ENG231 - Electrical Machines And Transformers - Assesment 2 Lab 4

Baley Eccles - 652137

[2024-09-17 Tue 10:17]

Contents

1 ENG231 - Electrical Machines And Transformers - Assesment 2 Lab 4 1
1.1 Name Plate . . . 1
1.2 DC Test . . . 1
1.3 Open Circuit Test . . . 2
1.4 Short Circus Test . . . 3
1.5 Performance Test / Full Load Test . . . 4
1.6 Three-phase Transformer Configurations . . . 6
1.6.1 Y-Y Connected Transformer . . . 6
1.6.2 Δ-Y Connected Transformer . . . 7
1.6.3 Y-Δ Connected Transformer . . . 7
1.6.4 Δ-Δ Connected Transformer . . . 7

2 Bibliography 8

3 Appendix A 9

1 ENG231 - Electrical Machines And Transformers - Assesment 2 Lab 4

1.1 Name Plate

[Group] Report your transformer nameplate ratings

VA ratings	500
Primary voltage (V)	240
Secondary voltage (V)	115
Primary current (A)	2.1
Secondary current (A)	4.4
Turns ratio	2.1

1.2 DC Test

[Group] Report your transformer DC test results, commenting on the relative resistances observed for each side of the transformer winding.

Primary resistance (R_{1dc}) (Ω)	1.5
Secondary resistance (R_{2dc}) (Ω)	0.4

The primary side has a higher resistance than the secondary side, this is because the primary side has more turns. This will result in a longer wire and hence a larger resistance.
[Group] Calculate an 'expected' or 'estimated' total equivalent winding AC resistance Req as viewed from LV side and HV side of the transformer.

$$
\begin{aligned}
a &= 2.1 \\
R_{eqHV} &= a^2 R_2 + R_1 \\
R_{eqHV} &= 3.264\Omega \\
R_{eqLV} &= a^2 R_1 + R_2 \\
R_{eqLV} &= 7.015\Omega
\end{aligned}
$$

1.3 Open Circuit Test

	Primary				Secondary
	V1	I1	Poc	PF	V2
LV side open	110	0.563	10.3	0.165	220
HV side open	240	0.375	12.5	0.138	120

[Group] Calculate turns ratio for your transformer (a = N1 / N2) based on measured open-circuit voltages. Explain why there is a difference (if there is any difference) between your measurements and the nameplate voltages?

LV side open

$$
\begin{aligned}
a &= \frac{V_2}{V_1} \\
a &= 2
\end{aligned}
$$

HV side open

$$
\begin{aligned}
a &= \frac{V_2}{V_1} \\
a &= 2
\end{aligned}
$$

Both sides result is the same turns ratio.
[Group] Calculate power factor from voltage, current and power measurements and verify that it matches your measured value (from power analyser)

LV side open

$$
\begin{aligned}
PF &= \frac{P_{oc}}{V_1 I_1} \\
&= 0.16631
\end{aligned}
$$

HV side open

$$
\begin{aligned}
PF &= \frac{P_{oc}}{V_1 I_1} \\
&= 0.13889
\end{aligned}
$$

The calculated power factor is very close to the measured power factor, which is to be expected.
[Group] Calculate the core resistance Rc1 and the magnetising reactance Xm1. (Do this now in the lab and check with the demonstrator that you have something reasonable before you continue)

LV side open

$$
\begin{aligned}
R_{c1} &= \frac{V_1^2}{P_{oc}} \\
&= 1174.76\Omega \\
X_{m1} &= \frac{V_1}{\sqrt{I_1^2 + \left(\frac{V_1}{R_{c1}}\right)^2}} \\
&= 192.73\Omega
\end{aligned}
$$

HV side open

$$
\begin{aligned}
R_{c1} &= \frac{V_1^2}{P_{oc}} \\
&= 4680\Omega \\
X_{m1} &= \frac{V_1}{\sqrt{I_1^2 + \left(\frac{V_1}{R_{c1}}\right)^2}} \\
&= 633.92\Omega
\end{aligned}
$$

[Individual] Comment on the differences, if any, between supplying power and measuring from the HV side or the LV side
The LV side shows a higher power factor compared to the HV side. This means that the LV side consumes more power. This makes sense with the calculated resistances, the LV side has a higher resistance and hence a higher power draw. Although, this could also be due to the differences in input voltage during each test.

