Department of Electrical
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Faculty of Engineering & Architectural Science

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Instructor	Professor Arani

Assignment/Lab Number:	2
Assignment/Lab Title:	SIngle and Polyphase Transformers

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Objectives:

The purpose of this lab is to examine the no-load conditions of transformers while analyzing the current waveforms without a load. The purpose of this lab is to also study three-phase and Δ/Y configurations, determining the polarities of the terminals of transformers, and to study the losses in a transformer. In this lab the parameters of a equivalent circuit will be determined through the use of open and short circuit testing. The results and conclusions will be presented in this report.

Prelab:

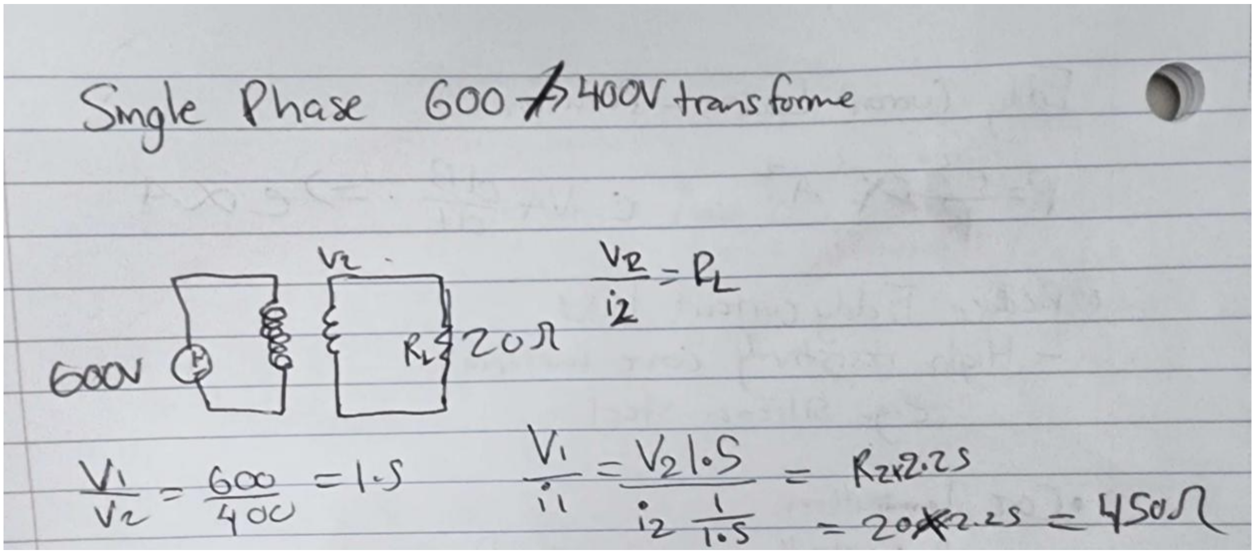
1)In the case of two magnetically coupled windings, if the current flows in the same direction resulting in the same direction of magnetic flux (can be determined using the right hand rule) then this is the ‘’Additive’’ polarity and the sum of the fluxes from the coil would be the total flux in the core. If the current flowing through the coils are opposing resulting in an opposing polarity of flux (right hand rule) this the subtractive “polarity” and the resulting flux will be the difference of the flux generated by the coils.

2) Transformers use kVA as this unit is simply AxV and independent of power factor. This is due to the fact that losses in the transformer are not dependent on the power factor as well. The loads that the transformer will be connected to is also unknown at the time of manufacturing and so power factor can not be calculated for its rating to be given in kW. If power factor was a factor required for a transformer to function then the rating would need to be in kW.

3) A rated voltage and rated current are a KVA rating that describe the maximum voltage or current the windings in the transformer are designed to function in. Anything above this rating could be dangerous or cause excessive wear or damage to components.

4) An open-circuit test is done from the LV side because of how available low voltage power supplies are. Aside from this, if it was on the high voltage side then the applied voltage would be very large and the no load current would be very small. The short circuit test is done on the high voltage side because the current will be small and so it is easier to short.

5)



6) Iron-core transformers are considered non linear magnetic circuits because they have a non-linear BH curve due to the nature of the material, iron. Iron is ferromagnetic so if an external magnetic field is applied, as it is decreased the magnetic dipoles tend to stay in that direction making the material slightly magnetized in the absence of the field. This creates a non linear curve of BH.

7) A single-phase transformers that is 110V to 110V can be used as an insulator or isolation transformer. It can be used to test equipment or devices by isolating them from the main circuit.

8) The equation for Hysteresis power loss is : $V_{Core}A_{BH}f$ and the equation for Eddy current power loss is e^2/R. When looking at both power losses, as long as voltage or frequency are increased, or both, the power loss will also increase. If Voltage is doubled Power loss will increase 4 times due to Eddy current and two times if the frequency is doubled due to Hysteresis. The total power loss will be the sum of these two.

9) The possible three phases connections are as follows: Δ/Y, Δ/Δ, Y/Δ, and Y/Y.

