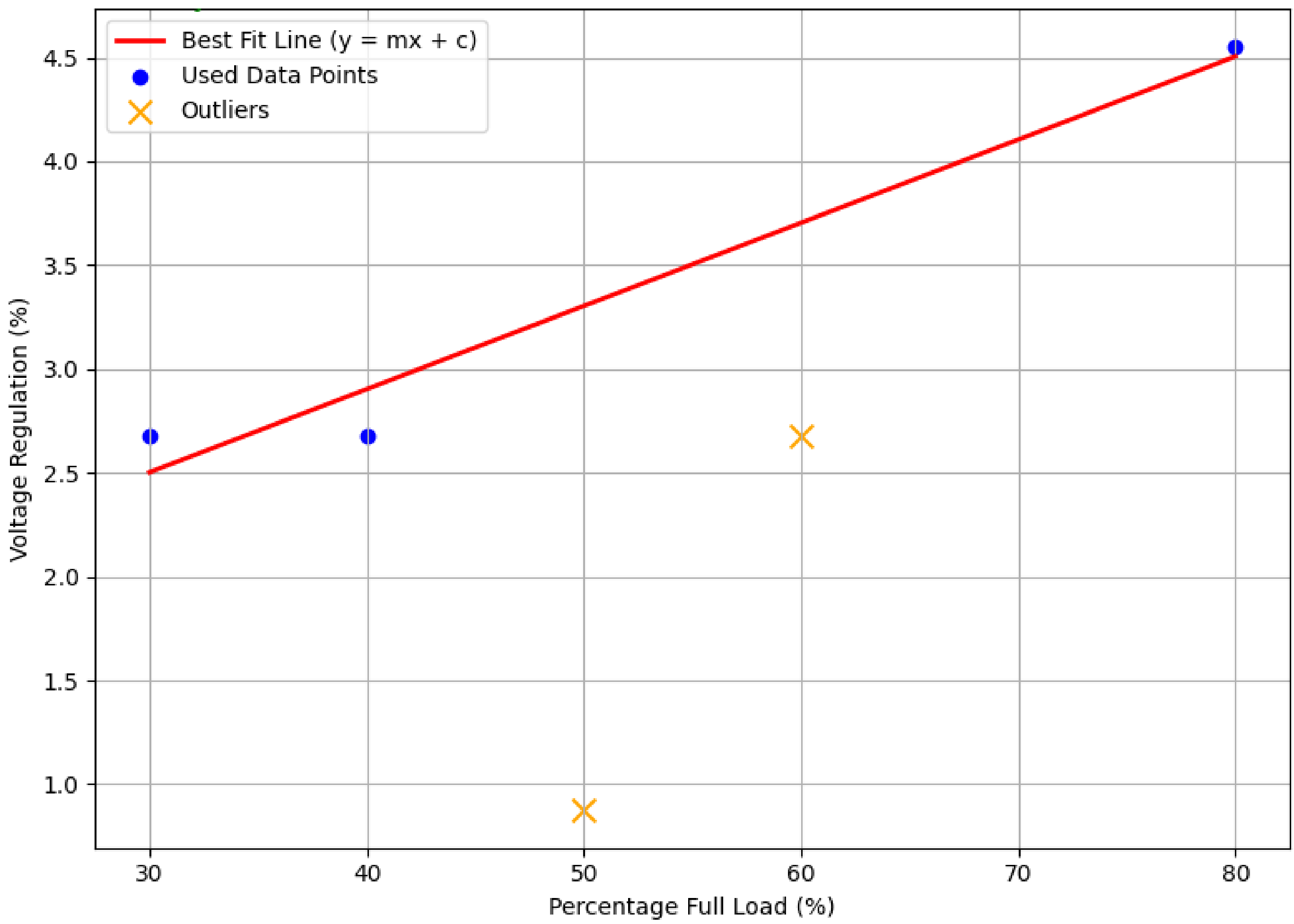


Figure 12: Variation of voltage regulation with percentage full load

TABULATION

Table 9: Variation of efficiency with percentage full load

Percentage full load (%)	Efficiency (%)
30	97.67
40	94.74
50	97.14
60	95.65
80	95.59

