Single Phase Transformer Tests

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1 INTRODUCTION

The objective of this lab was to get more familiar with equipment not used in lab 1 (Three Phase Measurements) and use single-phase transformers. The tests done were: coil polarity, number of coil turns, dc resistance, open-circuit, short-circuit, load test, and saturation. Through these tests, understanding of transformers and their usage was increased. Specifically, seeing that the core saturates at some point, internal impedance exist, and how the polarity test can be done to compute the high and low sides. Physically stepping up and down voltages while maintaining good efficiency through transformers truly shows why they so widely used for power distribution.

All data/measurements taken are provided in the appendix at the bottom of the document.

2 RESULTS

2.1 *Polarity, coil turn and dc resistance tests*

For the polarity tests a few simple measurements are taken in 2 different setups. Though there are many ways to find the polarity of the transformer, we were given the way that required more setups rather than more measurements at once. We start by measuring resistances of the terminals to determine which terminals are the 2 coils, by seeing which are 0 resistance. Then we short what the 2 high lines of the two coils, by reference, and apply a voltage (much less than rated) to a coil and measure voltage across the other sides low line and low line of the the coil we applied voltage to: call this voltage V_{m1}. Then we apply the voltage to the same coil but short the other sides high line with low line of the coil we applied voltage to and measure the voltage across the high line of other side and low line of voltage applied side: call this voltage V_{m2}. If $V_{m1}<V_{m2}$ then the 2 high lines or 2 low lines, by reference have the same polarity and we mark them with the dots. This is because the V_{m1} measures low-low voltage while shorting high lines and V_{m2} measure high-low while shorting high-low. If the measured high-low is higher than low-low then obviously our reference selected was correct and the two high lines are relatively the same polarity. If $V_{m2}<V_{m1}$ then the opposite needs to be done where opposite high and low lines are marked with the dots since the polarity would be reversed.

The turn test is performed by the use of a *10-turn test coil*. With the use of this we know exactly how many turns 1 coil has and with the use of:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$= \frac{115}{13.1} \cdot 10 = N_1 = 88$$

Then by applying 115V across the 115V coil and measuring the voltage across the 10-turn test coil, we can use the equation above to find the number of turns on the 115V coil. Then to find the number of coils on the 230V coil we can again apply voltage on the 115V coil and measure voltage across the 230V coil and use the fact that we know 115V coil has 88 turns to again solve the equation above to get the number of turns on the 230V coil.

$$= \frac{221}{115} \cdot 88 = N_2 = 170$$

However, to make use of the equation above we have to assume that there are no losses in the coil and core itself, otherwise the number of turns is not accurate. Another assumption, based on the first one, is that P1 = P2 so current is also directly proportional to number of turns. None of this is completely true in a real transformer.

To measure the resistance of the coils we used a Ohmmeter and a dc test:

Ohm Meter: 115V coil has 0.2ohms, 230V coil has 0.9 ohms

DC Test: 115V coil $\frac{V}{I} = \frac{1.75}{6.6} = .25ohms$

$$\text{DC Test: 230V coil } \frac{V}{I} = \frac{3.19}{3.48} = .91ohms$$

Further, we can verify the turns and resistance again by using both of them together.

$$\text{Relative Impedance Formula: } r_1 = (\frac{N_1}{N_2})^2 \cdot r_2$$

$$= r_1 = (\frac{170}{88})^2 \cdot 0.25 = 0.93ohms$$

$$\%\text{ error} = (\frac{0.93 - .91}{.93}) \cdot 100 = 2.2\%$$

It is visible that they are very close readings and have % errors of <3%.

