Faculty of Science and Engineering

Department of Electrical and Electronic Engineering

Coursework 2 PLECS Simulation Lab Report

ACADEMIC YEAR 2019 / 2020

Course Code: EEEE1028

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Course : Please tick (√)

Electrical and Electronic Engineering (√)
Mechatronic Engineering ( )

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1.0 Introduction

PLECS is a simulation program where it was used to simulate and model the transformer in various situations. The aim of this experiment was to investigate the following:

-transformer turns ratio
-voltage regulation of the transformer
-Transformer Efficiency
-Transformer's Equivalent Circuit Parameters

To determine the transformer's turns ratio, the measured input voltage and output voltage are used and calculated with the following formula.

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

The voltage regulation of the transformer was determined by using measured values of the output and input voltage when the transformer is operating at rated power. While the transformer efficiency is determined using the measured values of the input and output active power. While to determine the transformer's equivalent circuit, Open Circuit Test and Short Circuit Test was performed. Where Open Circuit Test was able to determine the parameters at the magnetizing branch while Short Circuit Test was able to determine the parameters at the Primary Windings. Theoretical calculations were included to validate the results. Further calculations and analysis details are shown and stated clearly in the Procedure and Results and Discussions section.

2.0 Procedure

2.1 Investigation of transformer turns ratio and rated load

1. With reference to cwk2c.plecs file, the following system shown in Figure 1.0 was added into the simulation in transformer1.plecs file, as shown in figure 1.1.

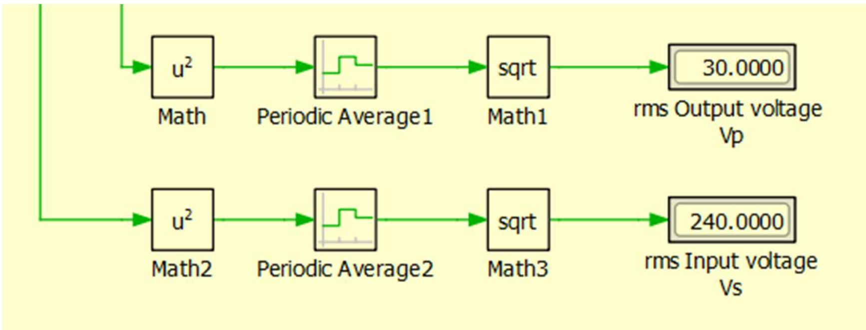

Figure 1.0 RMS voltage conversion system

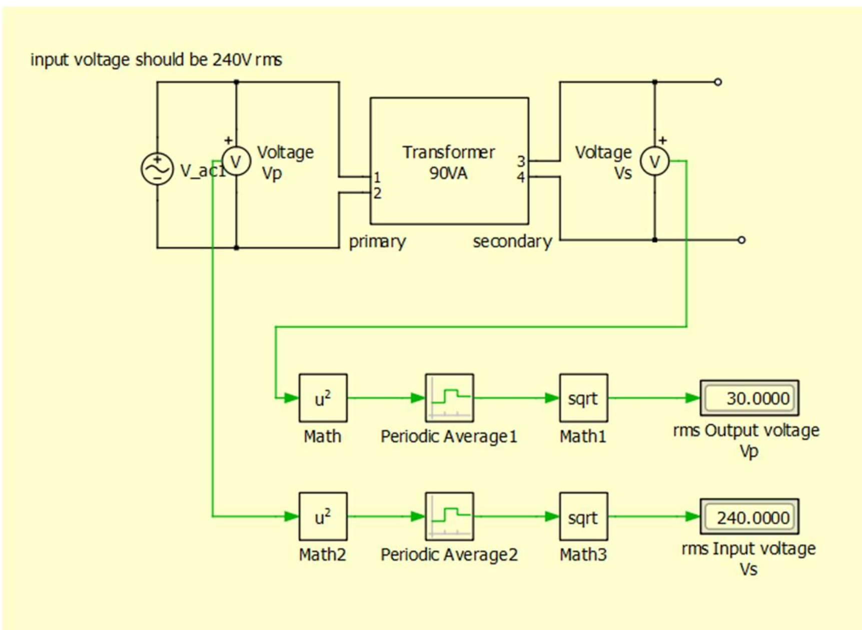

Figure 1.1 Simulation of the transformer (measure voltage)

2.2 Measurement of Regulation and Efficiency

2. The load resistance of $4*R_L$ was added into the circuit (Figure 2.0) along with systems to measure the current of the input and output current, primary and secondary active power (Figure 2.1) and Apparent power at the primary side when steady-state is achieved (Figure 2.2).
3. The results were then recorded and repeated using load resistances of $3*R_L$, $2*R_L$ and R_L.

