EE 255 – TRANSFORMER DESIGN

SAMARAKOON S.M.O.T.

E/21/345

GROUP EE.21.B.23

SEMESTER 04

04.06.2025

EE255: ELECTRICAL POWER

TRANSFORMER DESIGN

GROUP EE.21. B.23

PRE-LAB

VA Rating = 7

Primary voltage = 120 V

Secondary voltage = 20V

Data:

core size:

T	= 25	mm
S	= 26	mm
H	= 38	mm
L	= 12	mm

1. Calculate the number of turns required for the primary.

for a sine wave supply,

$$E = 4.44\,\phi_m . N . f$$

$$E = 4.44 \times B_m . A . N . f . S_f$$

$$E = 4.44 \times 1 \times (T \times S \times 10^{-6}) \times N \times 50 \times 0.9$$

$$(N/E) = 5005/(T \times S)$$

for an ideal transformer, $E = V$

$$N_p/V = 5005/(T \times S)$$

$$(N_p/120) = 5005/(T \times S)$$

$$\underline{N_p = 924}$$

② Calculate the number of turns required for the secondary.

$$(N/V) = 5005/(T \times S)$$

$$N_S/20 = 5005/(T \times S)$$

$$\underline{\underline{N_S = 154}}$$

③ Calculate $I_{load, Primary}$, $I_{load, secondary}$, I_m and total primary current.

$$I_{load, primary} = VA/V_{primary}$$

$$= 7/120$$

$$= \underline{\underline{58.33 mA}}$$

$$I_{load, Secondary} = VA/V_{secondary}$$

$$= 7/20$$

$$= \underline{\underline{0.35 A}}$$

$$I_m = I_{load, primary} \times 0.3$$

$$= \underline{\underline{17.499 mA}}$$

$$\text{Total primary current} = \sqrt{I^2_{load, primary} + I_m^2}$$

$$= \sqrt{58.33^2 + 17.499^2}$$

$$= \underline{\underline{60.90 mA}}$$

④ Select suitable coils for primary and secondary windings using table in Appendix.

Wire Gauge for primary = 36

Wire Gauge for Secondary = 26

(5.) Calculate the total available window area consumed by the coils.

Available window area = $H \times L$ − area loss when bobbin inserted.

$$= H \times L - 1.5 \times 2 \times L - 1.5 \times (H - 1.5 - 1.5)$$

$$= 38 \times 12 - 1.5 \times 2 \times 12 - 1.5 \times (38 - 1.5 - 1.5)$$

$$= \underline{\underline{367.5 \ mm^2}}$$

Ratio of effective copper area $= \dfrac{(\pi \times d^2/4)}{d^2} = 0.78$

Total area consumed by the coils $= \dfrac{(N_p \times A_p + N_s \times A_s)}{0.78}$

$$= \frac{(924 \times 0.024 + 154 \times 0.38)}{0.78} \ mm^2$$

$$= \underline{\underline{103.46 \ mm^2}}$$

$103.46 \ mm^2 < 367.5 \ mm^2$

Area consumed by coils < Available window Area

∴ windings can be accommodate with the window area available

EE 255: ELECTRIC POWER
Experiment: Transformer Design
(3 hours)

DATE: 2025/06/04 ……………………………………..

REG. NO: E/21/345 ………………………………….

Selection of Core material:

The transformer core, which provides the flux linkage between the primary and secondary coils of the transformer must be selected, based on:

(1) Magnetization characteristics - the variation of flux density (B) with ampere-turn per meter (A)
(2) Core loss - the variation of power loss per kg weight of the core (W) with flux density (B)

Manufacturers provide these characteristics as curves or tables. The core material selected for this particular case is grain oriented 3 silicon cold rolled steel (GOSS) laminate. For this laboratory class, consider the transformer core, which is constructed using laminates of the form and dimensions shown in Figure 1.