[Individual] Calculate the % increase in current observed when voltage is increased by 20% above rated voltage? Comment on your observations and discuss?

V_1 (V)	I_1 (A)	P_{oc} (W)	PF	V_2 (V)
138.25	1.28	18.4	0.102	275.4

Increase in current:

$$\%I_{increase} = \frac{1.28 - 0.563}{0.563} \cdot 100$$
$$\%I_{increase} = 127.35\%$$

This value shows that for a small increase in voltage we will get a disproportionally large increase in current. This implies a non-linear relationship between the current and voltage. Given that we are at the maximum rating for the transformer, we may be reaching the saturation region, this can be confirmed using the power factor, which is mostly reactive. This means that the energy from the increase in voltage is being used to magnetise the core, rather than transfer it to the other side.
[Individual] On the Power Analyser (still while operating at 20% above rated voltage) observe transformer supply V and I waveforms. Include a sketch or image of a key waveform observed to help describe what you have observed and why? Does the waveform vary as supply voltage is varied?
Our team forgot to do this. However, we would expect to see the waveforms differ from usual operation. As shown, the transformer is being saturated, when this happens the magnetic flux in the core becomes distorted, which will effect the voltage and current waveforms. The current waveform will be more distorted than the voltage waveform, due to the introduction of a third harmonic, which will make the waveform less sinusoidal. These effects will be present in the voltage waveform, but less pronounced.

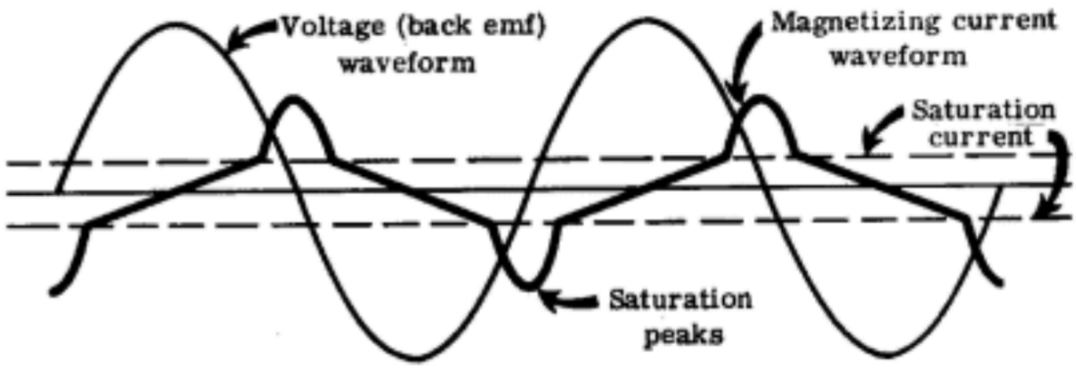

Figure 1: Current and voltage waveform for a saturated transformer.

1.4 Short Circus Test

	Primary				Secondary
	V1	I1	Psc	PF	I2
LV side Short circuited	7	1.76	10	0.863	3.5

[Group] Calculate R_{eq} & X_{eq}.

$$R_{eq} = \frac{P_{sc}}{I_1^2}$$
$$= 3.228\Omega$$
$$X_{eq} = \sqrt{\left(\frac{V_1}{I_1}\right)^2 - R_{eq}^2}$$
$$= 5.123\Omega$$

[Group] Calculate power factor from these values and verify your measured value.