2.2 *Open Circuit Test*

The open circuit test helps us find the core losses of the transformer once we have found the DC resistances of the coil. The reason we can assumes that open circuit only gives core losses is because the impedance of the coil is only a small percentage of total impedance, and we can neglect it. The measurements taken through Wattmeter help us with this as we know current, voltage, and power.

$$P = I^2 \cdot R_{\text{core}}$$

$$R_{\text{core}} = \frac{P}{I^2} = \frac{18.4}{.587^2} = 53.4ohms$$

$$Z = \frac{V}{I} = \frac{115.5}{.587} = 196.8$$

$$X_{\text{m}} = \sqrt{Z^2 - R^2} = 189.4ohms$$

2.3 *Short Circuit test*

This test allows us to find impedance in the coil, such as resistance and leakage. Since We are shorting one side of the transformer, we want to work at much lower than rated voltage as we do not want to go over current limit, so we increase voltage until we hit 80% of rated current. Again we need same values as the open circuit tests (Voltage, Power, Current) to find the values we want. We can compare these values again to the resistances found before to see the accuracy of this test. Since we are operating at a low voltage, then the flux through core is very low and the losses there become negligible due to the short.

$$P = I^2 \cdot R_{\text{230V coil}}$$

$$R_{\text{230V coil}} = \frac{P}{I^2} = \frac{33}{5.11^2} = 1.2ohms$$

$$R_{\text{115V coil}} = \frac{88}{170}^2 \cdot 1.2 = .32ohms$$

The values calculated here are not very close to what was measured during the dc test. The exact errors are: $\%\text{ error}_{\text{115V coil}} = (\frac{0.32 - .25}{.32}) \cdot 100 = 20.2\%$

$$\%\text{ error}_{\text{230V coil}} = (\frac{1.2 - .91}{1.2}) \cdot 100 = 24\%$$

The cause of this error can be due to the losses in wires/connections or faulty readings from instruments.

We can continue with these values to find the leakage losses:

$$Z = \frac{V}{I} = \frac{8.29}{4.11} = 2.02$$

$$X_{\text{230V coil}} = \sqrt{Z^2 - R^2} = 1.62ohms$$

$$X_{\text{115V coil}} = \frac{88}{170}^2 \cdot 1.62 = .43ohms$$

Finally, the short circuit test also gives the the impedance percentage of the transformer which is given by the following formula:

$$Impedance\% = \frac{V_{\text{SC}}}{V_{\text{rated}}} \cdot 100 = 3.6\%$$

2.4 *Load Test*

In this section of our tests, we measured values while changing the load on the high side of our transformer. Through all the tests the low side input was maintained at 115V. This test allows us to find full load efficiency of the transformer as it is basically input divided by output.

$$Efficiency = \frac{outputpower}{inputpower} \cdot 100 = \frac{870}{926} \cdot 100 = 94\%$$

Here full load is considered to be the lowest resistance we could get which is 50ohms.

Further we can also calculate the % Regulation through: this formula:

$$\%Regulation = \frac{V_{\text{No Load - V}_{\text{Full Load}}}}{V_{\text{Full Load}}} \cdot 100 = \frac{221.9-211.6}{211.6} \cdot 100 = 4.87\%$$

2.5 *Peak Values*

To find peak values of B and H we can use the following formulas:

$$B_{\text{max}} = \frac{R \cdot C}{N \cdot A} \cdot V_{\text{c}_{\text{max}}} = \frac{1000 \cdot 48E-6}{88 \cdot .0040} \cdot 6.28 = .86T$$

With max flux density we can find max flux:

$$\phi = BA = .86 * .0040 = 0.00344Wb$$

$$H_{\text{max}} = \frac{N \cdot i_{\text{max}}}{l} = \frac{88 \cdot .692}{.27} = 299.9\frac{A}{m}$$

Further through plotting the V_c v.s. i we can find the saturation flux density:

As B is proportional to V_c we can find the saturation flux density.

$$B_{\max} = \frac{R \cdot C}{N \cdot A} \cdot V_{c_{\max}} = \frac{1000 \cdot 48E-6}{88 \cdot .0040} \cdot 3 = .01T$$