- Neglecting third and fourth data set because of fault in water load,

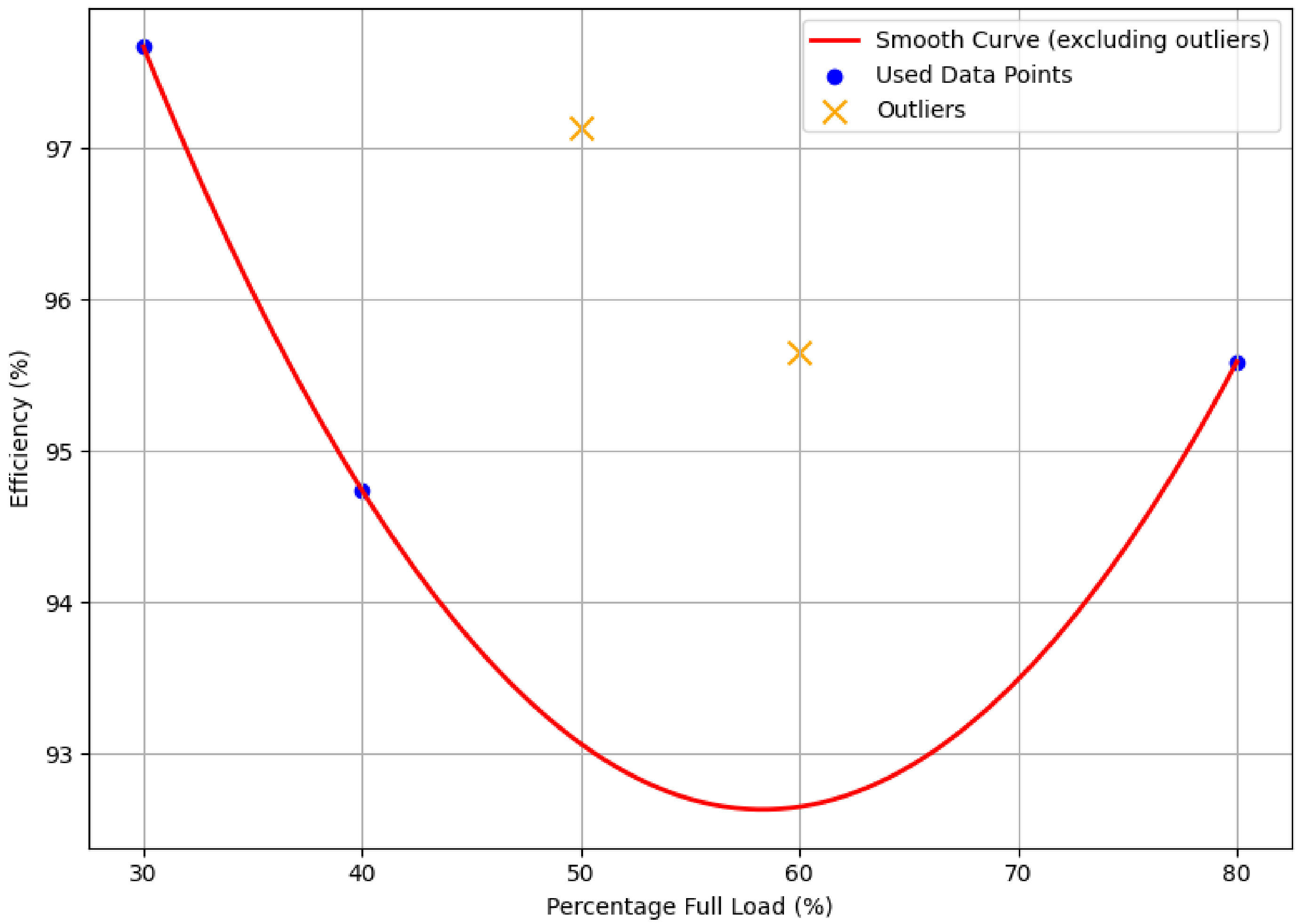


Figure 13: Variation of efficiency with percentage full load

PROBLEM

Using the approximate equivalent circuit shown in Figure 01 and equivalent parameters calculated from Open circuit and Short circuit test, calculate the Voltage Regulation and Efficiency of the transformer for 30%, 40%, 50%, 60% and 80% of full load. Assume a unity power factor. Tabulate the results.