$$PF = \frac{P_{sc}}{V_1 I_1}$$
$$= 0.81169$$

The calculated power factor closely matches the measured one.
[Individual] Compare R_{eq} (equivalent winding AC resistance) to the DC resistance values measured earlier (you will need to refer them both to the same side). Why do you think there is a difference (if there is any)? $R_{dcTotal} = 3.1\Omega$ and $R_{eq} = 3.228\Omega$, we can see that AC resistance is slightly larger than the DC resistance. This is because the AC resistance takes into account more effects that don't apply during DC, such as Eddy currents.
[Individual] Draw the full equivalent circuit for your transformer, labelling impedances with your determined transformer parameters

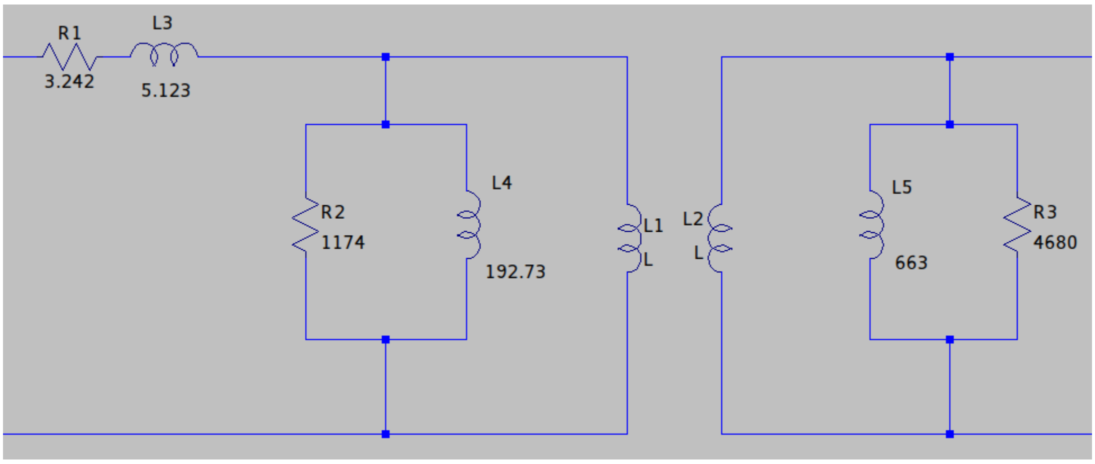

Figure 2: Full equivalent circuit for our transformer.

1.5 Performance Test / Full Load Test

	Load	0ohm	200ohm	150ohm	100ohm	75ohm	50ohm	33ohm	25ohm
Primary	V1	240	240	240	240	240	240	240	240
	I1	0.375	0.495	0.56	0.71	0.88	1.2	1.75	2.28

Continued on next page

Continued from previous page

	Load	0ohm	200ohm	150ohm	100ohm	75ohm	50ohm	33ohm	25ohm
	P1	12	80	102	147	191	277	409	537
	PF	0.138	0.677	0.76	0.861	0.912	0.954	0.977	0.958
Secondary	V2	120	120	119	118	118	117	116	115
	I2	0	0.56	0.753	1.12	1.5	2.2	3.3	4.4
	P2	0	67	90	133	177	262	386	509
	PF	NULL	1	1	1	1	1	1	1
% Voltage Regulation		0	0	0.8403	1.694	1.695	2.564	3.448	4.347
% Efficiency		0	83.75	88.24	90.48	92.67	94.58	94.37	94.78

