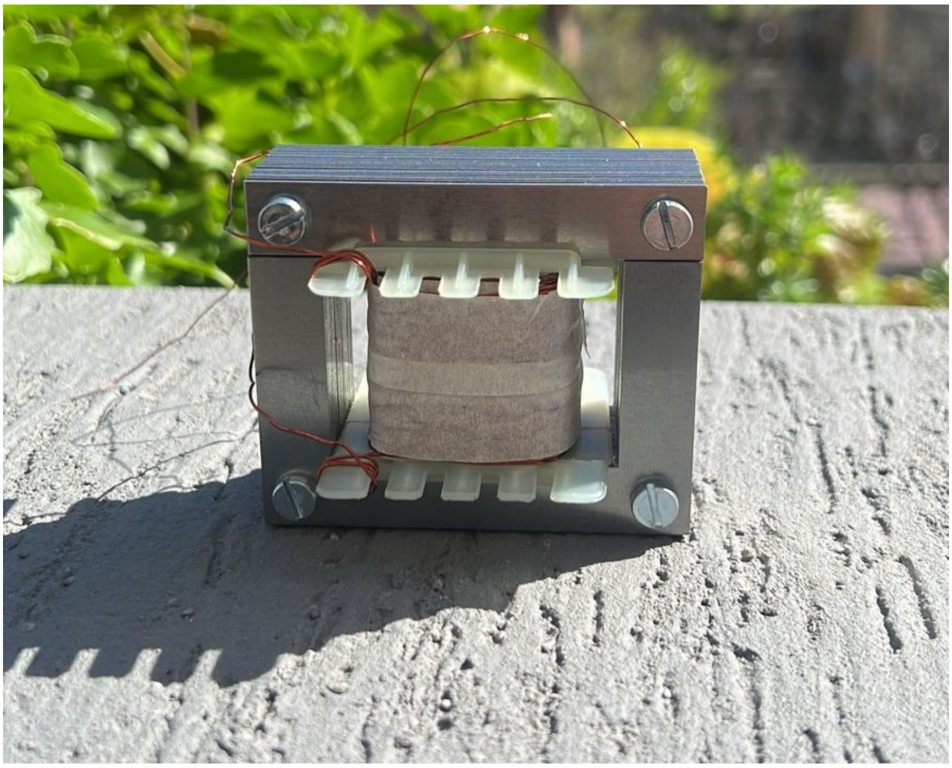
EEE2044S:
Transformer Project Report
2023



Group 11:
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MXXSAF002.

Task 1: Design

In Task 1, our objective was to create the design for a single-phase, shell-type transformer with the following parameters:

- Power Rating: 3VA
- Voltage Ratio: 15V/6V
- Operating Frequency: 50Hz

The initial design considered the dimensions of the bobbin and of the laminations, and from these dimensions our first prototype of the transformer was designed.
Taking into account Hmax and Bmax, the maximum and minimum number of turns, minimum core cross sectional area, minimum core depth and minimum number of laminations could be calculated. Then using the maximum current density, the minimum size and diameter of the conductor could be calculated. Taking into account the average of the maximum and minimum turns came to 108, so 100 was chosen for the amount of primary turns. Using the turns ratio, the secondary turns could therefore be calculated, as well as the secondary coil's core depth and number of laminations. After which the stacking factor was used to calculate the physical core depth. The total cross sectional area, available window size, and fill factor of the windings were all calculated. Finally, the weight of the core and minimum core loss were calculated.

Our Calculations:

1. $$Ipri = \frac{VA}{Vpri} = \frac{3}{15} = 0.2A$$
$$Isec = \frac{VA}{Vsec} = \frac{3}{6} = 0.5A$$

2. $$lc = 2(\frac{B}{2} - \frac{D}{2})(C - H) = 0.1651m$$
$$Hmax = \frac{N1max \times Irated}{lc}$$
$$Nmax = \frac{Hmax \times lc}{Irated}$$
$$Nmax = \frac{180 \times 0.1651}{0.2}$$
$$Nmax = 148.59\ turns$$
$$\approx 149\ turns$$