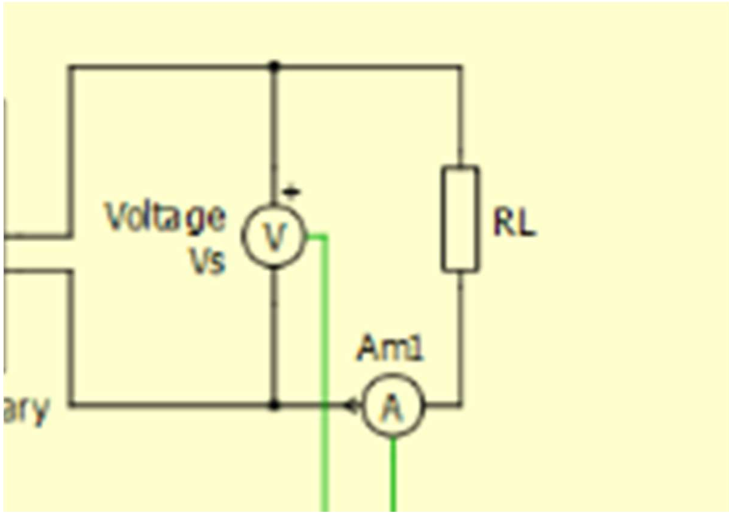

Figure 2.0 Load resistance added into circuit

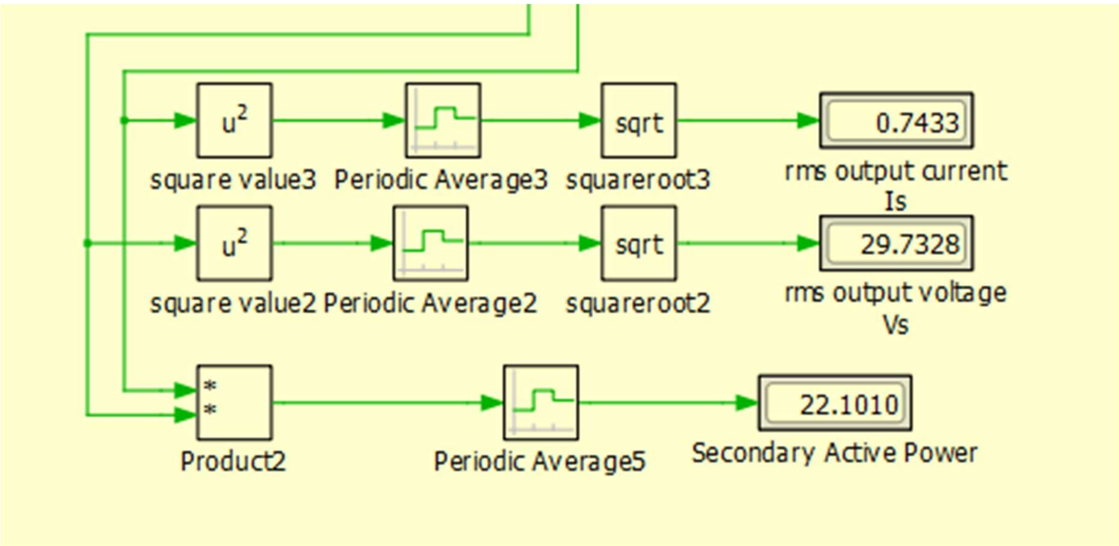

Figure 2.1 System to measure the current,voltage and power

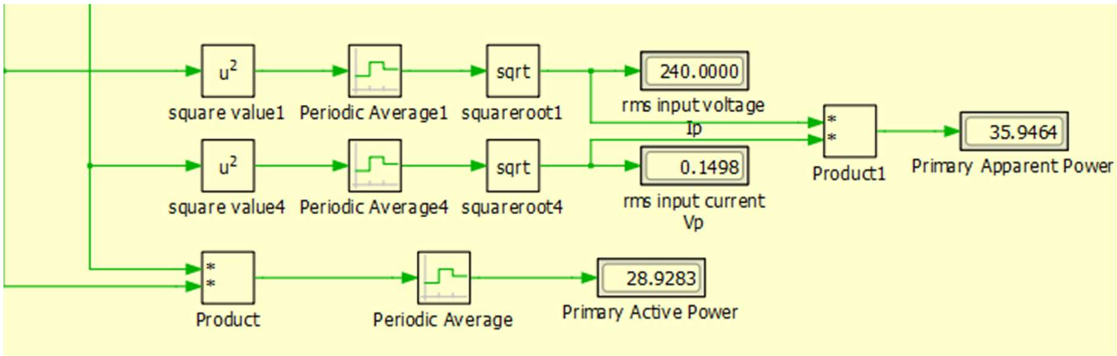

Figure 2.2 Additional system to measure Apparent power

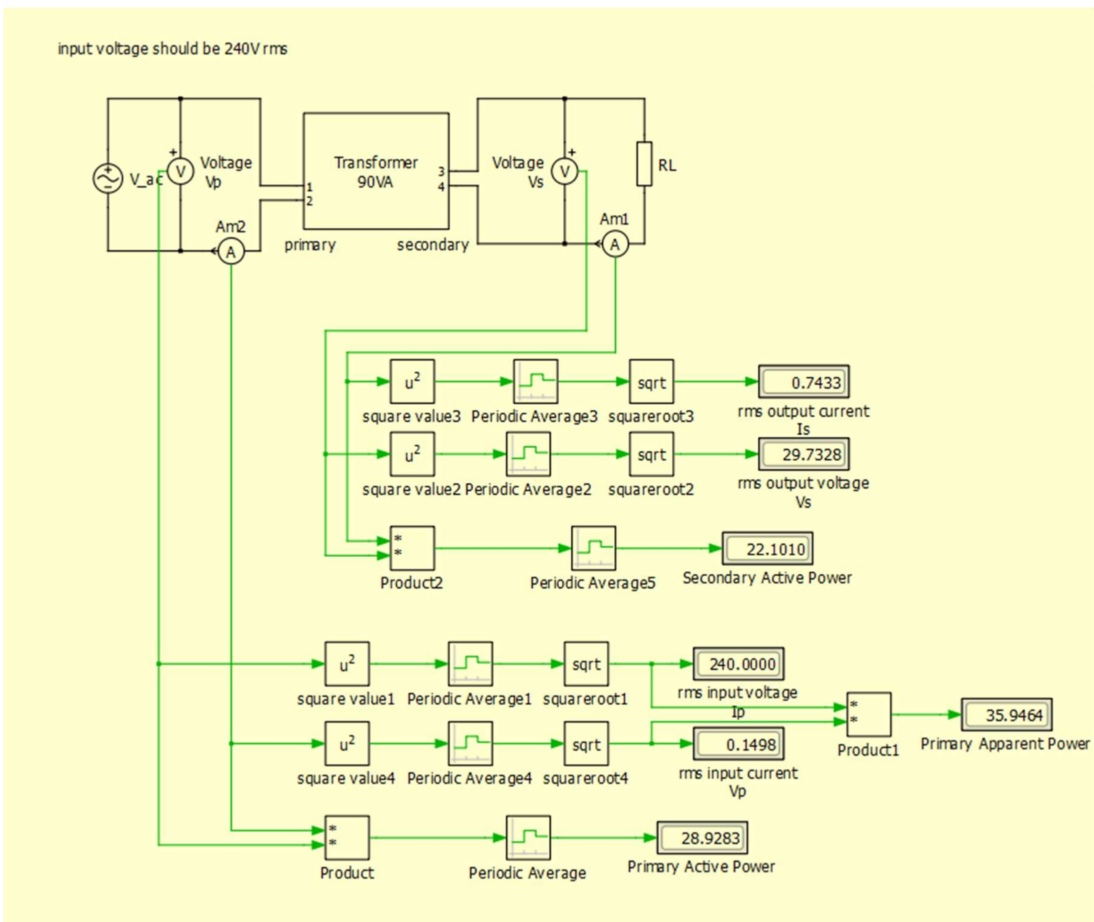

Figure 2.3 Full Circuit diagram

2.3 Determination of transformer equivalent circuit

4. The load resistor of the circuit has been removed in order to perform an Open-Circuit Test as shown in Figure 2.4.

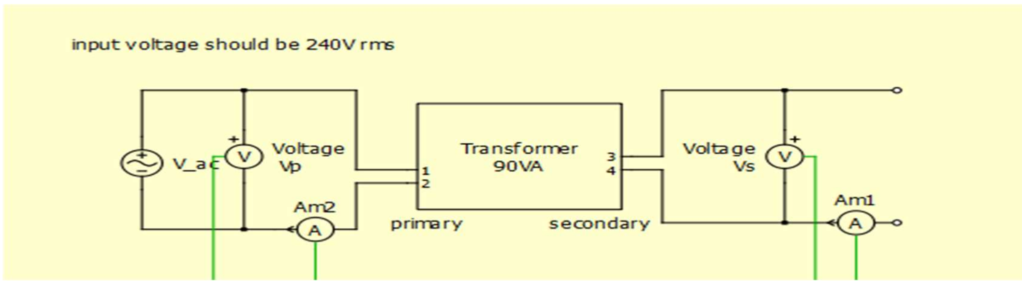

Figure 2.4 Open Circuit Test

5. The simulation was run after step 4 was complete.
6. The results and measurements were recorded.
7. The open circuit was connected to form a short-circuit as shown in Figure 2.5.

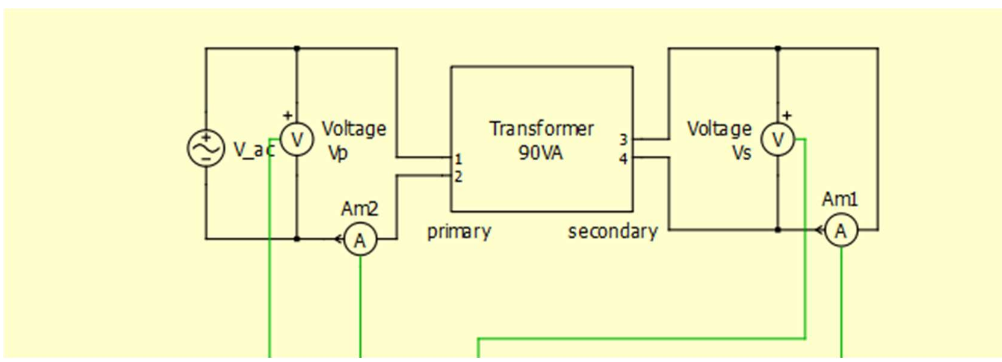

Figure 2.5 Short-Circuit Test

8. The simulation was run with the setting of amplitude of the voltage source to 10% of the rated value.
9. The amplitude was adjusted with iteration method until the value of the Output Current is within 10% of the rated value.