In lab Data and Observations:

1. Polarity Test of a Single-Phase Transformer

Q1. Assuming that the rated voltage of the transformer is applied on the LV winding, what will be the maximum and minimum values of V_{AX_1} in Fig. 1.

Additive polarity, Va1X1 = Va1a2 + Vx1x2 = 120V + 120V =240V

Subtractive polarity, Va1X1 = Va1a2 - Vx1x2 = 120V - 120V =0V

Table 1: Polarity test results

$V_{A_1A_2}$ = 30.4V	$V_{A_1X_1}$ = 84.2V	$V_{X_1X_2}$ = 115V

2. Investigation on the Waveform of the No-Load Current

Q2. What are the components of the no-load current in a transformer?

Core loss current and magnetization current

Figure 1: Voltage Waveform at 110% (Distortion)

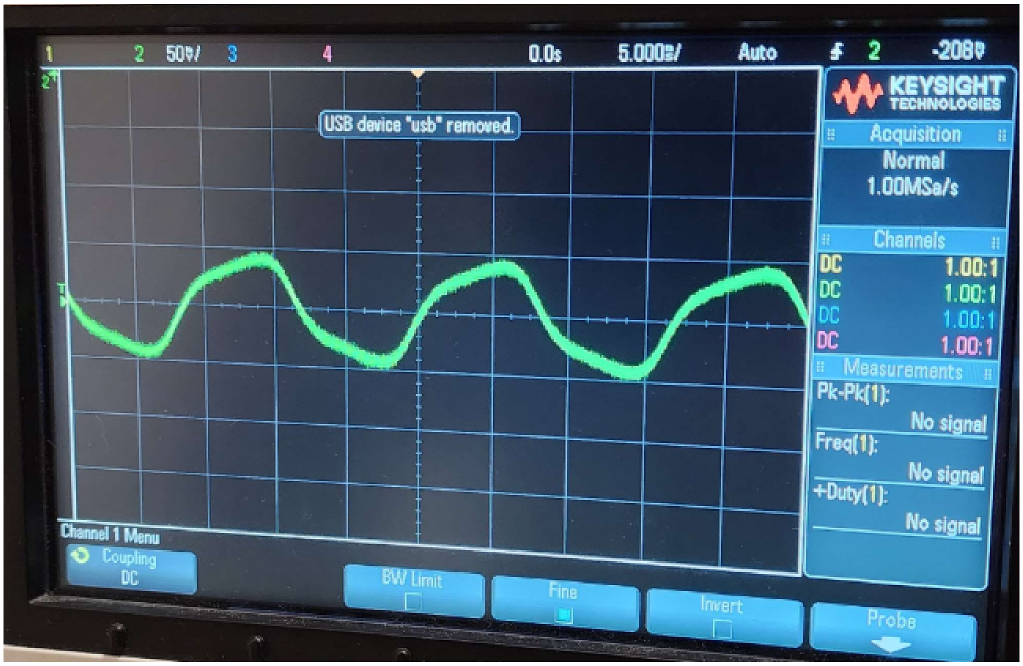


Figure 2: Voltage Waveform at 50%

Figure 3: Voltage Waveform at 100%

Q3. You are going to apply a sinusoidal voltage across the transformer winding. Are you expecting a sinusoidal waveform for the current?

Yes, there will be a sinusoidal waveform for the current and it will be out of phase.

3. Open-Circuit Test

Q4. What is the rated voltage of the LV side when it is connected as shown in Figures 3?

Reading at 110% = 115.9V

4. Short Circuit Test

Q5. What are the rated currents of the HV and LV windings?

HV = 1.2 A , LV = 2.4 A

Table 2: Open-circuit and short-circuit test results

Open circuit test			Short circuit test		
$V_{OC,LV}$ (V)	$I_{OC,LV}$ (A)	$W_{OC,LV}$ (A)	$V_{SC,HV}$ (V)	$I_{SC,HV}$ (A)	$W_{SC,HV}$ (W)
22.9	-	-	23.18	0.0578	0
46.2	0.263	9.89	46.36	0.0868	0
70.8	0.384	17.7	69.54	0.1135	0
92.7	0.628	29.8	92.72	0.141	0
115.9	1.15	42.7	115.9	0.171	0

The wattmeter could not detect the power through the high voltage side of the transformer due to a very very small current passing through the short circuit. Since power factor is not given the power in watts cannot be calculated.