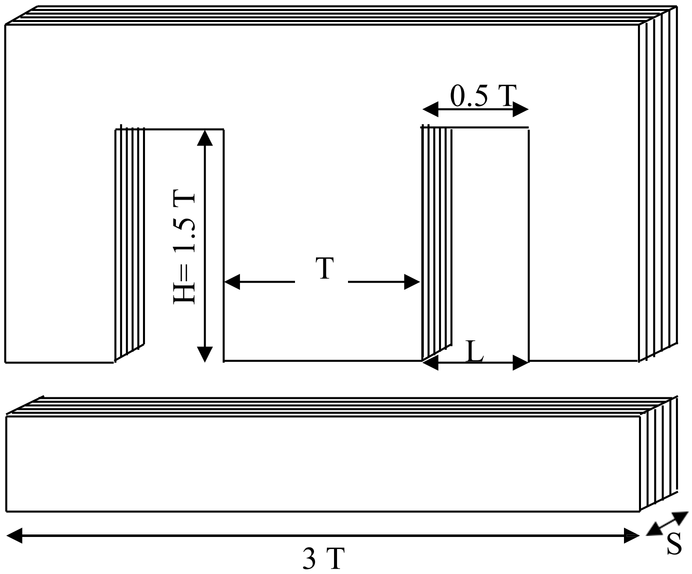

Figure 1: Dimension of the transformer core

Turns per volt ratio:

This depends on the core material and can be calculated as follows.
For a sine wave supply, the induced e.m.f. (E) can be calculated by,

$$E = 4.44 \cdot \phi_m \cdot N \cdot f \qquad (\phi_m = \text{Maximum flux density})$$

By substituting $\phi_m = B_m \cdot A$, f= 50 Hz,

$$E = 4.44 \cdot B_m \cdot A \cdot N \cdot 50 \cdot S_f$$

Here stacking factor S_f, which compensates the reduction in iron area because of the insulating layer on the lamination, can be taken as 0.9.

For the selected lamination materials, the maximum flux density can be taken as 1.0 Tesla.

$$A = T \times S \times 10^{-6}$$

$$E = 4.44 \times 1.0 \times T \times S \times 10^{-6} \times N \times 50 \times 0.9$$

Turns per volt ratio $= (N/E) = 5005 / (T \times S)$

Note: for an ideal transformer E = V.

The primary voltage of the transformer is 110 V and the induced voltage in the secondary has to be selected according to your group number. Using the (N/E) ratio calculated above, the number of turns required for primary and secondary can be calculated.

Primary and secondary currents:

$$I_{load,primary} = VA / V_{primary} \quad \text{and} \quad I_{load,secondary} = VA / V_{secondary}$$

For a small transformer, magnetizing current I_m can be approximated to 30% of $I_{load,primary}$.

Therefore, $I_m = I_{load,primary} \times 0.3$

If the transformer is operated at full load at unity power factor operation, then the magnetizing current is in quadrature with the load current.

Therefore, total current of primary coil at full load $= (I_{load}^2 + I_m^2)^{1/2}$

Selection of coil wires for windings:

The winding coils are chosen so that they can withstand the maximum current (the current through the coil at maximum load) and are selected by referring to coil manufacturer's data sheets e.g. See Appendix.

Available window area:

Available window area $= H \times L$ –area loss when the bobbin is inserted (see Fig.2)

$= H \times L - 1.5 \times 2 \times L - 1.5 \times (H-1.5-1.5)$ (mm^2)

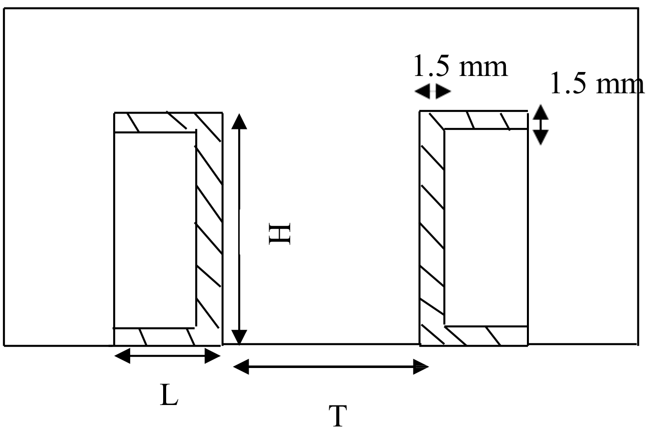

Figure 2: Area loss due to bobbin

Total area consumed by the coils:

Let d is the diameter of a copper a coil.
ratio of effective copper area = $(\pi \times d^2/4)/(d^2) = 0.78$

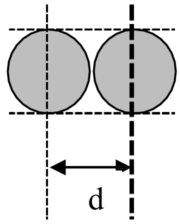

Figure 3: Total copper area

Total area consumed by the coils = ($N_p \times$ cross sectional area of primary coil + $N_s \times$ cross sectional area of secondary coil)/0.78

This should less than available window area.

Pre-lab Calculations

Data

Core size:

T	=	25 mm
S	=	26 mm
H	=	38 mm
L	=	12 mm

Calculations

1. Calculate the number of turns required for the primary
2. Calculate the number of turns required for the secondary
3. Calculate $I_{load,primary}$, $I_{load,secondary}$, I_m and total primary current
4. Select suitable coils for primary and secondary windings using Table in Appendix. When you come to the lab, please check the availability of coils in the laboratory and select the nearest coil gauge for your calculated value.
5. Calculate the total available window area and area consumed by the coils. Check whether you can accommodate the windings within the window area available.

Appendix

Table 01: Appendix

Wire Gauge (SWG)	Diameter/ mm	Area/ mm^2	Current/ A
26	0.46	0.166	0.38
28	0.38	0.101	0.26
29	0.35	0.096	0.22
30	0.305	0.073	0.18
36	0.178	0.024	0.068
39	0.127	0.012	0.032
40	0.12	0.011	0.027

30, 36, 39, 40 - Primary Coil
26, 28, 29 - Secondary Coil

EE 255 ELECTRIC POWER
TRANSFORMER DESIGN

The rating of the transformers to be designed by the respective groups are given below. You should design your transformer according to those ratings. All the calculations should be done prior to the practical and you have to bring the report when you are attending to the practical.

Table 02

Group No	VA rating	Primary Voltage/ V	Secondary Voltage/ V
01	2	110	10
02	3	110	15
03	2	110	10
04	3	110	15
05	2	110	10
06	3	110	15
07	2	110	10
08	3	110	15
09	2	110	10
10	6	110	24
11	2	110	8
12	9	110	25
13	2	110	8
14	6	110	24
15	3	120	12
16	9	120	25
17	3	120	12
18	9	120	25
19	3	120	9
20	7	120	20
21	3	120	9
22	9	120	24
23	7	120	20
24	9	120	24
25	7	120	24
26	6	120	24
27	9	120	24
28	6	120	24

Load Test

Apparatus

1. Single phase transformer
2. Variac (230V, 50 Hz)
3. Wattmeters – 2 Nos (120V/1A)
4. Voltmeters – 2 Nos (0-150V & 0-30V)
5. Ammeters – 2 Nos (0-0.5A)
6. Rheostat