3. i) $$V1rms = 4.44 \times N1 \times Bmax \times f \times A$$
$$Amin = \frac{V1rms}{4.44 \times N1 \times f \times Bmax}$$
$$Amin = \frac{15}{4.44 \times 149 \times 50 \times 1}$$
$$Amin = 4.53473 \times 10^{-4}$$

ii) $$d = \frac{A}{w} = \frac{4.53473 \times 10^{-4}}{0.0254} = 0.01785\ m$$
$$d = 178.5m\ for\ Amin$$
$$NLmin = \frac{178.5}{0.0005} = 35.706 = 36$$

iii) $If\ NLmax\ =\ 80,\ then\ Amax\ =\ 0.04m\ \times\ 25.4mm$

$N1\ =\ \frac{V1}{4.44 \times Bmax \times f \times A}\ =\ 66.503$

$Therefore\ the\ minimum\ number\ of\ turns\ is\ 67.$

4. $A_{Tpri}\ =\ \frac{(\frac{VA}{Vrms})}{Jmax}\ =\ \frac{(\frac{3}{15})}{2.5}\ =\ 0.08$

$A_{Tsec}\ =\ \frac{(\frac{VA}{Vrms})}{Jmax}\ =\ \frac{(\frac{3}{6})}{2.5}\ =\ 0.2$

$D_{Tpri}\ =\ 2\ \times\ \sqrt{\frac{At1min}{\pi}}\ =\ 2\ \times \sqrt{\frac{0.08}{\pi}}\ =\ 0.319$

$D_{Tsec}\ =\ 2\ \times\ \sqrt{\frac{Atmin}{\pi}}\ =\ 2\ \times \sqrt{\frac{0.2}{\pi}}\ =\ 0.505$

5. $Nmax\ =\ 149\ turns$

$Nmin\ =\ 67\ turns$

$Therefore\ N\ =\ 100\ turns\ will\ be\ used$

$a\ =\ \frac{V1}{V2} = \frac{15}{6} = \frac{N1}{N2}\ =\ \frac{100}{Nsec}$

$Therefore\ Nsec\ =\ 40$

$For\ secondary\ coil:$

$Amin\ =\ \frac{6}{4.44 \times 40 \times 50 \times 1}\ =\ 6.7567\ \times 10^{-4} m^2$

$width\ of\ secondary\ coil\ is\ D\ =\ 25.4mm$

$d\ = \frac{A}{w} = \frac{6.7567 \times 10^{-4}}{0.0254}\ =\ 0.0266m$

$Nl\ =\ \frac{0.266}{0.0005}\ =\ 106.4$ = 53.2

$Therefore,\ minimum\ number\ of\ layers\ for\ secondary\ coil\ is\ 54\ turns.$

6. $Ks\ =\ 0.95\ = \frac{physical\ core\ depth}{Nl \times thickness}$

$physical\ core\ depth\ =\ 0.0005\ \times\ 100\ \times\ 0.95\ =\ 0.0475$

7. $a)\ total\ cross\ -\ section\ area\ of\ the\ windings$

$thickness\ of\ coating\ material\ =\ 0.05mm$

$thickness\ of\ insulation\ between\ primary\ and\ secondary\ windings$

$=\ 0.2mm$

$A1\ =\ \frac{Dtpri + 0.05}{2}\ =\ \frac{0.319 + 0.05}{2}\ = 0.18457691\ =\ 0.185$

$A2\ =\ \frac{Dtsec + 0.05}{2}\ =\ \frac{0.505 + 0.05}{2}\ = 0.27731325\ =\ 0.277$

$area\ of\ wire\ =\ ((100\pi\ \times\ (0.18457)^2)\ +\ (40\pi\ \times (0.277313)^2)$