Resistance Measurement of the *LV* and *HV* windings
$R_{DC,LV}$= 0.8 Ohms Ω
$R_{DC,LV}$= 0.3 Ohms Ω

5. Load Test

Table 3: Load test results

Load Step	Primary (HV)			Secondary (LV)	
	$V_1(V)$	$I_1(A)$	$W_1(W)$	$V_2(V)$	$I_2(A)$
1	117	0.418	47.7	61	0.540
2	116	0.674	77.3	60.6	1.063
3	116	0.952	110	60.4	1.577
4	116	1.23	141	60.1	2.091
5	116	1.51	174	59.9	2.619
6	116	1.78	206	59.8	3.134

6. Polyphase Transformers

Table 4: Measurement results for the three-phase Y/Δ connected transformer at full load

Primary (Y connected)	$V_{L,X1Y1}$	$V_{p,X1X2}$	$V_{p,Y1Y2}$	$V_{p,Z1Z2}$	V_{nN}	$I_{L,X}$	$I_{L,Y}$	$I_{L,Z}$
	118	118	118	118	0	2.33	2.28	2.28
Secondary (Δ connected)	$V_{L,A1B1}$	$V_{p,A1A4}$	$V_{p,B1B4}$	$V_{p,C1C4}$	-	$I_{L,A}$	$I_{L,B}$	$I_{L,C}$
	61.2	61.2	61.9	61.1	-	4.24	4.22	4.26

Q6. Suppose the HV side of the Y/Δ connected transformer in Fig. 6 is supplied from a balanced 208V 3-phase source. What are the possible readings of V_{Delta}? You may include both a correct connection and an also incorrect connection of the windings. Use a phasor diagram to answer this question.

Incorrect connection will give a reading of 240V and correct connection will read 0V.

Q7. What happens if the source voltage is not symmetrical? Consider a correct connection only.

If the source voltage is not symmetrical in a 3 phase power system, it can damage the equipment and be a potential safety risk. Aside from this it decreases the efficiency of generation, distribution and transmission. Neutral Voltage is no longer 0.

Q8. V_{Delta} should read zero for correct connection. What should you do in case V_{Delta} reads a large voltage?

The power supply should be immediately disconnected and the incorrect or bad connection should be identified immediately.

Post Lab:

1.

1. Use the recorded data in Table 1 and draw to scale the phasors of $V_{A_1A_2}$, $V_{A_1X_1}$, and $V_{X_1X_2}$; show how you can determine whether or not A_2 and X_2 have the same polarities.

Since it was observed that X2 and A2 had the same voltage magnitude, the phasor voltages of V_{A1A2} and V_{A1X2} to provide a phasor sum at V_{X1X2}. The voltage is recorded at V_{A1X2}. This is due to the fact that mutual inductance exists.

2.

2. Comment on the waveforms of the no-load current. Answer the following questions knowing that the applied voltage is sinusoidal at all times:
   a. Why the waveform of the current is not sinusoidal?
   b. Why the waveform of the current changes as the voltage increases?
   c. Why the peak value of the current increases significantly at higher values of the applied voltage.

a) The transformer has a metal core which is non-linear magnetic, this results in a current waveform that is not sinusoidal waveform.
b) As voltage increases with a fixes resistance, current will increase. So long as the resistance is fixed, current will increase proportionally to voltage.
c) Due to the non-linear nature of the core, at higher voltages current sharply spikes up. At higher voltages current increases at a very high rate as voltage is increased. Since the core material is ferromagnetic the dipoles align themself in the opposite direction due to induced voltage (due to the dipoles + and - end). The current peaks when this phenomenon occurs and increases from there.

3. Calculate the parameters of the equivalent circuit referred to the LV side. You should use the collected data from the OC test at rated voltage and also the SC test in this calculation.

Data from last row of open circuit test table:

Open Circuit:

$$R_{c2} = \frac{V_2^2}{P_2} = \frac{115.9^2}{42.7} = 314.6\Omega$$

$$I_2^2 = I_{c2}^2 + I_{m2}^2 = (\frac{V_2}{R_{c2}})^2 + (\frac{V_2}{X_{m2}})^2$$

$$X_{m2} = \frac{V_2}{\sqrt{(I_2)^2 - (\frac{V_2}{R_{c2}})^2}} = \frac{115.9}{\sqrt{(1.15)^2 - (\frac{115.9}{314.6})^2}} = 106.4\Omega$$

Short Circuit:

$$R_{eq1} = \frac{P_1}{I_1^2} = 0\ \Omega$$

$$(\frac{V_1}{I_1})^2 = Z_{eq1}^2 = R_{eq1}^2 + X_{eq}^2 = (\frac{P_1}{I_1^2})^2 + X_{eq1}^2$$

$$X_{eq1} = \sqrt{(\frac{V_1}{I_1})^2 - R_{eq1}^2} = \sqrt{(\frac{115.9}{0.171})^2 - 0} = 677.8\Omega$$

Transfer from HV to LV:
Turns ratio a = 1100/115.9 = 9.49

$$R'_{eq1} = \frac{1}{a^2}(R_{eq1}) = 0\Omega$$

$$X'_{eq1} = \frac{1}{a^2}(X_{eq1}) = \frac{1}{9.49^2}(677.8) = 7.53\Omega$$

4. Explain the difference between DC and AC resistance of a winding. Transfer $R_{DC,HV}$ to the LV side and calculate $R_{DC,eq} = R_{DC,LV} + R'_{DC,HV}$. Compare $R_{DC,eq}$ to the R'_{eq} calculated from the SC test and comment on your results.