Procedure

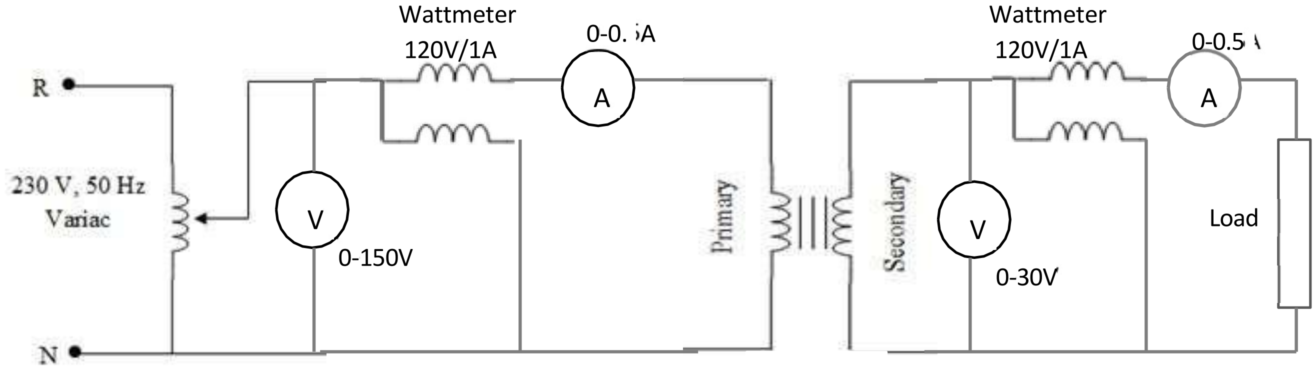

Figure 4: Load test circuit diagram

1. Connect the circuit as shown in figure 4 and set the variac to zero position.
2. Set the rheostat to the maximum position.
3. Adjust the variac and set the primary voltage to 230V.
4. Set the secondary current values as given in the table by varying the rheostat.
5. Record the readings of Wattmeters, ammeters and voltmeters.

Observations

Table 03: Observation data

Percentage full load(%)	Secondary current value (A)	Primary Side			Secondary Side	
		Voltmeter/V	Ammeter/A	Wattmeter/W	Voltmeter/V	Wattmeter/W
30	0.520	120	0.120	15	16.6	8
40	0.390	120	0.100	13	17.2	7
50	0.325	120	0.095	11	17.4	6
60	0.275	120	0.080	10	17.6	5
80	0.215	120	0.070	9	18.2	4
90	0.190	120	0.065	9	18.0	4
100	0.180	120	0.065	8	18.2	3

Calculations

Considering the 7th data set of the table,

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

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

$= 8 / (120.0 \times 0.65)$

$= \underline{\underline{1.03}}$

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

$= ((20 - 18.2) \times 100) / 18.2$

$= \underline{\underline{9.89\%}}$

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

$= 3 \times 100 / 8$

$= \underline{\underline{37.5\%}}$

Results

Table 04: Results

Percentage full load (%)	Power Factor	Voltage Regulation (%)	Efficiency (%)
30	1.04	20.48	53.33
40	1.08	16.28	53.85
50	0.96	14.94	54.55
60	1.04	13.64	50.00
80	1.07	9.89	44.44
90	1.15	11.11	44.44
100	1.03	9.89	37.50

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

Tabulation & Graphs

Table 05: Variation of Voltage Regulation vs Percentage Full Load

Percentage full load (%)	Voltage Regulation (%)
30	20.48
40	16.28
50	14.94
60	13.64
80	9.89
90	11.11
100	9.89