[Group] Plot measured secondary voltage and efficiency against secondary current

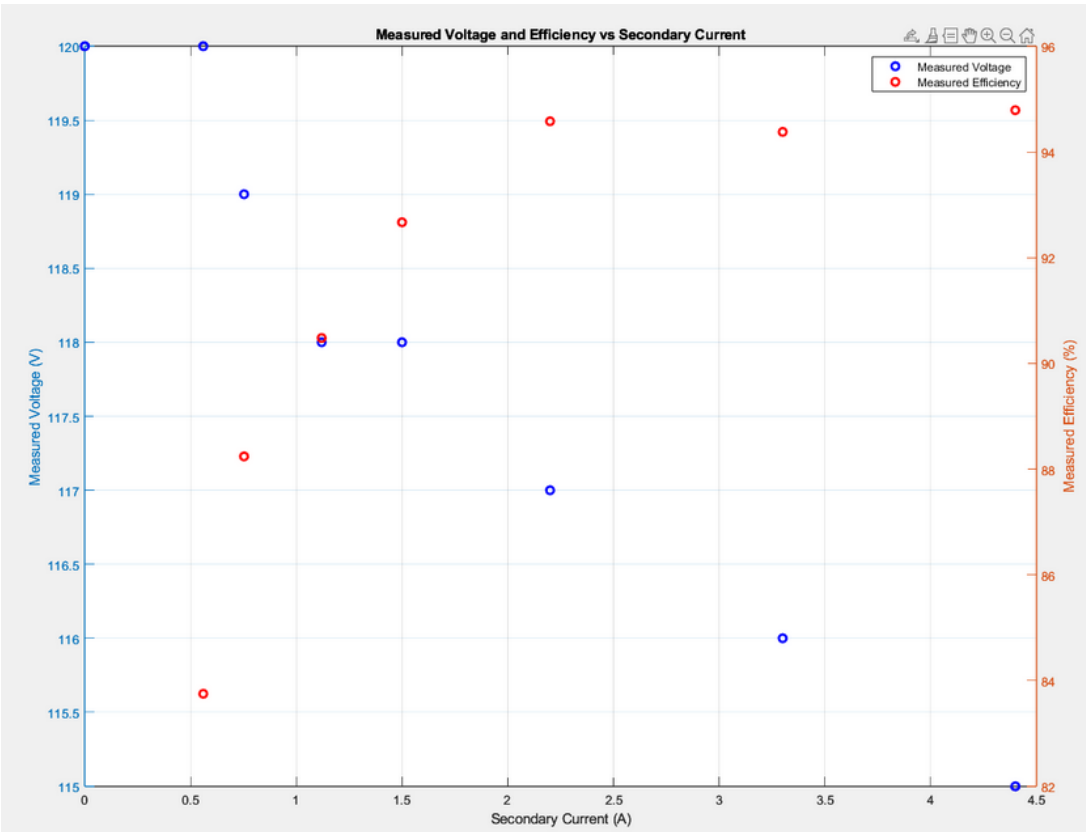

Figure 3: Measured Secondary Voltage and efficiency and secondary voltage.

[Group] Compare observations with either calculated or simulated values based on your already determined equivalent circuit, by including 'theoretical' curves of output voltage and efficiency vs output (secondary) current on the same plots as your measured data.