The difference between DC and AC resistance of a winding is that AC resistance is greater than DC resistance.

$$R_{AC} = aR_{DC}$$

$R_{DC,LV} = 0.3\ \Omega,\ R_{DC,HV} = 0.8\Omega$

Voltage ratio, a = $\frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{1100}{115.9} = 9.49$

$$R_{DC,eq} = R_{DC,LV} + R'_{DC,HV} = 0.308\Omega$$

$$V_{SC,HV} = 116\ V,\ W_{SC,HV} = 0,\ I_{SC,HV} = 0.171\ A$$

$$Z_{SC,HV} = \frac{V_{SC,HV}}{I_{SC,HV}} = \frac{116}{0.171} = 678.4\Omega$$

$$R_{SC,HV} = Z_{SC,HV cos\phi} = 678.4 \times 0 = 0 = R_{eq}$$

$$R_{eq} << R_{DC,eq}$$

Due to the low voltage applied in a short circuit test instead of the maximum rated voltage, those were the results.

5.

Steps	Extracted from load test results					Theoretical Results			
	I_2(A)	P_{in}(W)	P_{out}(W)	η%	Reg%	P_{in}(W)	P_{out}(W)	η%	Reg%
1	0.540	47.7	32.94	69.06	91.8	48.91	32.94	67.35	91.8
2	1.063	77.3	64.42	83.34	91.4	78.18	64.42	82.40	91.4
3	1.577	110	95.25	86.60	92.1	110.43	95.25	86.25	92.1

4	2.091	141	125.67	89.13	93.0	142.68	125.67	88.08	93.0
5	2.619	174	156.88	90.16	93.7	175.16	156.88	89.56	93.7
6	3.134	206	187.41	90.98	94.0	206.5	187.41	90.76	94.0

6. Use the equivalent circuit of the transformer and calculate the theoretical values of the voltage regulation and efficiency of the transformer for six values of secondary currents; use the same values of the secondary current as you have measured in load test. Also, assume that the input

voltage is constant, and equal to V_1 in the load test. Do not forget transferring the valued to appropriate side before your calculations. Fill in your results in the corresponding cells of Table 5. The procedure for the calculations is given in the appendix

a)$P_{in}=V_1I_1$=(117)(0.418)=48.91 P_{out}=47.7W (table 3)
b)η%=97.5%
c)Reg%= (117-61)/61=91.8%

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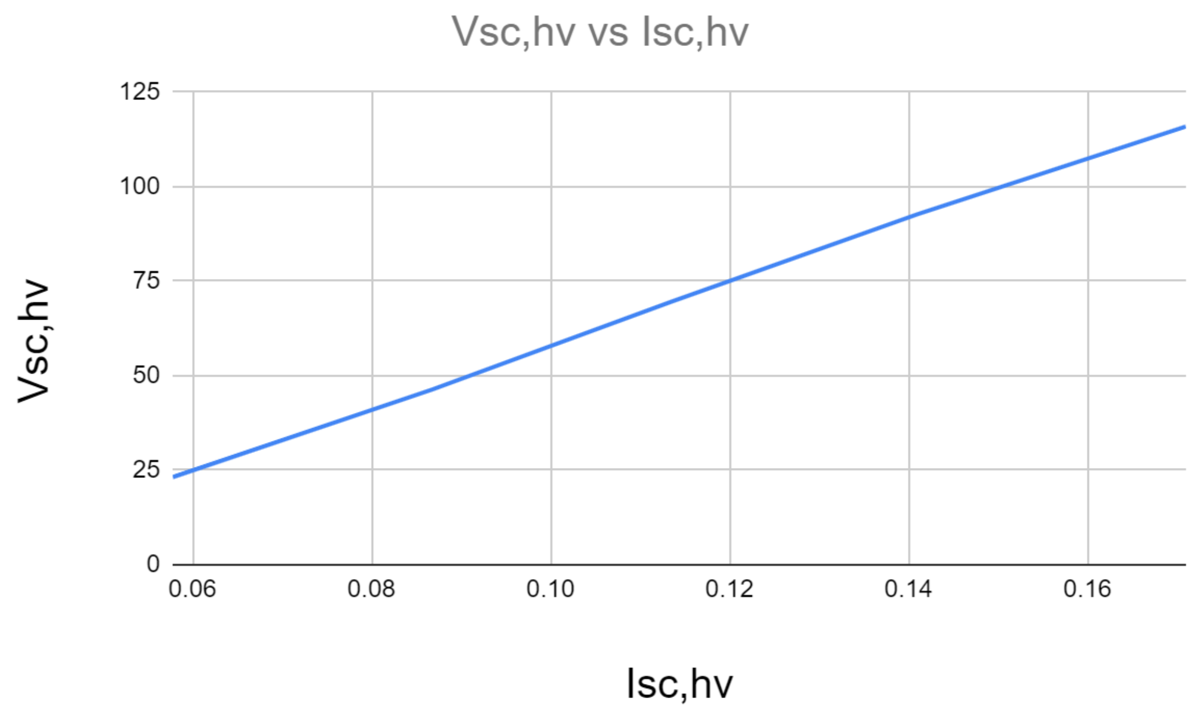
7.