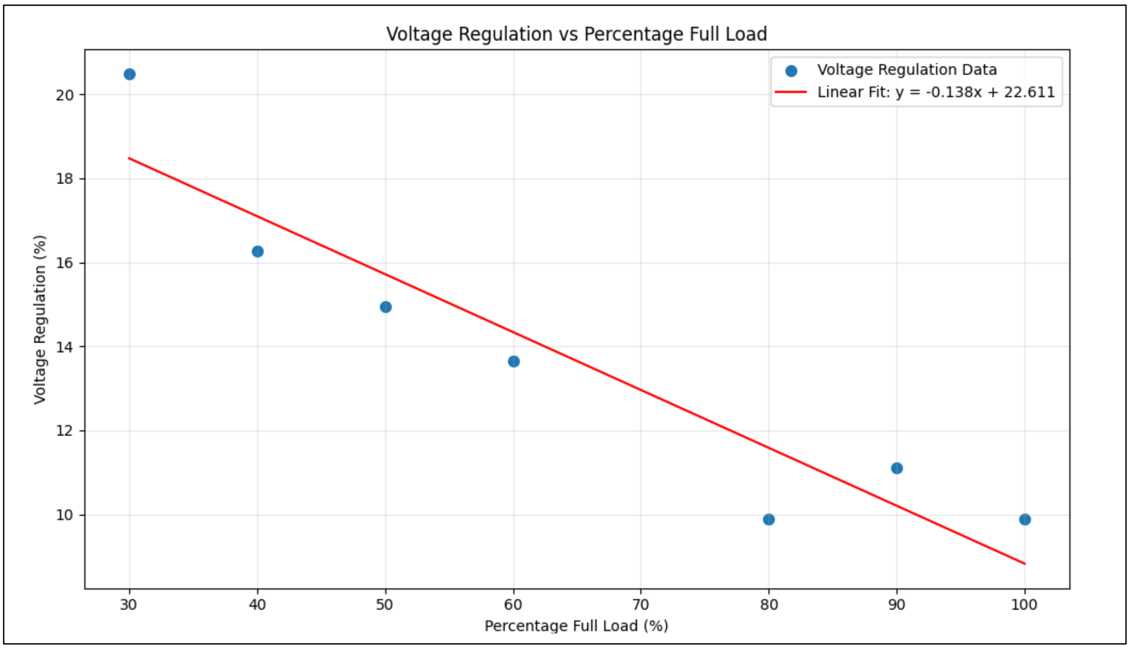

Figure 5: Voltage Regulation VS Percentage Full Load

Table 06: Variation of Efficiency vs Percentage Full Load

Percentage full load (%)	Efficiency (%)
30	53.33
40	53.85
50	54.55
60	50.00
80	44.44
90	44.44
100	37.50

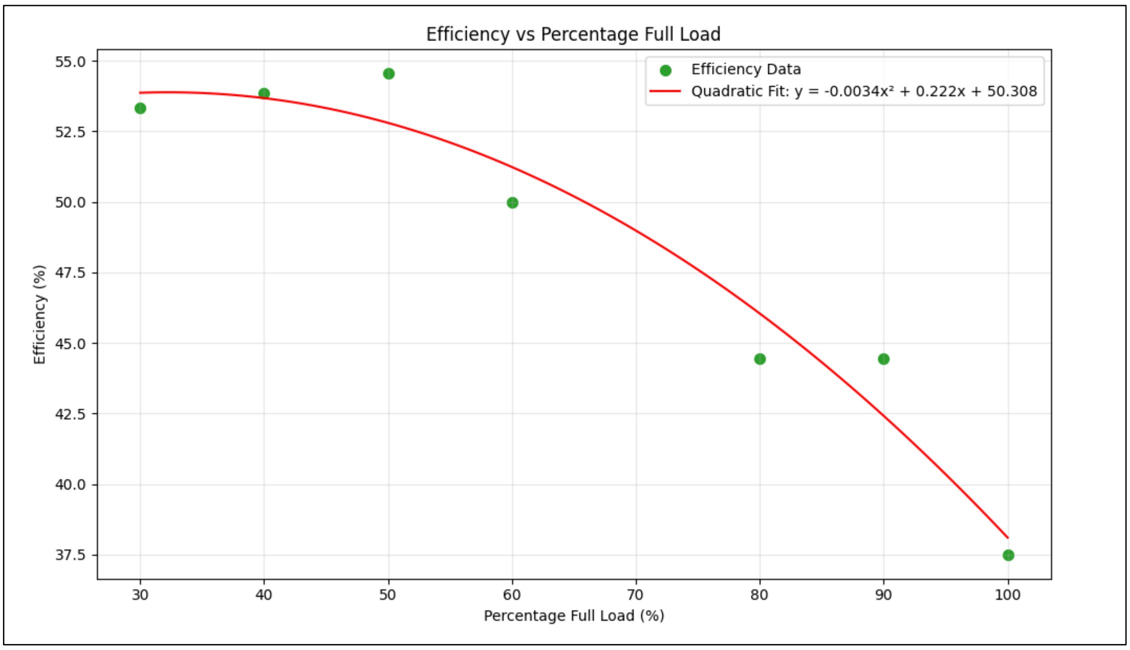

Figure 6: Efficiency VS Percentage Full Load

Discussion

1. Compare and contrast the Voltage regulation Vs. percentage full load, obtained for the transformer used in the single phase transformer laboratory and that of the transformer wound by you. Clearly state the possible reasons for any deviation.