10. The results and measurements were recorded.

2.4 Measurement of Phase Angle between Input and Output Currents and Voltages

11. The amplitude of the voltage source was re-adjusted to 339.4113V, which leads to the RMS value of 240V. The resistor of 10ohm was placed into the circuit as shown in Figure 2.0. 4 scopes were added into the circuit to measure the phase angle. The amendments to the circuit are clearly shown in Figure 2.6.

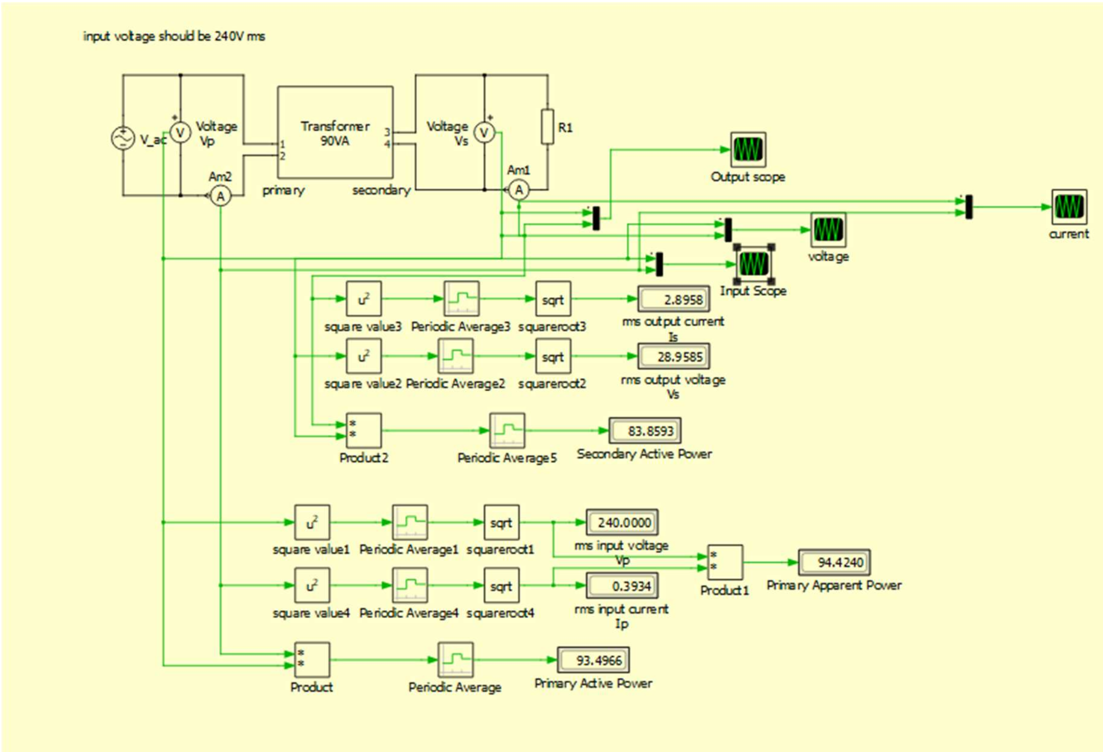

Figure 2.6 Whole Circuit to measure phase angle

3.0 Results and Discussions

3.1 Investigation of transformer turns ratio and rated load

The value 339V was input into the AC voltage source in the circuit is the peak value of the 240V_{rms}. The value can be obtained through the mathematical equation shown in Equation 1.0. The approximate value of 339.4113V was used instead of 240V is due to the system uses the parameter amplitude for the AC voltage source, therefore a peak value is needed instead of a RMS value.