$=\ 20.366\ mm^2$

$b)\ available\ window\ size\ for\ windings\ =\ 4.9\ \times\ 33.6\ =\ 164.64$

$c)\ fill\ factor\ = \frac{20.366}{164.64}\ =\ 0.1237\ =\ 0.124$

8. $a)\ W_c = Vcore \times \rho core$

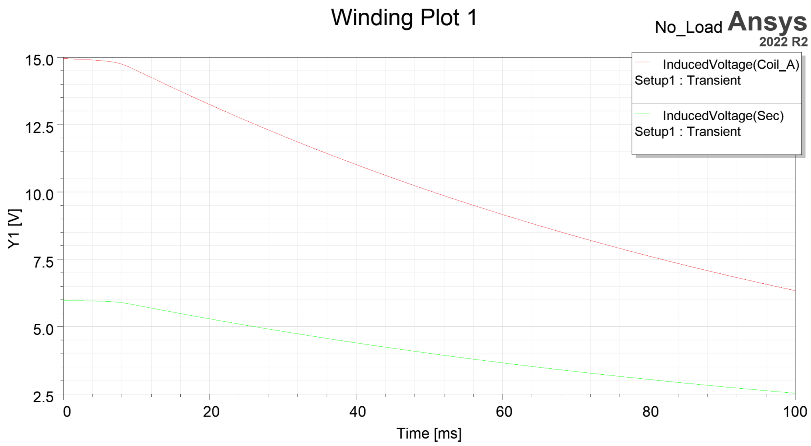
$Vcore = Core\ Area \times core\ depth = 20.366 \times 0.0475$