$$I_{FL} = \frac{1.1\ kVA}{115\ V} = 9.565\ \mathrm{A}$$

$$\frac{N_p}{N_s} = \frac{230\ V}{115\ V} = 2 = a$$

$$I_P = \frac{1}{a} I_s \quad (Here, a\ is\ the\ turns\ ratio)$$

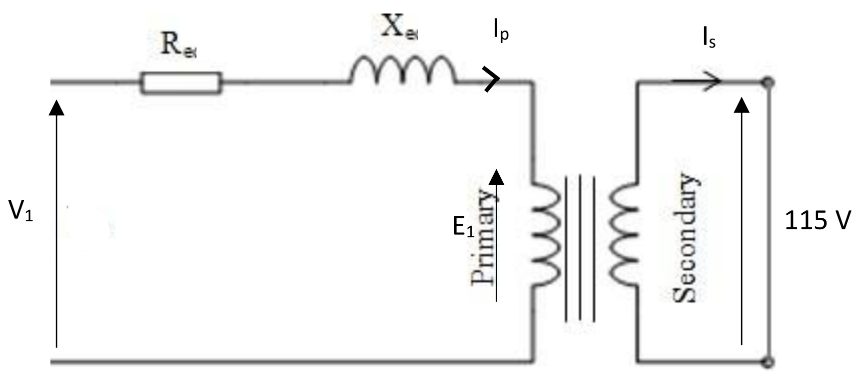


Figure 14: Equivalent Circuit shown in Figure 1

KVL to primary,

$$V_1 = E_1 + I_p\left(R_{eq} + X_{eq}\mathrm{j}\right) \tag{1}$$

1. 30% Full Load

- Secondary current (I_s): $0.3 \times 9.57 = 2.87$ A
- Primary current (I_p): $2.87/2 = 1.44$ A

Calculations:

1. Primary voltage (V_1):
$$V_1 = 230 + 1.44 \times (4.24 + j2.207) = 236.13\angle 0.77^\circ \text{ V}$$
2. Voltage regulation (VR%):
$$VR\% = \frac{236.13 - 230}{230} \times 100 = 2.67\%$$
3. Output power (P_{out}):
$$P_{out} = 115 \times 2.87 = 330.05 \text{ W}$$
4. Power loss (P_{loss}):
   - Copper loss: $1.44^2 \times 4.24 = 8.79$ W
   - Core loss: $\frac{230^2}{3778.571} = 14.00$ W
   - Total loss: $8.79 + 14.0 = 22.79$ W
5. Input power (P_{in}):
$$P_{in} = 330.05 + 22.79 = 352.84 \text{ W}$$
6. Efficiency (η):
$$\eta = \frac{330.0}{352.84} \times 100 = 93.67\%$$

2. 40% Full Load

- Secondary current (I_s): 3.83 A
- Primary current (I_p): 1.91 A

Calculations:

1. Primary voltage (V_1):
$$V_1 = 230 + 1.91 \times (4.24 + j2.207) = 238.14\angle 1.01^\circ \text{ V}$$
2. Voltage regulation (VR%):
$$VR\% = \frac{238.14 - 230}{230} \times 100 = 3.57\%$$
3. Output power (P_{out}):
$$P_{out} = 115 \times 3.83 = 440.45 \text{ W}$$
4. Power loss (P_{loss}):
   - Copper loss: $1.91^2 \times 4.24 = 15.47$ W
   - Core loss: $\frac{230^2}{3778.571} = 14.00$ W
   - Total loss: $15.47 + 14.00 = 29.47$ W
5. Input power (P_{in}):
$$P_{in} = 440.45 + 29.47 = 469.92 \text{ W}$$
6. Efficiency (η):
$$\eta = \frac{440.45}{469.92} \times 100 = 93.73\%$$

3. 50% Full Load

- Secondary current (I_s): 4.785 A
- Primary current (I_p): 2.39 A

Calculations:

1. Primary voltage (V_1):
$$V_1 = 230 + 2.39 \times (4.24 + j2.207) = 240.19\angle 1.26^\circ \text{ V}$$
2. Voltage regulation (VR%):
$$VR\% = \frac{240.19 - 230}{230} \times 100 = 4.43\%$$
3. Output power (P_{out}):
$$P_{out} = 115 \times 4.785 = 550.03\text{W}$$
4. Power loss (P_{loss}):
   - Copper loss: $2.39^2 \times 4.24 = 24.22$ W
   - Core loss: $\frac{230^2}{3778.571} = 14.00$ W
   - Total loss: 38.22 W
5. Input power (P_{in}):
$$P_{in} = 550.03 + 38.22 = 588.25 \text{ W}$$
6. Efficiency (η):
$$\eta = \frac{550.03}{588.25} \times 100 = 93.50\%$$

4. 60% Full Load

- Secondary current (I_s): 5.74 A
- Primary current (I_p): 2.87 A

Calculations:

1. Primary voltage (V_1):
$$V_1 = 230 + 2.87 \times (4.24 + j2.207) = 242.25\angle 1.50^\circ \text{ V}$$
2. Voltage regulation (VR%):
$$VR\% = \frac{242.25 - 230}{230} \times 100 = 5.33\%$$
3. Output power (P_{out}):
$$P_{out} = 115 \times 5.74 = 660.10 \text{ W}$$
4. Power loss (P_{loss}):
   - Copper loss: $2.87^2 \times 4.24 = 34.92$ W
   - Core loss: $\frac{230^2}{3778.571} = 14.00$ W
   - Total loss: 48.92W
5. Input power (P_{in}):
$$P_{in} = 660.10 + 48.92 = 709.02 \text{ W}$$
6. Efficiency (η):
$$\eta = \frac{660.10}{709.02} \times 100 = 93.10\%$$