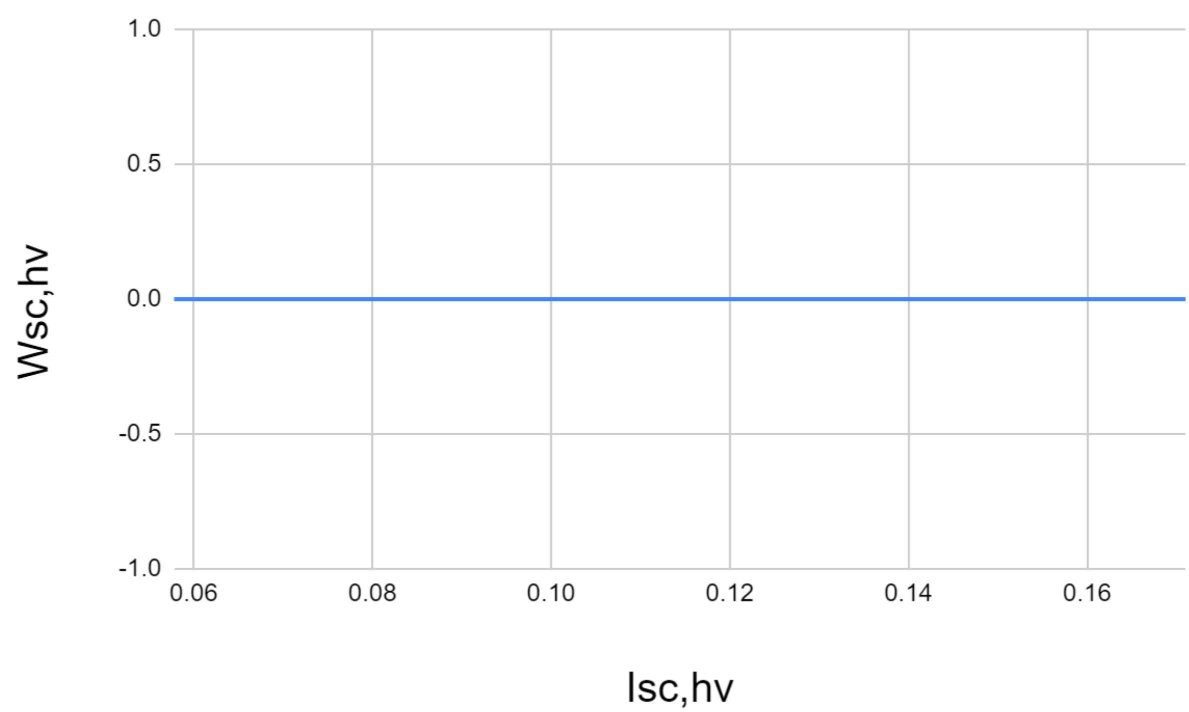
Compare the experimental result for the regulation and efficiency to corresponding theoretical results and comment on any discrepancies.

The experimental and theoretical values are in agreement with each other and are very close. There is some error but this could be due to weak connections from bad wires or connections that are not in full contact. Other sources of error include core loss such as Eddy current loss and hysteresis loss. Also the power factor was neglected (assumed to be 1) which causes a small amount of error since the circuit is purely resistive.

8. Use the equivalent circuit of the transformer and calculate the theoretical values of voltage regulation and efficiency of the transformer at the following loads:
   a. Full-load at 0.8 power factor lagging,
   b. Full-load at 0.8 power factor leading.