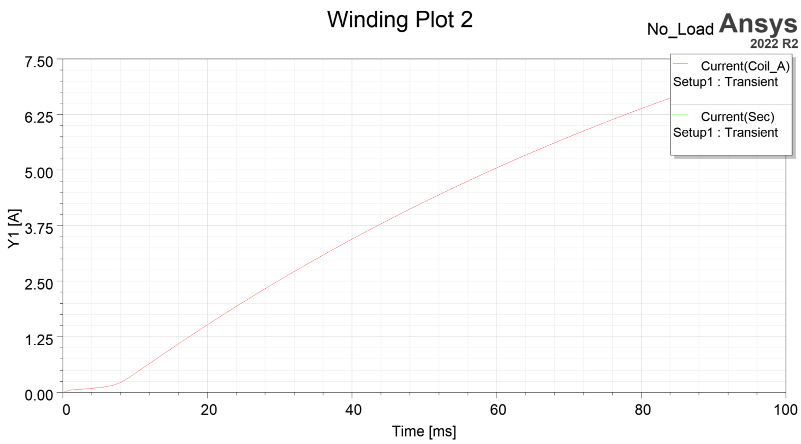
$= 0.9867\ mm^3$

$b)\ maximum\ core\ loss = 2.0$

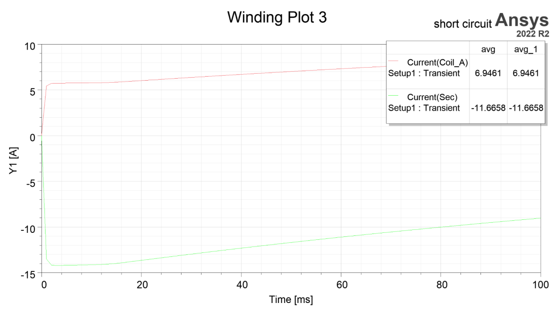
Task 2: Ansys FEM Analysis

Question 3

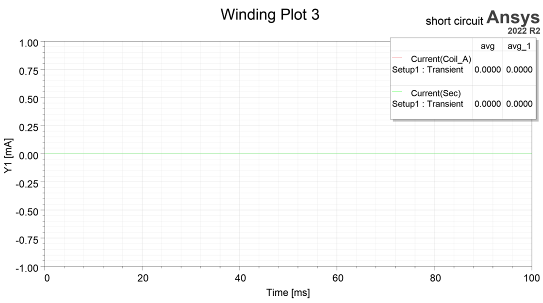




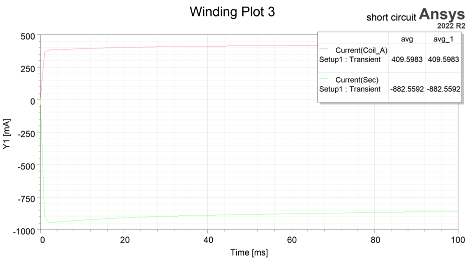
Question 4



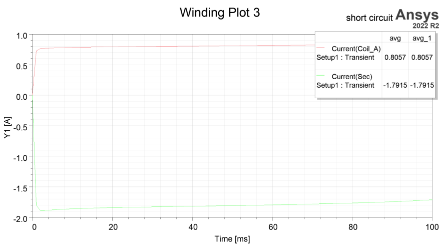
V=15V



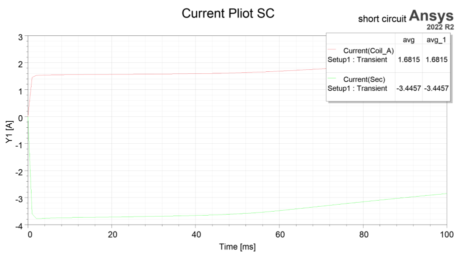
V=0



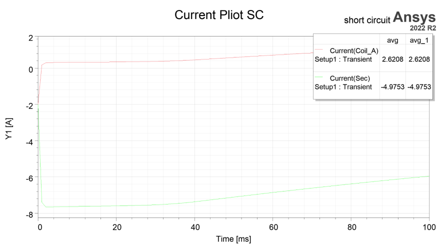