3 CONCLUSION

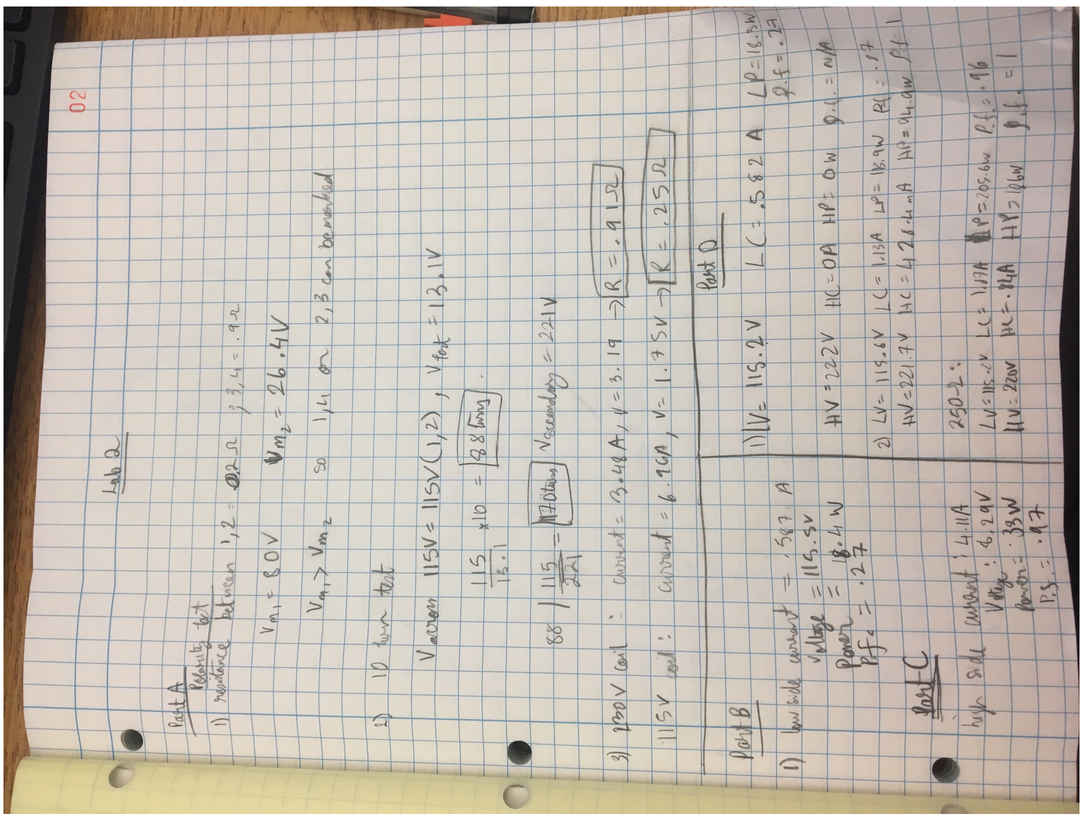
This lab gave us an introduction to an instrument that is not used in other ECE labs. It is evident why transformers are so widely used because of their ease of use and understanding. The different tests we conducted to determine internal impedance and peak values we very helpful as they can be applied again in a very similar manner. The one test that was quite surprising was the 10-turn test coil as it gives a lot of information that can be used in other calculations. The open/short circuit tests are easy to perform and tell us the losses immediately. Finally, testing the device under different loads shows how in real situations efficiency is never 100% and it was evident through losses and drops in voltages. Overall it was an informative lab that gave a lot of knowledge.

4 REFERENCES

[1] P.W. Sauer, P.T. Krein, P.L. Chapman, *ECE 431 Electric Machinery Course Guide and Laboratory Information*, University of Illinois at Urbana-Champaign, 2005.

5 APPENDIX

Picture:



Part D continued

167.6Ω

LV = 115V LC = 2.7A LP = 302W pf. = .98

HV = 219.8 HC = 1.27A HP = 280W pf = 1

125Ω

LV = 115V LC = 3.45A LP = 391W pf. = .98

HV = 217.8V HL = 1.68A HP = 367W pf = 1

100Ω

LV = 115V LC = 4.22A LP = 481W pf = .99

HV = 217V HC = 2.07A HP = 454W pf = 1

50Ω

LV = 114.5V LC = 8.1A LP = 926W pf = 1

HV = 211.6V HC = 4.11A HP = 870W pf. = 1

Part E

57V on 115V coil : LV = 57.8V LC = 158.9mA LP = 8.2W pf = .89

HV = 111.4V HL = 0 HP = 0 pF = N/A

115V on coil : LV = 115.2V LC = 618.4mA LP = 31.2W pf = .44
HV = 222V HP, HC, pf = 0/N/A

Measurements : top length = 111.86 mm
height = 66 mm
Depth = 81mm
Width = 22.5mm