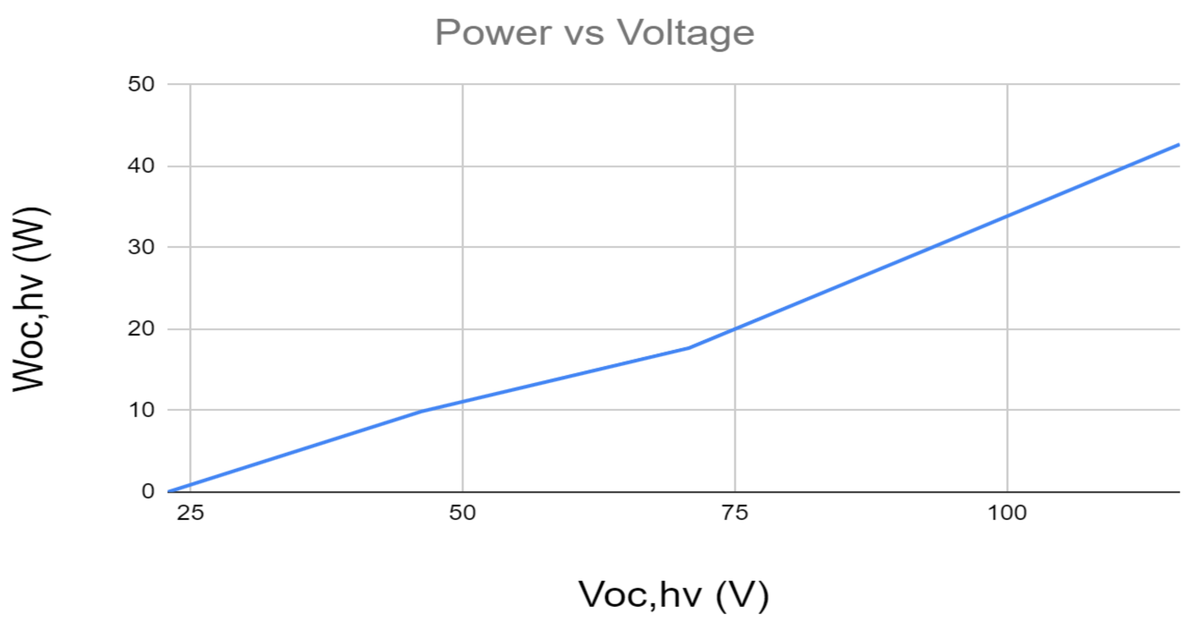
9. Use the collected results from the SC test and plot the variations of the applied voltage ($V_{SC,HV}$) and the copper losses ($W_{SC,HV}$) against the short-circuit current squared ($I^2_{SC,HV}$)• Do you expect a specific shape for each of these graphs (e.g. straight line, ...)? Do they meet your expectations? Comment on each of them.

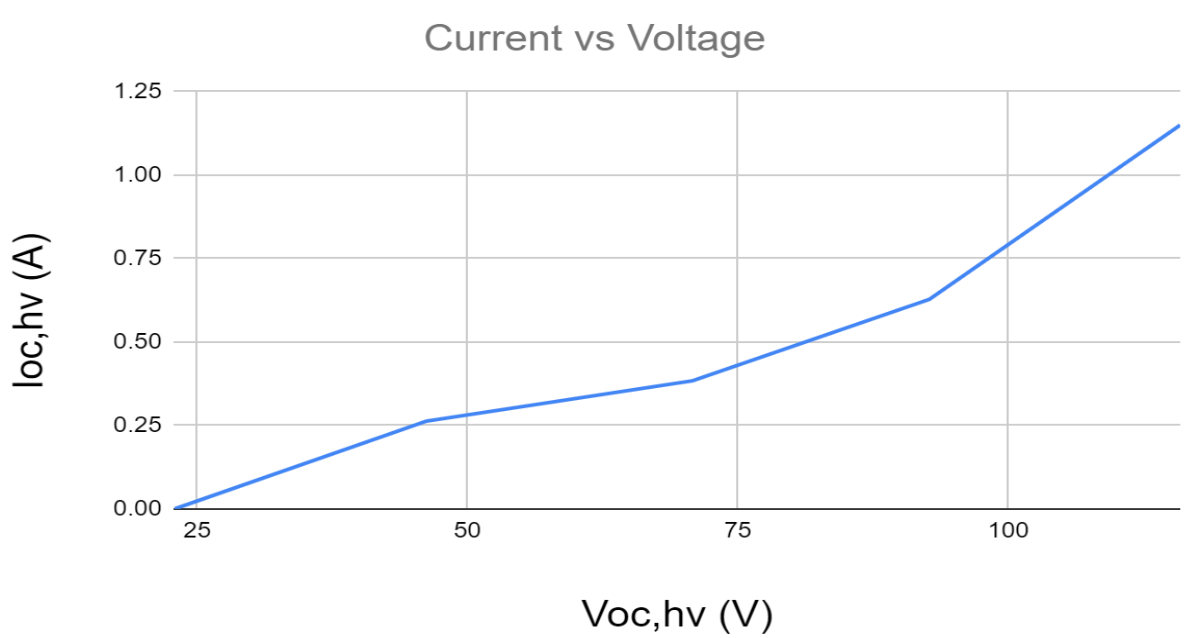

Vsc,hv vs Isc,hv
125
100
75
50
25
0
Vsc,hv
0.06
0.08
0.10
0.12
0.14
0.16
Isc,hv


1.0
0.5
0.0
-0.5
-1.0
Wsc,hv
0.06
0.08
0.10
0.12
0.14
0.16
Isc,hv

The first graph met the expectation, but due to the instrument not working properly, we weren't able to get the correct Watt readings, thus the second graph turned out like that.