V=1V



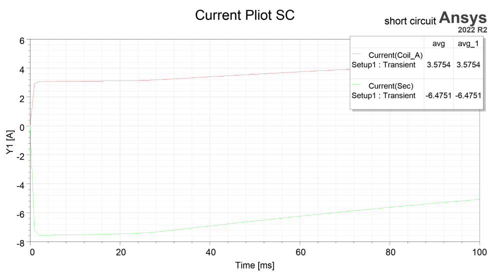
V= 2V



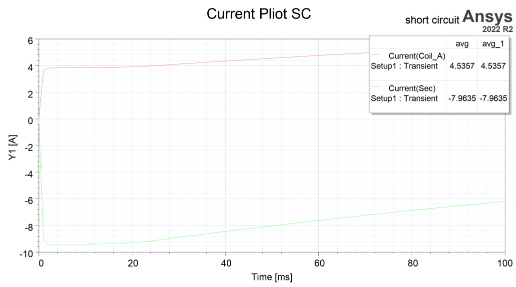
V=4V



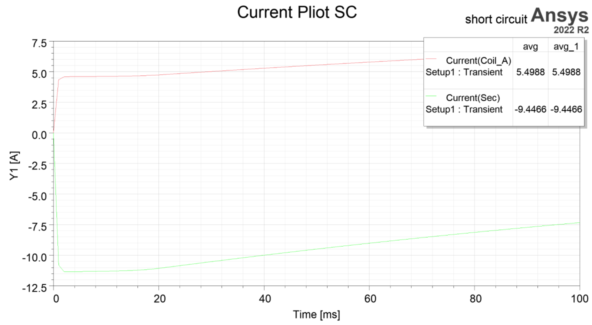
V=6V



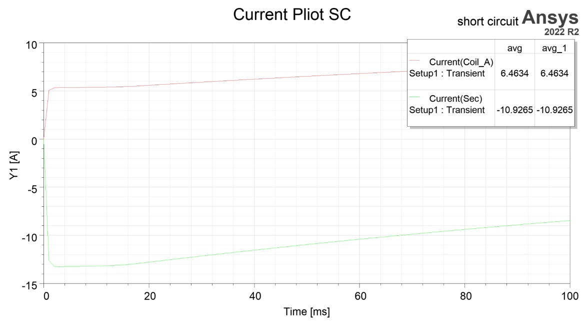
V =8V



V=10V

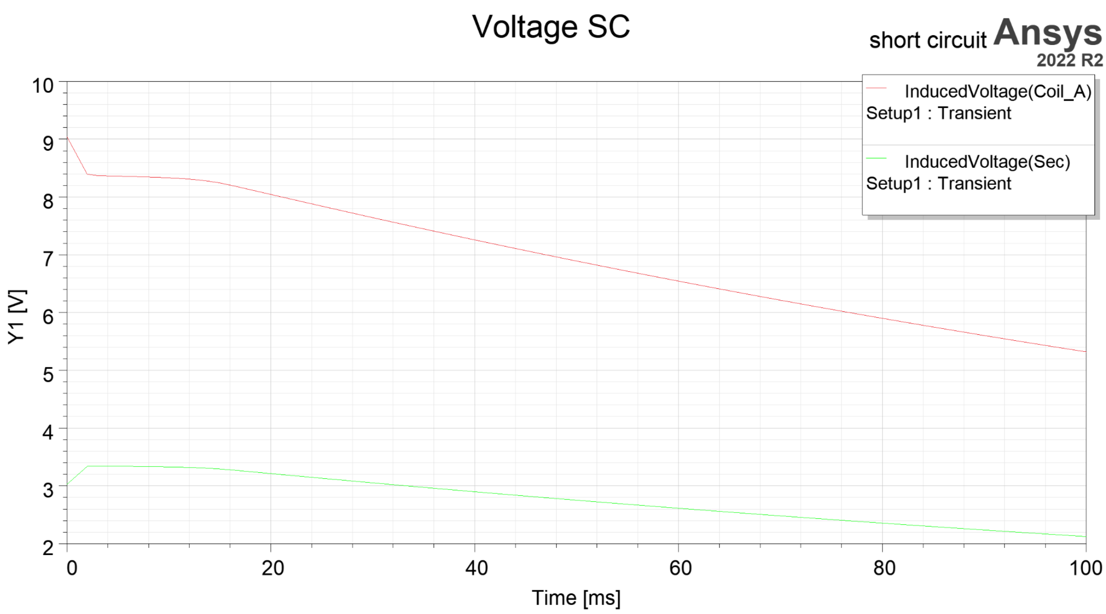


V=12V

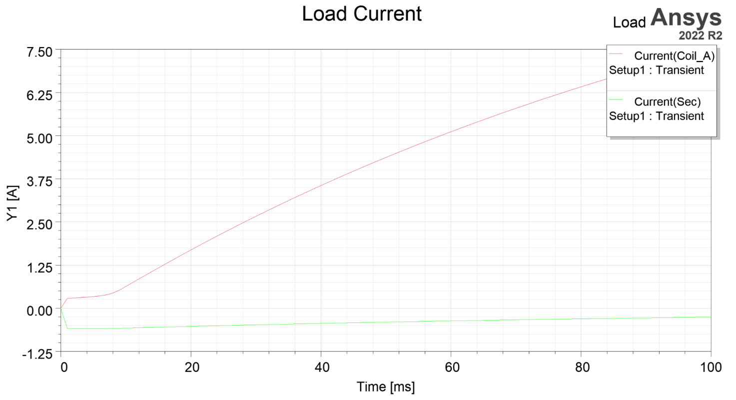


V =14V

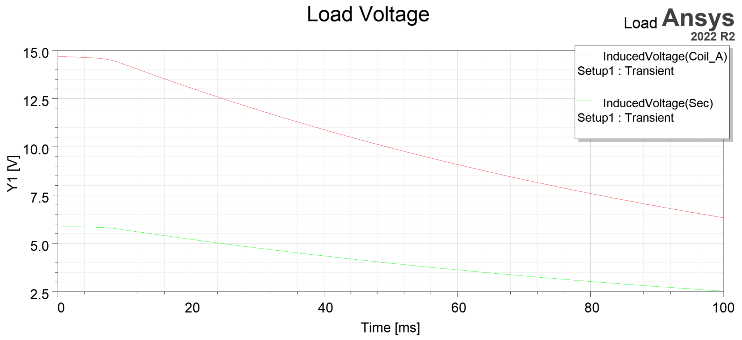
Graph plotted for induced voltage/time:



Question 5



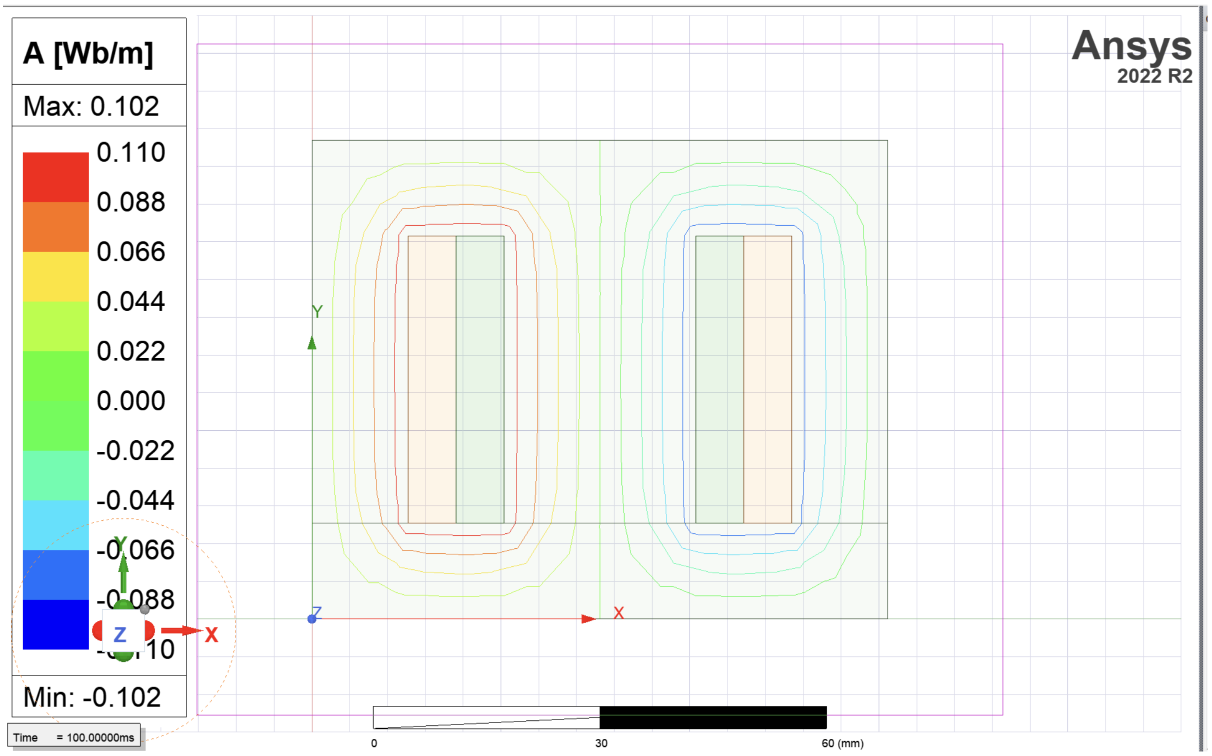
R=10ohm



At R = 10 ohm, current is roughly equal to 0.5 A, which is the rated current. At no load, V = 6V, at load, V2 = 5.85V.

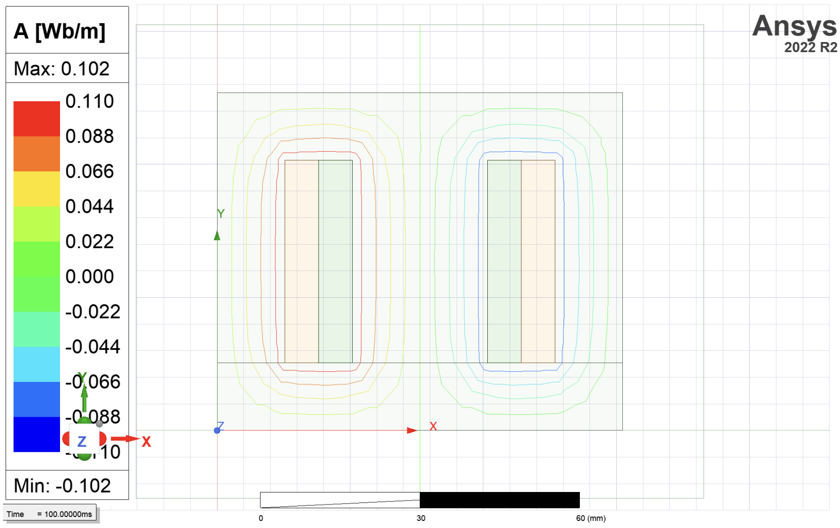
$VR = V2nl - V2l \div V2l = (6 - 5.85) \div 5.85 = 0.02564$

Question 6



From the above figure, it can be seen that flux ranges from -0.102 to 0.102 Wb/m at a max distance that is still within the core. Therefore there is flux leakage from the coils, however the core does prevent leakage out of the core, but the leakage makes it very close to the edge of the core. To lessen the flux leakage, the number of laminations could be increased, increasing the path for magnetic flux to flow through, thus lessening the flux leakage.

Question 7



The maximum allowable magnetic flux density is 1 Wb/m. As the saturation reaches a max absolute value of 0.102wb/m, the core stays very far from saturation and does not saturate.