$$240 \times \sqrt{2} = 339.4113V$$

Equation 1.0

By running the simulation, in Figure 1.1 it shows the Input voltage 240.0000V_{rms}, while the Output Voltage is approximately equal to 29.7327V_{rms} or 30V_{rms}. Thus, the turns ratio(a) of the transformer can be calculated which is shown in Equation 2.0. The approximate value of 8 is obtained as the turns ratio.

$$a = \frac{240}{30} = 8$$

Equation 2.0

While the MVA rating on the transformer is 90VA, the rated current for the secondary side of the transformer can be calculated with the formula S = VI. Where S is the apparent power, V is the voltage and I is the current. The detailed calculations are shown in Equation 3.0

$$S = VI$$

$$I = \frac{S}{V} = \frac{90}{30} = 3A$$

Equation 3.0

The load resistance can be measure now with the current obtained in Equation 3.0 by using Ohm's Law (V=IR).

$$R_L = \frac{V}{I} = \frac{30}{3} = 10\Omega$$

Equation 4.0

3.2 Measurement of Regulation and Efficiency

The results for the test conducted are shown in Table 1.0.

Load Resistance (Ω)	Input Current rms I_p (A)	Output voltage rms V_s (V)	Output Current rms I_s (A)	Apparent Power (VA)	Input Active Power (W)	Output Active Power (W)
40	0.1315	29.7328	0.7433	31.5536	28.9231	22.1010
30	0.1600	29.6448	0.9882	38.4093	36.2682	29.2937
20	0.2183	29.4702	1.4735	52.3995	50.8286	43.4247
10	0.3934	28.9585	2.8958	94.4240	93.4966	83.8593

Table 1.0 Table of measured data for part 2.3

MATLAB Code for Graph Plot

```
x=[0.7433 0.9882 1.4735 2.8958]
y=[29.7328 29.6448 29.4702 28.9585];
x1=0.7433;
x2=2.8958;
y1=29.7328;
y2=28.9585;
m=(y2-y1)/(x2-x1); % calculate gradient
plot(x,y);
title('Graph of Vs against Is')
ylabel('Secondary Voltage, Vs') % label for y axis
xlabel('Secondary Current, Is') % label for x axis
fprintf("%f",m);
```