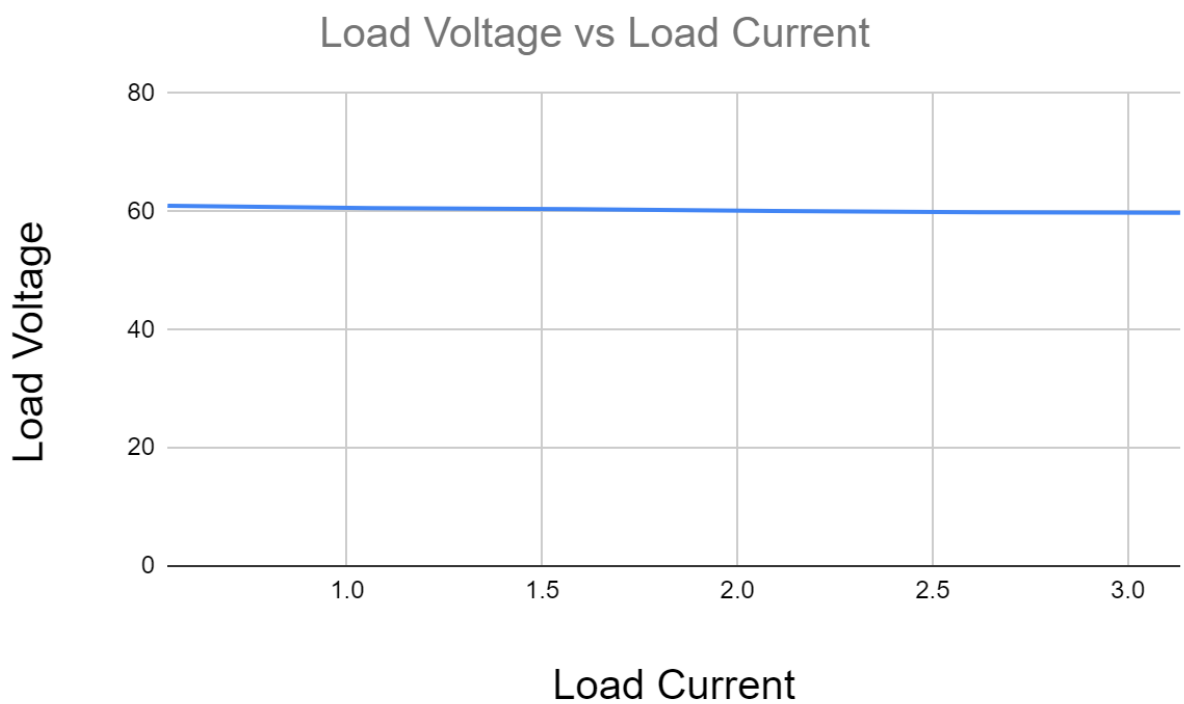
10. Use the collected results from the OC test and plot the variations of the core losses ($W_{OC,LV}$) and the magnetizing current ($I_{OC,LV}$) against the input voltage ($V_{OC,LV}$) in the same coordinate systems. Do you expect any specific shape for each of these graphs? Do they meet your expectations? Comment on each of them.

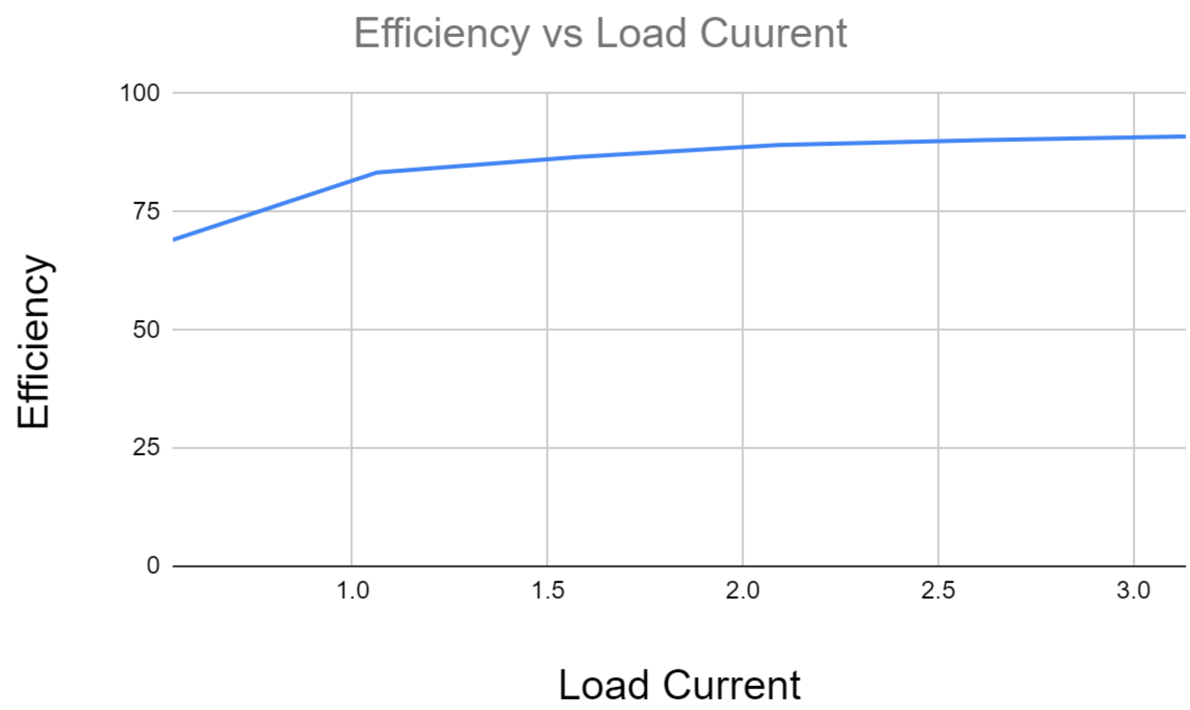




The graphs are supposed to be linear with some distortions and they are both similar so the results match our expectations.