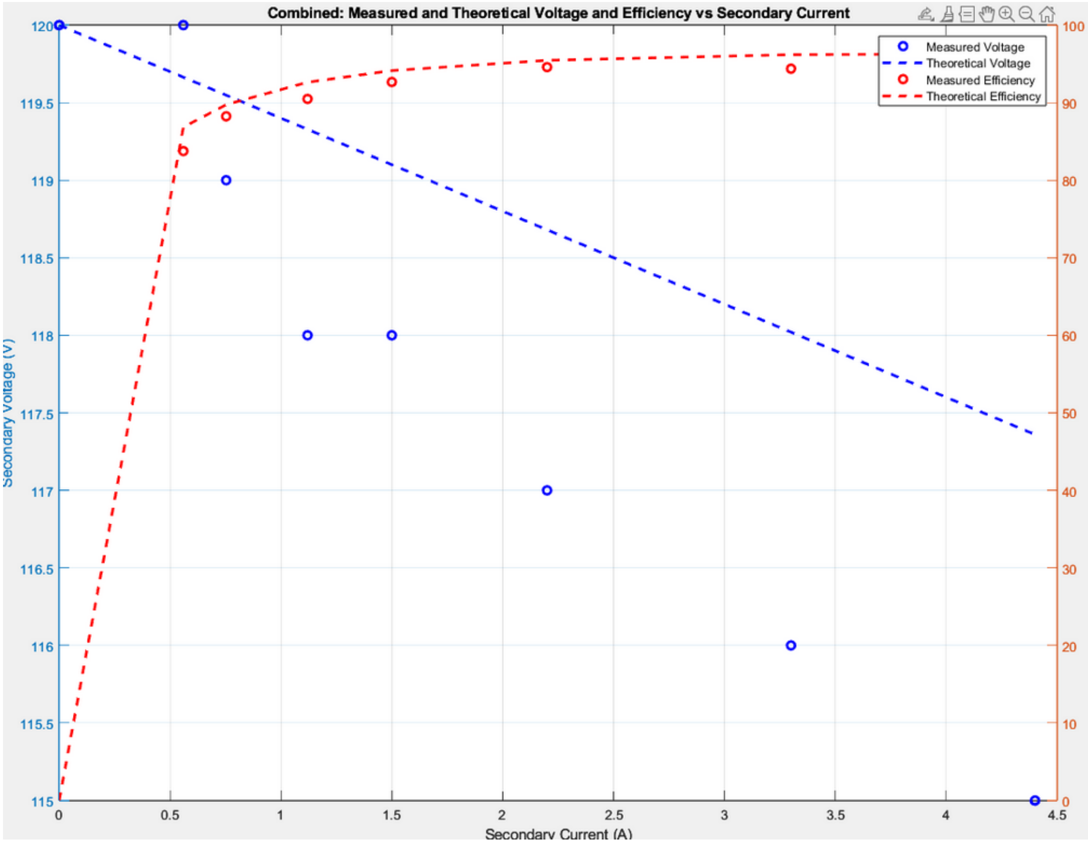

Figure 4: Measured and theoretical secondary voltage and efficiency.

[Individual] Discuss generally your results, noting any major differences between observed and calculated values. Please make any other comments on your observations which you think may be interesting or relevant.
The voltage regulation tended to increase as the load increased, this is a measure of how well the transformer can maintain a output voltage as the load changes. Having a low voltage regulation (0% -> 4.5%) indicates that the transformer is able to keep a consistent voltage for a varying load.
The power factor initially started low and increased as the load increased, this means that the energy at low loads is not being used efficiently. As the load increased the current became more resistive and hence improved power factor.

1.6 Three-phase Transformer Configurations

1.6.1 Y-Y Connected Transformer

[Group] Present data tables showing expected and measured values for Y-Y connection.

	Primary Side				Secondary Side	
Quantity	Expected	Observed		Quantity	Expected	Observed
VRN	139	139		Vrn	139	139
VWN	139	141		Vwn	139	142
VBN	139	139		Vbn	139	139
VRW	240	243		Vrw	240	243
VWB	240	243		Vwb	240	243
VBR	240	240		Vbr	240	240

1.6.2 Δ-Y Connected Transformer

[Group] Present data tables showing expected and measured values for Δ-Y connection.

	Primary Side				Secondary Side	
Quantity	Expected	Observed		Quantity	Expected	Observed
VRW	180	183		Vrn	180	180
VWB	180	181		Vwn	180	183
VBR	180	181		Vbn	180	181
				Vrw	311	315
				Vwb	311	315
				Vbr	311	320

1.6.3 Y-Δ Connected Transformer

[Group] Present data tables showing expected and measured values for Y-Δ connection.

	Primary Side				Secondary Side	
Quantity	Expected	Observed		Quantity	Expected	Observed
VRN	139	141		Vrw	139	141
VWN	139	142		Vwb	139	140
VBN	139	140		Vbr	139	140
VRW	240	245				
VWB	240	243				
VBR	240	242				

1.6.4 Δ-Δ Connected Transformer

[Group] Present data tables showing expected and measured values for Δ-Δ connection

	Primary Side				Secondary Side	
Quantity	Expected	Observed		Quantity	Expected	Observed
VRW	240	243		Vrw	240	243
VWB	240	243		Vwb	240	243
VBR	240	240		Vbr	240	240

[Individual] Discuss your 3-phase transformer observations, noting for example the impact connection configuration has upon primary to secondary line-to-line voltage ratio, commenting on any significant differences between observed and expected voltages.
For each configuration we expected a voltage ratio that is some combination of $\sqrt{3}$. The expected and observed data varied by a couple of volts, this may be because of the inaccuracies in the measuring tools and accuracy of the three-phase variac.
[Individual] Although you didn't measure it, what else would you have expected to alter between input and output voltages, and why would that be the case?
The phase shift. For Δ-Y and Y-Δ we would expect a 30^o phase shift between primary and secondary voltages. This is due to the way each of the types are connected to one another.