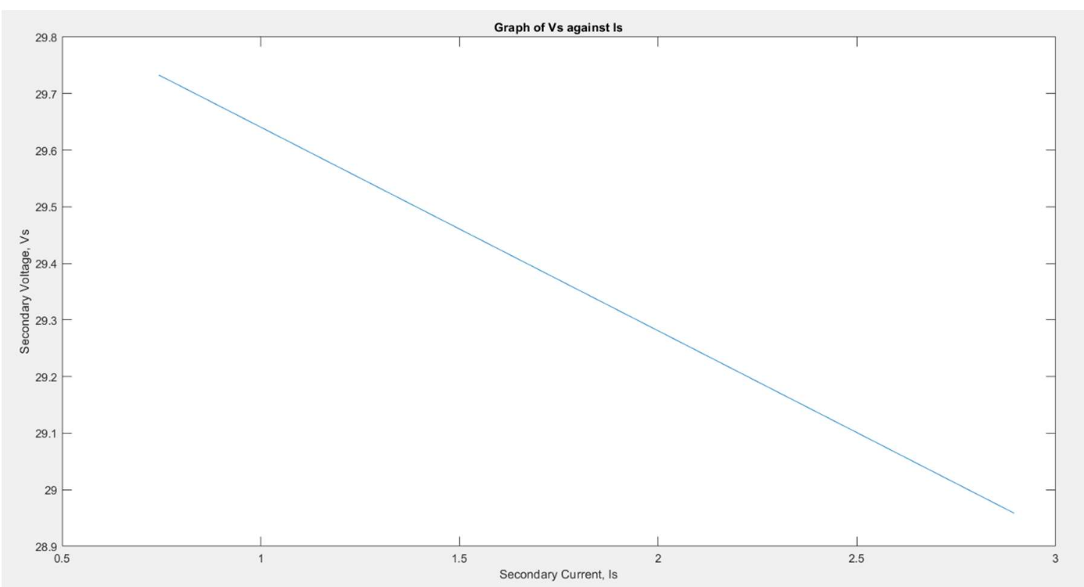

Figure 3.0 Graph for V_s against I_s

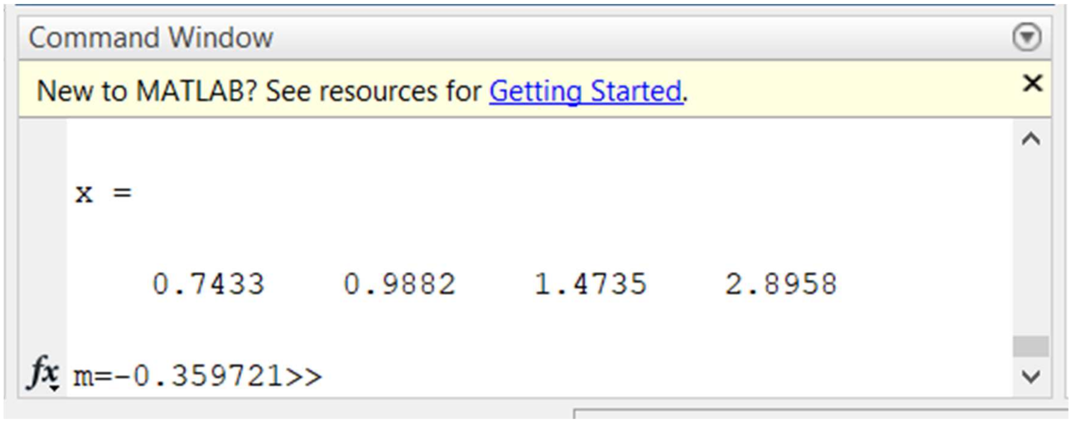

Figure 3.1 Gradient of the Slope

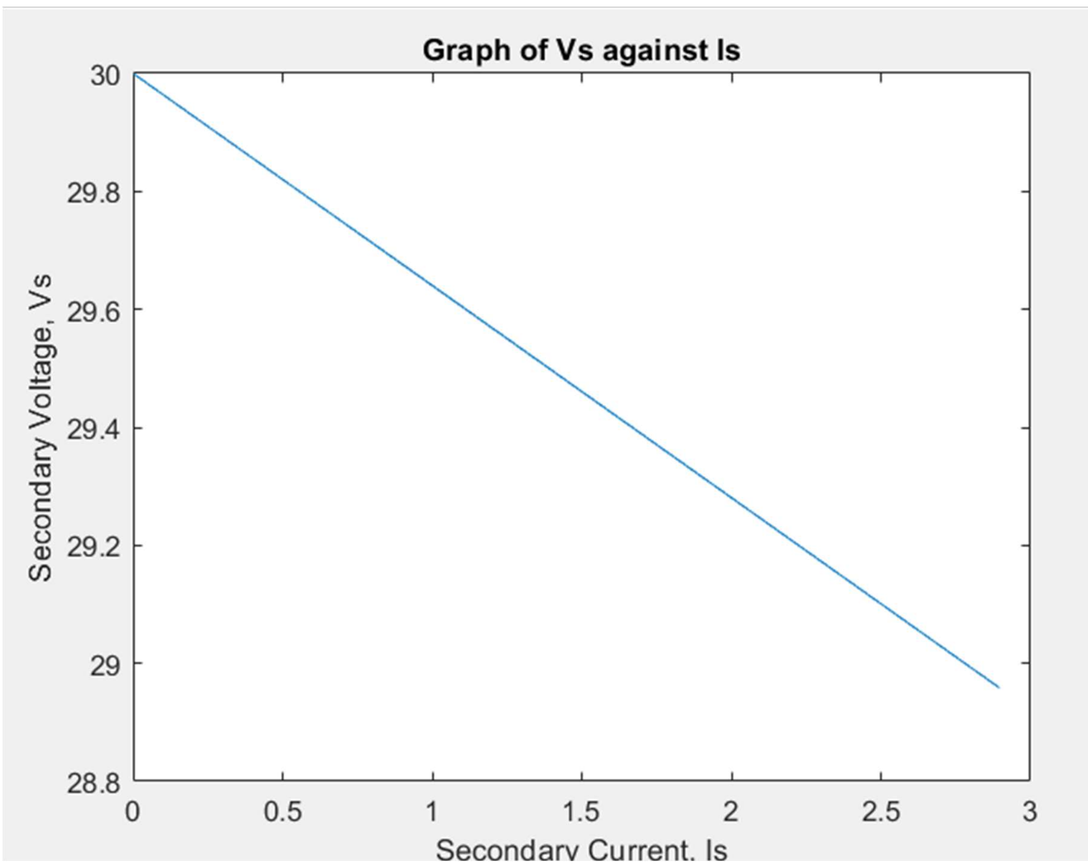

Figure 3.2 Slope of the graph to show Y-intercept

According to the Table 1.0, when operating at rated power, the efficiency and voltage regulation can be calculated based in the highlighted values stated in the table.

Efficiency = $\frac{P_{output}}{P_{input}} \times 100\% = \frac{83.8593}{93.4966} \times 100\% = 89.6924\%$

Equation 5.0

Voltage Regulation = $\frac{V_{s\,no\,load} - V_{s\,Full\,Load}}{V_{s\,Ful\,load}} \times 100\%$

Voltage Regulation = $\frac{30-28.9585}{28.9585} \times 100\% = 3.5965\%$

Equation 6.0

The slope or gradient of the graph shows the Voltage Regulation (VR) of the transformer. The Figure 3.3 shows the detailed workings on the VR.

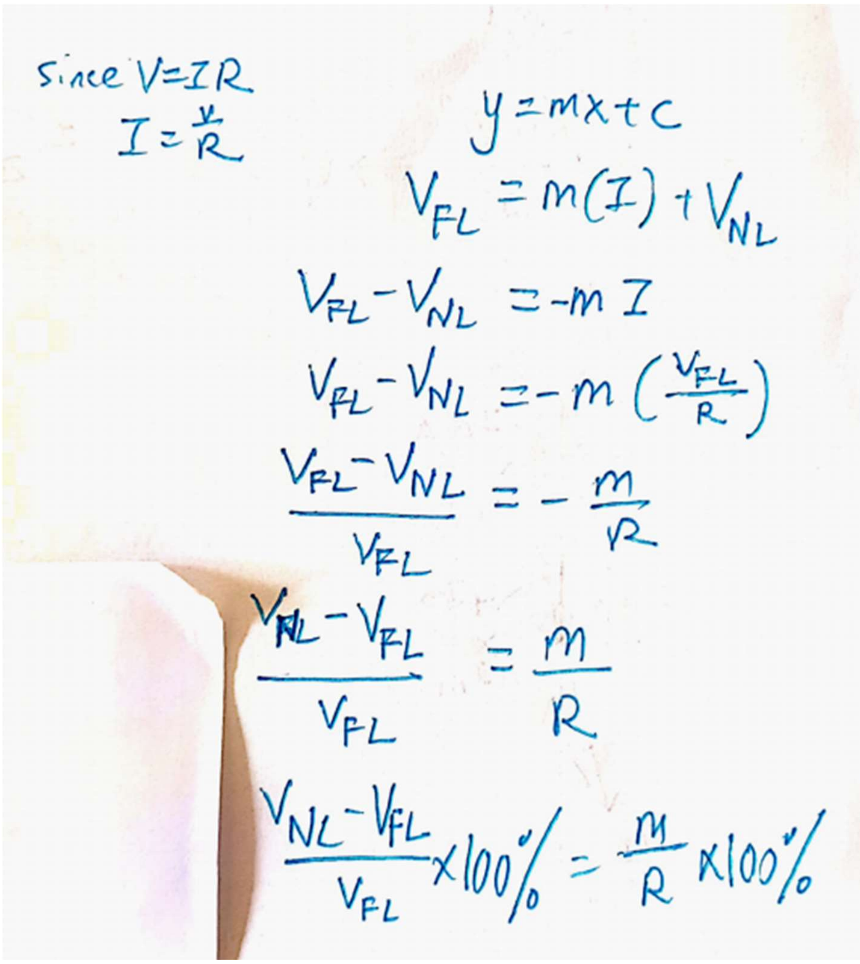

Figure 3.3 Proof of the slope to be VR

3.3 Determination of transformer equivalent circuit

Open Circuit Test

Primary Current rms (A)	Primary Voltage rms (V)	Primary Active Power (W)	Primary Apparent Power (VA)
0.0592	240.00	6.6236	14.2095