11. Use the collected results from the load test and plot the variations the load voltage and the efficiency against the load current.



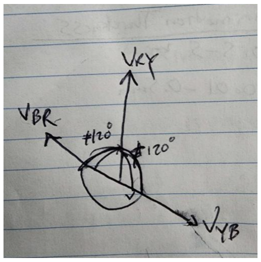


12. Summarize the observed relationships between the line and phase voltages, and between the line and phase currents for a Y/Δ connected transformer.

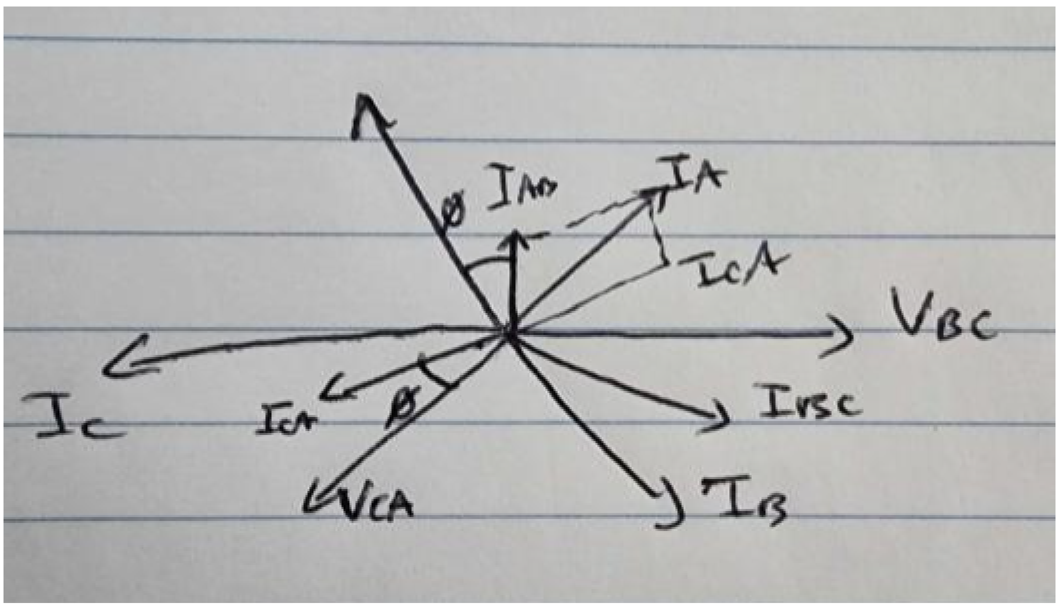
For a Y connection, the relationship between V_{line} and V_{phase} is $V_{line}=\sqrt{3}\ V_{phase}$ and $I_{line}=I_{phase}$. For a Δ connection, $V_{line}=V_{phase}$ and $I_{line}=\sqrt{3}\ I_{phase}$. So for the Y configuration currents are the same while voltages are related by a factor of $\sqrt{3}$ and for the delta connection, voltages are the same and currents are related by a factor of $\sqrt{3}$.

13. If you had closed the secondary Delta connected windings of the three-phase transformer without checking the zero voltage as in Fig. 6, what could happen? Support your answer by using a phasor diagram.

Without checking the zero voltage it is possible that there was an improper connection. This is dangerous as it could destroy the windings. Without checking the zero voltage it cannot be determined if the delta windings have been properly connected in series as well. I the voltage is non zero it shows that the voltages are no longer symmetrical (not 120 degrees out of phase with each other). This can damage equipment and be a safety hazard at most, and at bare minimum it will provide an extremely inefficient system. Having a non zero voltage is also dangerous as current may also be quite large and go past the rating of the transformer.



14. Draw a phasor diagram and show the phase difference between corresponding line-to-line voltages in the primary and secondary of the Δ/Y connected transformer.



15. Make general comments on the experiment and the results.

In this experiment, experimental values were quite close to expected and theoretical values. One mistake made by our team was using the Wattmeter to record current in table 2 for the short circuit test. The current was too small and so we needed to use the current clamp (ammeter) to get the current reading. It is expected that the current will be small as it is from the high voltage side. During the No-Load current test, the oscilloscop provided the correct waveform. At 110% there was distortion and at 50 to 100 % the waveform was an almost perfect sinusoid. This lab allowed for us to understand some important characteristics of a transformer through the short/open circuit test and also the fact that the current does not always provide a perfect sinusoid though the input voltage might, due to core losses.

Conclusion

Overall the lab was a success as all experimental values provided results as expected and very close to theoretical values. In order to reduce error in the future, power factor could be measured and be a part of calculations. Better wires and better equipment could be used.