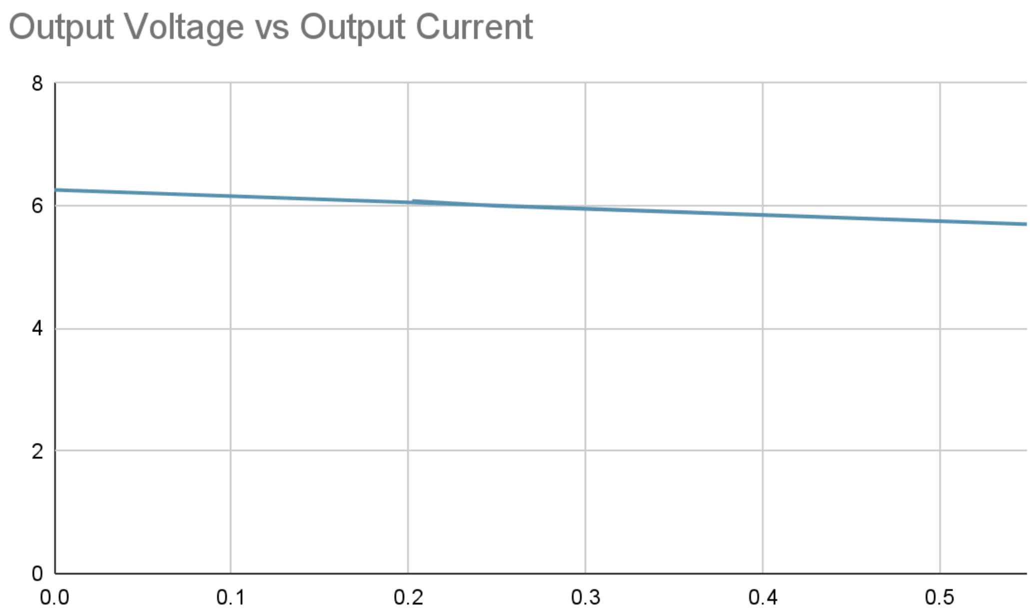
Task 3: Construction and Testing

1. We constructed the transformer according to our design specifications using the provided materials.

2. The predicted voltage ratio of (15/6) = 2.5 is correct. See table 1 below.

3. Two reasons that there are deviations from the calculated and tested values are:
    - Uncertainties in the multimeter
    - Human error in hand winding the coil

4. Actual VA rating of the transformer = 3.
   At 10 ohms, the transformer has a VA of 3.13.
   As the load is increased to 120%, the VA is decreased.



5. Input power measured to be 2.97W and output measured to be 1.23W. Efficiency is (1.23/2.97) x 100 = 41.41

6. Two sets of multimeters were used to measure the input and output voltage, current, power and power factor respectively. A set of resistors was used to create a varying load from 10-30 ohms, while a variac was used to create input voltage.

7. We calculated the mass of the copper used in the windings and googled the price of copper per kilogram. We then did the same for the laminations and the steel plates and came to an estimated value of the transformer of **R85.**
   The result of the cost was compared with two other groups, who got the same value. This is due to the fact that they did the same amount of coils in the primary and secondary winding and all the same materials were used for the core and laminations. Our cost would differ with groups that used different numbers of coils in the primary and secondary windings because it affects the weight of the copper.

			Voltage	Current	power Real	Apparent power	PF	VAR	Ratio
		pri	15.02	0.3278	1.692	4.945	0.34		2.39936102
		sec	6.26	0	0	0			
			Voltage	Current	power Real(W)	Apparent power			
Resistor	10	pri	15	0.431	5.112	3.923	0.79	4.018	2.63157895
		sec	5.7	0.549	3.178	3.211	1	0.0055	
Resistor	20	pri	15.04	0.368	3.52	5.518	0.64	4.26	2.50666667
		sec	6	0.294	1.77	1.7728	1	0.0048	
Resistor	30	pri	15.03	0.353	2.97	5.34	0.56	4.44	2.47203947
		sec	6.08	0.202	1.23	1.23	1	0.015	
									average ratio
									2.50241153

Table 1: Results

Conclusion:

In conclusion, our group successfully designed, analysed, constructed and tested a single-phase, shell-type transformer in accordance with the project's requirements. We validated our design through Ansys Maxwell simulations, and our practical testing provided valuable insights into the transformer's performance and cost-effectiveness.

Overall, this project allowed us to gain a comprehensive understanding of transformer design and analysis, emphasising the importance of theoretical calculations and practical testing in achieving optimal transformer performance.