Table 2.0 Measurements of Open Circuit Test

In this terms, Primary current is I_p and Primary Voltage is V_p.
I_c can be calculated based on the formula P=VI, detailed calculations is shown in Equation 7.0.

$$\frac{P}{V_p} = \frac{6.6236}{240} = 0.0276A = I_c$$

Equation 7.0

I_m can be calculated by using the Pythagoras theorem as shown in Equation 8.0.

$$I_m = \sqrt{{I_o}^2 - {I_c}^2}$$
$$I_m = \sqrt{0.0592^2 - 0.0276^2}$$
$$I_m = 0.0524A$$

Equation 8.0

R_c can be calculated based on the formula $P = \frac{V^2}{R}$

$$R_c = \frac{V_p}{I_c} = \frac{240}{0.0276} = 8695.6522\Omega$$

Equation 9.0

X_m can be calculated based on the formula V=IR (Ohm's Law)

$$X_m = \frac{V_p}{I_m} = \frac{240}{0.0524} = 4580.1527\Omega$$

Equation 10.0

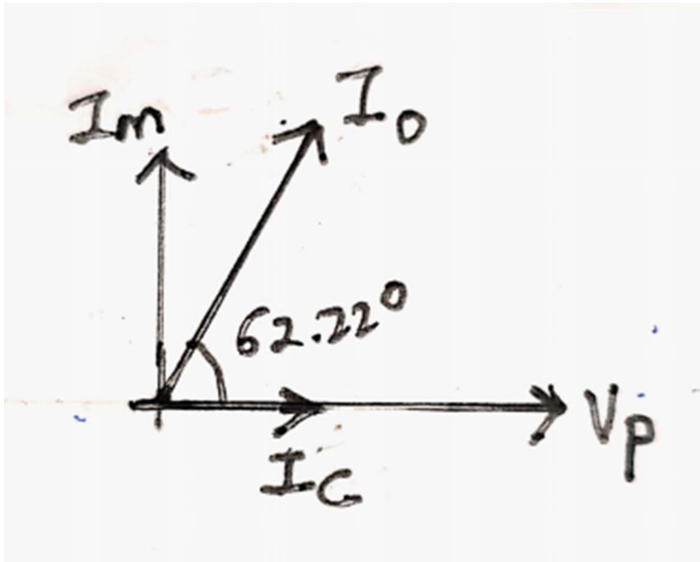

Figure 4.0 Phasor Diagram of V_p,I_o,I_c and I_m

Theoretical Calculations (Open Circuit Test)

Power factor:

$$\theta = cos^{-1}\left(\frac{P}{V_p \times I_p}\right) = cos^{-1}\left(\frac{6.6236}{240 \times 0.0592}\right) = 62.21°$$

Admittance (Parallel Impedance):

$$Y = \frac{I_p}{V_p}\angle\theta° = \frac{0.0592}{240}\angle 62.21°$$
$$= (1.1500 \times 10^{-4} + j2.1821 \times 10^{-4})\Omega$$

R_c:

$$R_c = \frac{1}{1.15 \times 10^{-4}} = 8695.6522\Omega$$

X_m:

$$X_m = \frac{1}{2.18 \times 10^{-4}} = 4582.7414\Omega$$

For R_c there is no percentage difference due to the experimental values and theoretical values are similar. While for the X_m there is a percentage difference of 0.0565% which is considerably negligible as the difference is minor which is within a range of 5% from the theoretical value.

Percentage Difference = $\frac{experimental\ value - theoreti\quad value}{theoretical\ value} \times 100\%$

Percentage Difference = $\frac{4580.1527-4582.7414}{4582.7414} \times 100\% = -0.0565\%$

Short-Circuit Test

Primary Current rms (A)	Primary Voltage rms (V)	Primary Active Power (W)	Primary Apparent Power (VA)
0.4138	9.6874	3.9203	4.0087

Table 3.0 Measurements of Short-Circuit Test

In order for the output current to be within a 10% range from the rated value 3A, the amplitude of the voltage source was adjusted to a value of 13.7000V (peak value) which is approximately 4.0364% from the rated value 339.4113V (peak value). The output current in this case is 3.2983A (rms value).

Since $I'_s = I_P$,

$$V_R = \frac{P}{I'_s} = \frac{3.9203}{0.4138} = 9.4739V$$

Equation 11.0

$$V_X = \sqrt{{V_P}^2 - {V_R}^2} = \sqrt{9.6874^2 - 9.4739^2} = 2.0226V$$

Equation 12.0

$$R = \frac{V_R}{I'_s} = \frac{9.4739}{0.4138} = 22.8948\Omega$$

Equation 13.0

$$X = \frac{V_X}{I'_s} = \frac{2.0226}{0.4138} = 4.8879\Omega$$

Equation 14.0

Equation 11.0 until Equation 14.0 shows the calculation for voltages of R and X, winding resistance of R and winding leakage reactance X respectively.

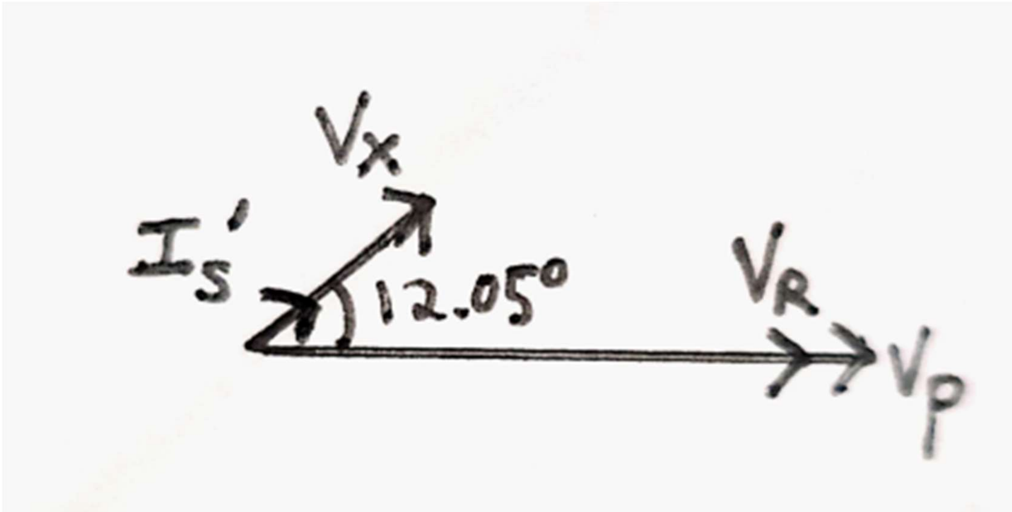

Figure 4.1 Phasor Diagram of V_p,V_R,V_x and I_s'

Theoretical Calculations (Short Circuit Test)

Power factor:

$$\theta = cos^{-1}\left(\frac{P}{I_p \times V_p}\right) = cos^{-1}\left(\frac{3.9203}{0.4138 \times 9.6874}\right) = 12.05°$$

Admittance (Series Impedance):

$$Y = \frac{V_p}{I_p}\angle\theta° = \frac{9.6874}{0.4138}\angle 12.05° = (22.8950 + j4.8874)\Omega$$

R=22.8950Ω
X=4.8874Ω

For R and X there is no percentage difference due to the experimental values and theoretical values are approximately similar where the values differ only by 0.0002 and 0.0005 respectively.