2 Bibliography

Crowhurst, N. H. (2010). Waveforms when saturation occurs [Illustration]. Basic Audio. http://vias.org/crowhurstba/crowhurst_basic_audio_vol2_069.html

3 Appendix A

Code used to produce Figures 1 and 2:

```
% Define fake values for load resistance, secondary current (I2), voltage (V2), and efficiency
R_load = [200, 150, 100, 75, 50, 33, 25];  % Load resistance in ohms
I2 = [0, 0.56, 0.753, 1.12, 1.5, 2.2, 3.3, 4.4];  % Secondary current from experimental data
V2_actual = [120, 120, 119, 118, 118, 117, 116, 115];  % Actual voltage data from experiment
Eff_actual = [NaN, 83.75, 88.24, 90.48, 92.67, 94.58, 94.38, 94.79];  % Actual efficiency data

% Theoretical values for secondary voltage (V2) and efficiency (Eff)
V2_no_load = 120;          % No-load voltage (V)
R_internal = 0.5;          % Internal resistance of the transformer
X_leakage = 0.1;           % Leakage reactance of the transformer
V2_theoretical = V2_no_load - (R_internal + X_leakage) .* I2; % Voltage drop calculation

% Define theoretical efficiency curve
P_out = V2_theoretical .* I2;          % Output power (P2 = V2 * I2)
P_core_loss = 10;                      % Constant core loss (iron losses)
P_copper_loss = R_internal * I2.^2;    % Copper losses (I2^2 * R)
P_in = P_out + P_core_loss + P_copper_loss;  % Total input power
Eff_theoretical = (P_out ./ P_in) * 100;  % Theoretical efficiency (%)

% Calculate Percentage Error for Voltage and Efficiency
Voltage_Error = abs(V2_theoretical - V2_actual) ./ V2_theoretical * 100;
Efficiency_Error = abs(Eff_theoretical - Eff_actual) ./ Eff_theoretical * 100;

% Replace NaN values in Efficiency Error where actual data is missing (no load)
Efficiency_Error(isnan(Eff_actual)) = NaN;

% 1. Plot Original Graph (Actual Measured Data)
figure;
yyaxis left;
plot(I2, V2_actual, 'bo', 'LineWidth', 2);
xlabel('Secondary Current (A)');
ylabel('Measured Voltage (V)');
title('Measured Voltage and Efficiency vs Secondary Current');
grid on;
hold on;

yyaxis right;
plot(I2, Eff_actual, 'ro', 'LineWidth', 2);
ylabel('Measured Efficiency (%)');
legend('Measured Voltage', 'Measured Efficiency');

% 2. Plot Theoretical Graph (Predicted Values)
figure
yyaxis left;
plot(I2, V2_theoretical, 'b--', 'LineWidth', 2);
xlabel('Secondary Current (A)');
ylabel('Theoretical Voltage (V)');
title('Theoretical Voltage and Efficiency vs Secondary Current');
grid on;
hold on;
```

```
yyaxis right;
plot(I2, Eff_theoretical, 'r--', 'LineWidth', 2);
ylabel('Theoretical Efficiency (%)');
legend('Theoretical Voltage', 'Theoretical Efficiency');

% 3. Plot Combined Graph (Measured and Theoretical Data)
figure
yyaxis left;
plot(I2, V2_actual, 'bo', 'LineWidth', 2); hold on;
plot(I2, V2_theoretical, 'b--', 'LineWidth', 2);
xlabel('Secondary Current (A)');
ylabel('Secondary Voltage (V)');
title('Combined: Measured and Theoretical Voltage and Efficiency vs Secondary Current');
grid on;

yyaxis right;
```