Table 07: Variation of Voltage Regulation vs Percentage Full Load transformer used in the single phase transformer laboratory and that of the transformer wound

Percentage full load (%)	Voltage Regulation for transformer wounded in lab (%)	Voltage regulation for transformer used single phase lab (%)
30	20.48	2.68
40	16.28	2.68
50	14.94	0.877
60	13.64	2.68
80	9.89	4.55

As we can see from the above comparison table, the transformer wound in the lab shows significantly higher voltage regulation values across all load percentages compared to the standard transformer used in the single-phase laboratory. For instance, at 30% load, the wound transformer has a voltage regulation of 20.48%, whereas the lab transformer shows only 2.68%. Even at higher loads such as 80%, the wound transformer still shows 9.89%, while the lab transformer maintains a lower 4.55%.

This large deviation is likely due to several factors:

- Core material and construction quality: The lab transformer likely uses higher-grade materials with better magnetic properties and minimal core losses. In contrast, the wound transformer may have gaps or misalignments in the core laminations, increasing leakage reactance and resistance.

- Winding compactness and precision: The factory-made transformer likely has machine-wound coils with tight coupling, reducing impedance and maintaining voltage better under load. The hand-wound transformer may have loose or uneven windings leading to increased resistance and flux leakage.

- Load test conditions and measurement accuracy: Slight differences in how loads are applied and measured (e.g., contact resistance, meter calibration) could also introduce discrepancies.

Overall, the higher regulation in the wound transformer indicates greater voltage drop under load, which is expected mainly because of construction quality of the transformer.

2. Compare and contrast the Efficiency Vs. percentage full load, obtained for the transformer used in the single phase transformer laboratory and that of the transformer wound by you. Clearly state the possible reasons for any deviation.

Table 08: Variation of Efficiency vs Percentage Full Load transformer used in the single phase transformer laboratory and that of the transformer wound

Percentage full load (%)	Efficiency for transformer wounded in lab (%)	Efficiency for transformer used single phase lab (%)
30	53.33	97.67
40	53.85	94.74
50	54.55	97.14
60	50.00	95.65
80	44.44	95.59

The efficiency of the transformer used in the lab is significantly higher than the wound transformer across all load conditions. For example, at 30% load, the lab transformer reaches an efficiency of 97.67%, whereas the wound transformer only achieves 53.33%. Even at higher loads (50%–80%), the lab transformer maintains efficiency above 95%, while the wound transformer's efficiency declines from 54.55% to 44.44%.

The key reasons for this deviation can be listed as folow:

- Higher copper and core losses in the wound transformer: Due to less efficient winding techniques, smaller wire gauges, and potentially imperfect joints, both copper losses (I^2R) and core losses are likely elevated in the wound transformer.

- Lower power output and poor load matching: The efficiency calculation is highly sensitive to the output power. In the wound transformer, mismatch in winding turns or poor magnetic coupling may lead to a lower real output power and thus lower efficiency.

- Measurement and construction tolerances: Laboratory transformers are manufactured with precision, whereas hand wound transformers we made might have inconsistencies in insulation, wire tension, or contact points, all affecting performance.

In summary, the wound transformer has much lower efficiency due to greater internal losses and construction limitations, while the lab transformer benefits from optimized design, precise construction, and high-quality materials.

References

[1] Oshadha345, “Electrical-Power/University Work/Transformer Design Lab/Trnaformer_Design_Lab_report.ipynb at main · Oshadha345/Electrical-Power,” GitHub, 2025. https://github.com/Oshadha345/Electrical-Power/blob/main/University%20Work/Transformer%20Design%20Lab/Trnaformer_Design_Lab_report.ipynb (accessed Jul. 24, 2025).

[2] Electronics Tutorials, “Transformer Construction of the Core and Transformer Design,” *Basic Electronics Tutorials*, Jul. 31, 2018. https://www.electronics-tutorials.ws/transformer/transformer-construction.html (accessed Jul. 24, 2025)