3.4 Measurement of Phase Angle between Input and Output Currents and Voltages

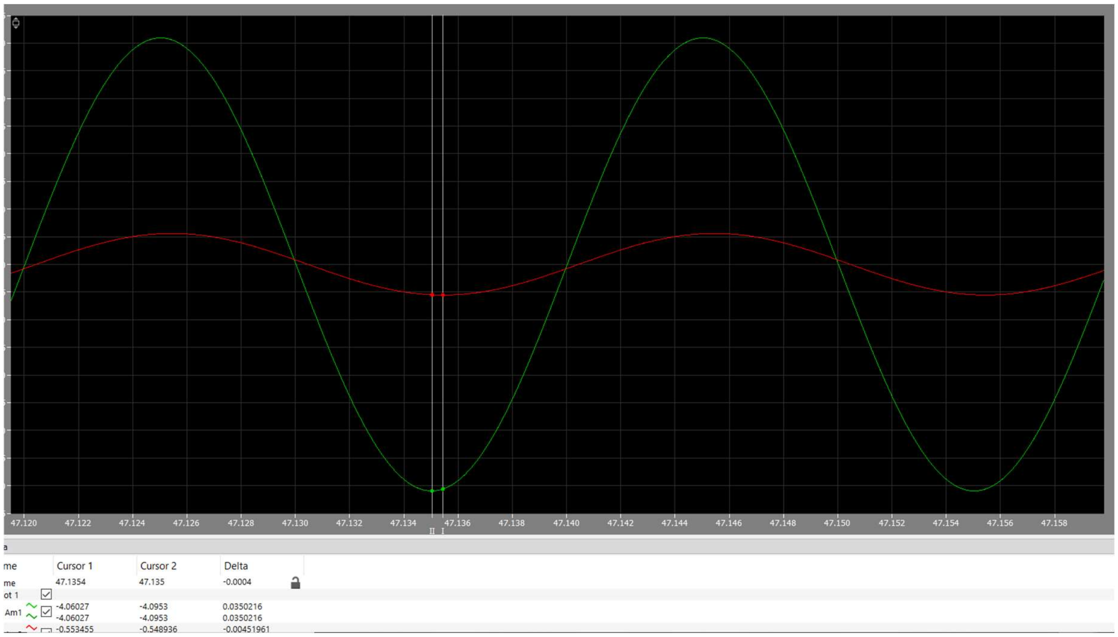

Figure 5.0 Plot of Input current and Output current

Based on the Figure 5.0, it clearly states that the delta or difference in phase between the input and output current is 0.0004, where the input current (I_p) is 0.3934A_{rms} while the output current (I_s) is 2.8958A_{rms} at steady-state conditions. The phase angle is calculated and shown in Equation 15.0, and the phasor diagram for both currents are illustrated in Figure 5.1.

$$\text{Phase Angle} = \frac{Delta}{0.02} \times 360 = \frac{0.0004}{0.02} \times 360 = 7.2°$$