5. 80% Full Load

- Secondary current (I_s): 7.66 A
- Primary current (I_p): 3.83 A

Calculations:

1. Primary voltage (V_1):
$$V_1 = 230 + 3.83 \times (4.24 + j2.207) = 246.38\angle 1.97^\circ \text{ V}$$
2. Voltage regulation (VR%):
$$VR\% = \frac{246.38 - 230}{230} \times 100 = 7.12\%$$
3. Output power (P_{out}):
$$P_{out} = 115 \times 7.66 = 880.90 \text{ W}$$
4. Power loss (P_{loss}):
   - Copper loss: $3.83^2 \times 4.24 = 62.20$ W
   - Core loss: $\frac{230^2}{3778.571} = 14.00$ W
   - Total loss: 76.20 W
5. Input power (P_{in}):
$$P_{in} = 880.90 + 76.20 = 957.10 \text{ W}$$
6. Efficiency (η):
$$\eta = \frac{880.90}{957.10} \times 100 = 92.26\%$$

Table 10: Results for theocratically obtained Voltage regulation and Efficiency

Percentage full load (%)	Voltage Regulation (%)	Efficiency (%)
30	2.67	93.67
40	2.67	93.67
50	4.43	93.50
60	5.33	93.10
80	7.12	92.26

DISCUSSION

1. Does the core loss vary with the load? Why?

   No. Core loss stays almost the same regardless of load. It only depends on the supply voltage and frequency, which we kept constant. It's made of hysteresis and eddy current losses in the core. So even when load changes, this loss doesn't really change. That's why in calculations and open circuit test, we treat it as constant.

2. In the open circuit test, why the copper loss in the primary can be neglected?

   Because the current is very low in this test. Only a small magnetizing current flows to create flux in the core. Since copper loss = I^2R, and I is tiny here, the copper loss is almost zero. So we ignore it and assume the whole wattmeter reading is due to core loss only.

3. In the short circuit test, why can the core loss be neglected?

   In this test, we apply a very low voltage which just enough to push full current through the windings. Since voltage is so small, the flux in the core is also small. That means hysteresis and eddy current losses are minimal. So we ignore core loss and just focus on copper loss, which is dominant.

4. Discuss any three points, which you have gained from this experiment. If any practical problems observed that can also be included in this discussion.

   - I now know how to practically find transformer losses using simple tests without loading it fully.
   - I understood how voltage regulation works and how to measure it using load variation.
   - I learned how equivalent circuit parameters like Req and Xeq actually come from the open and short circuit tests, not just theory.

   One issue: water load wasn't stable at some points (like 50% and 60%), which gave weird data. We had to skip those values from the graphs.

5. Compare voltage regulation and efficiency obtained during load test with theoretically calculated values in PROBLEM.

Looking at the two tables, the observed voltage regulation and efficiency values are generally better than the theoretical ones.

Table 11: Results for theocratically obtained Voltage regulation and observed voltage regulation

Percentage full load (%)	Observed Voltage Regulation (%)	Theoretical Voltage Regulation (%)
30	2.68	2.67
40	2.68	2.67
50	0.877	4.43
60	2.68	5.33
80	4.55	7.12

For voltage regulation, both observed and theoretical values are almost the same at 30% and 40% load — around 2.68%. That means the transformer behaved as expected at light load. But from 50% load onwards, there's a big gap. At 50%, the theory says 4.43% regulation, but we measured only 0.877%. Same for 60% and 80%, where theory shows a rise, but the actual values are lower. This could be due to the transformer having tighter winding or lower leakage than we assumed. Also, maybe our load setup caused less voltage drop than what we expected in calculations.

Table 12: Results for theocratically obtained Efficiency and observed Efficiency

Percentage full load (%)	Observed Efficiency (%)	Theoretical Efficiency (%)
30	97.67	93.67
40	94.74	93.67
50	97.14	93.50
60	95.65	93.10
80	95.59	92.26

For efficiency, the measured values are always higher than theory. At 30% load, we got 97.67%, which is a lot better than the 93.67% we calculated. Even at 80%, the observed value was 95.59%, still better than the theoretical 92.26%. So clearly, the transformer was running more efficiently in real life.

Overall, the real transformer worked better than theory predicted. That's a good thing, but also shows us that theoretical models are just approximations, the actual build and setup can perform better (or worse) depending on real-world factors.

References

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