Equation 15.0

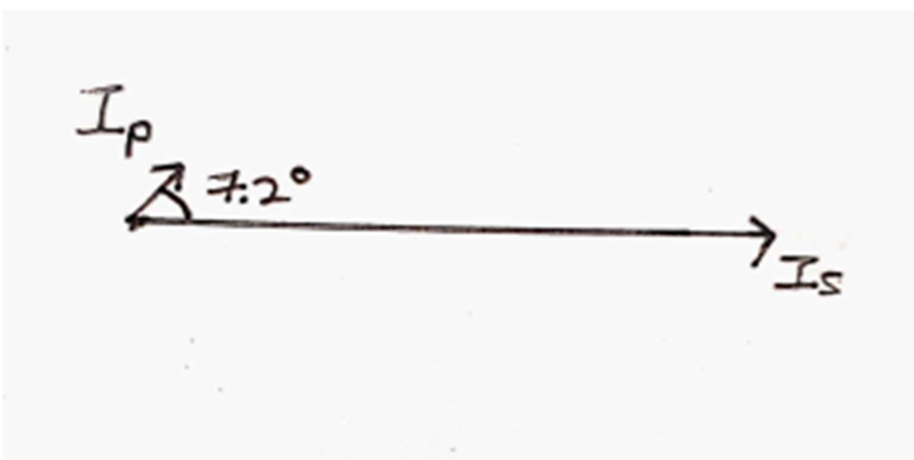

Figure 5.1 Phasor diagram for currents I_p and I_s

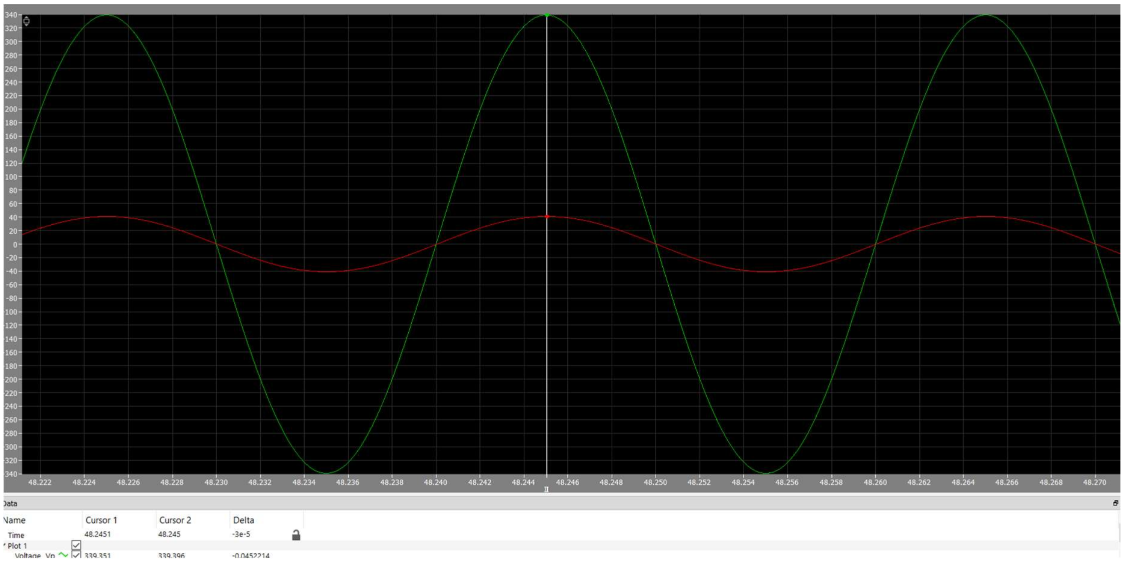

Figure 6.0 Plot of Input Voltage and Output Voltage

Based on the Figure 6.0, it clearly states that the delta or difference in phase between the input and output voltage is 3×10^{-5}, where the input voltage (V_p) is $240.00V_{rms}$ while the output voltage (V_s) is $28.9585V_{vrms}$ at steady- state conditions. The phase angle is calculated and shown in Equation 15.1 and the phasor diagram for both voltages are illustrated in Figure 6.1.

$$\text{Phase Angle} = \frac{Delta}{0.02} \times 360 = \frac{3\times10^{-5}}{0.02} \times 360 = 0.54°$$

Equation 15.1

Figure 6.1 Phasor diagram for voltages V_p and V_s

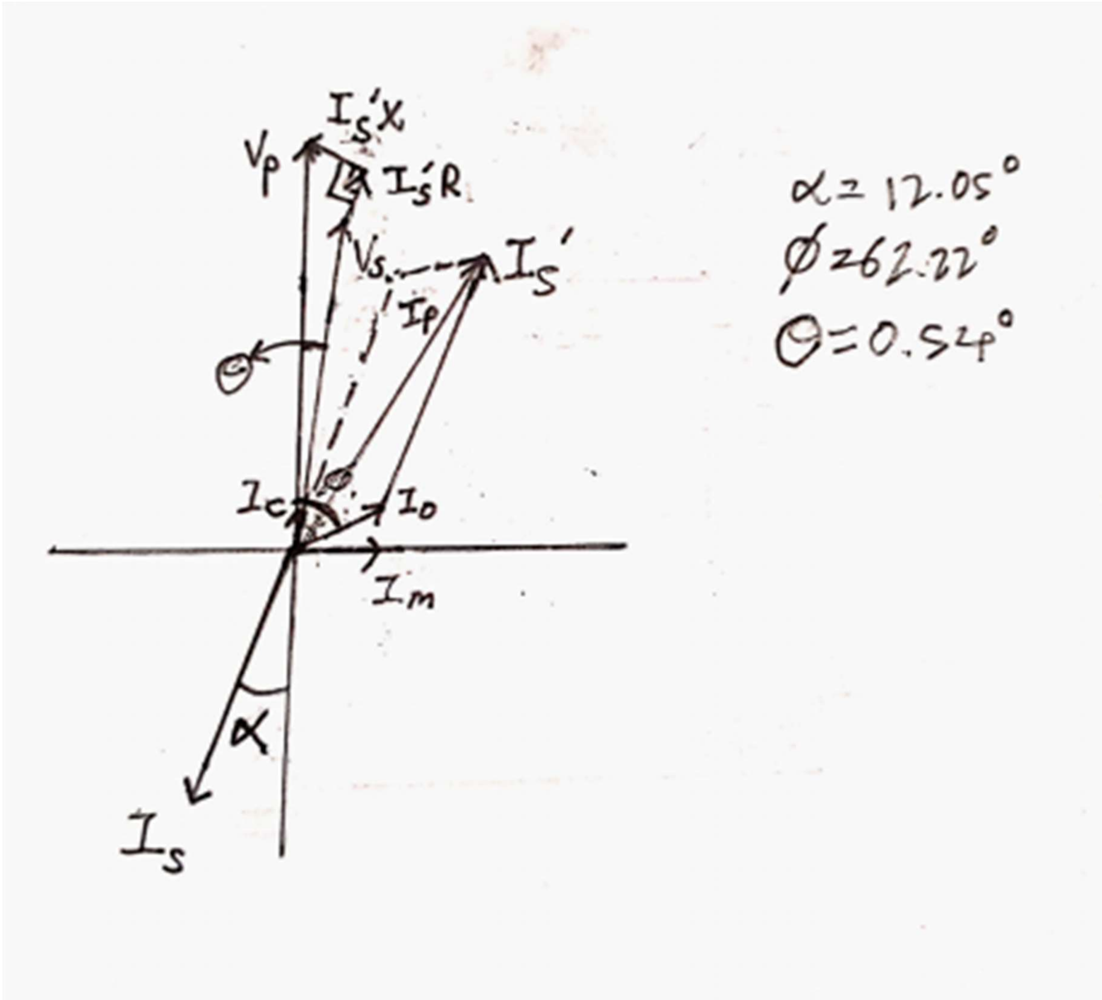

Figure 7.0 Phasor diagram for compilation of voltages and currents in the transformer

4.0 Conclusions

In conclusion, all the objectives of the experiment were able to be completed. The PLECS simulation results were considered as accurate as the equivalent circuit parameters have negligible percentage difference with the theoretical values calculated.

5.0 Reference

[1] Chapman S.J. (1985) **Electric Machinery Fundamentals**. pp.65-108.

[2] Gonzalez-Longatt F. (2019) **Electrical Science A.** [online] Available at: https://www.researchgate.net/project/Electrical-Science-A [accessed 25th April 2020]

[3] Hughes E. (2008) **Hughes Electrical and Electronic Technology Tenth Edition.** pp.680-706.

Additional Comments

Regarding the coursework, the instructions were considerably clear and understandable. However, in section 2.5 it would be preferred if the required voltages and currents could be included to allow precise works to be done. Lastly, a precise and detailed marking rubric is highly suggested in order for students to understand the requirement of the report.