UCD School of Electrical, Electronic and Communications Engineering

EEEN20090 Electrical Energy Systems II

Transformer Parameter and Loss Measurement

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Declaration

I declare that the work described in this report was done by the people named above, and that the description and comments in this report are my own work, except where otherwise acknowledged. I have read and understand the consequences of plagiarism as discussed in the EECE School Policy on Plagiarism, the UCD Plagiarism Policy and the UCD Briefing Document on Academic Integrity and Plagiarism. I also understand the definition of plagiarism.

Signed: Fergal Lonergan

Date: 25/3/25

Summary

In this report I will explain the reason for which this lab was undertaken, explain the method used, present and interpret the results and findings and finally provide recommendations which I have drawn from undertaking the lab.

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Introduction

In this lab we were tasked with measuring particular properties of a transformer in order to build a more accurate model of a real transformer which could then be used for more detailed analysis. The lab was divided into three sections, each testing a different aspect of the transformer under certain conditions in order to obtain the properties we needed to build our transformer model. An ideal transformer contains none of these “non-ideal” properties and even though it is ok to use it for simple circuit analysis it is not an accurate model for a real transformer.
The three sections, or tests, where divided as such :

- DC Winding resistance
- Open Circuit test
- Short circuit test

Theory

For circuit analysis there are two different types of transformer, the ideal and the real transformer. The ideal transformer consists of two separate coils of wire each wrapped around a single iron core. It is so-called “ideal” because it assumes that there are no losses in power from the transformer as well as there being no leakage flux. This however is not the case. We apply an AC voltage to one side of the transformer, this is known as the primary side, and on the other side, the secondary side, we can get a stepped up or down voltage depending on the turns ratio between the twoAs a result the current in the secondary side must reflect the step up or step down ratio as the supplied power must be kept constant, no loss as stated above.
Of course if an ideal transformer is able to step up or step down voltage, it is just as capable at stepping up or down the currents in either side of the transformer should that be required. This is summarised in the figure below, the ideal transformer, in which V_1 and I_1 refer to the voltage and current on the primary side of the transformer, and similarly V_2 and I_2 refer to the voltage and current on the secondary side of the transformer. N_1 refers to the number of turns in the primary coil whereas N_2 refers to the number of coils in the secondary coil.

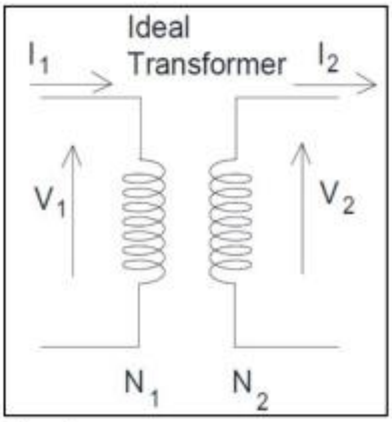

Figure 1

The relationship between the primary voltage and secondary voltage in relation to the turns ration is:

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

Whereas the relationship between the primary and secondary currents in relation to the turns ratio is:

$$I_1N_1 = I_2N_2$$

Real transformers however have many non-ideal properties that the ideal transformer simply fails to take into account. These non-ideal properties must then be taken into account when modelling a real transformer in order to get accurate results. In our model of our ideal transformer we assumed that the transformer had zero impedance, perfect magnetic coupling between the primary and secondary coils as well as a core reluctance of zero. This is not the case in an ideal transformer and as a result these properties must be taken into account in our transformer model. For the purpose of this lab we will consider these properties even though there are more non-ideal properties of transformers that have been factored out in our calculations.
Our new model of a real transformer can be seen in the equivalent circuit below. This new model takes into account the non-ideal characteristics of a transformer detailed above and should enable us to make much better estimations for how our transformer will act under the conditions tested in the lab.

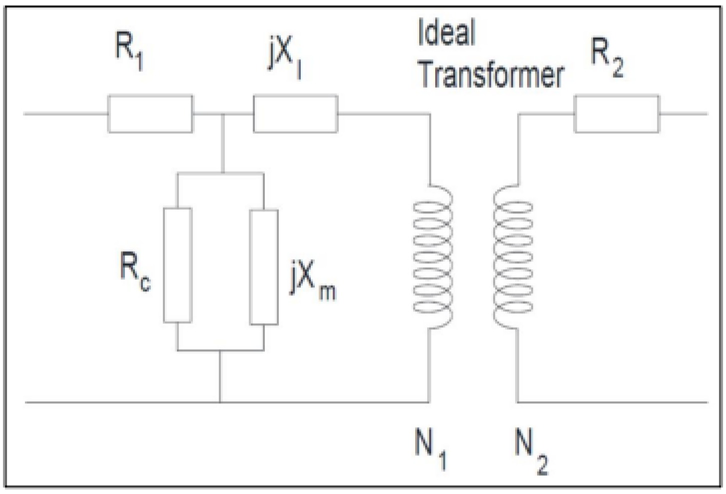

Figure 2

R_1 : Primary winding resistance
R_2 : Secondary winding resistance
X_1: leakage reactance in the primary coil of our transformer
X_m: Magnetising reactance in the primary coil of our transformer
R_c: Resistance for total core loss due to Eddy currents and hysteresis in transformer

In order to adapt the transformer circuit shown below it is necessary to find values for each of the variables labelled above. In order to do this we must put our circuit through three separate tests, the tests we undertook in the lab.

DC Winding Resistance

This test allows us to measure the primary and secondary winding resistance, R1 and R2 respectively, using the four terminal test. We use the four terminal test in order to get an accurate reading for our resistance as our normal Ohmmeter is not reliable at measuring resistances this ……….. . The test involves us passing a substantially large DC current to our primary and secondary sides and measuring the voltage drop which will be due to the winding resistance. Seeing as we are using a DC current we eliminate the inductive and coupling effects of the transformer.

Open Circuit Test

Using this test we are able to find values for Rc and Xm. In order to do this we must open circuit the secondary side of our transformer, hence the name open circuit test. The equivalent circuit can then be modelled in Figure 3 below. Looking at the circuit we note that the primary current will be very low in comparison to its rated current, and so we discount the voltage drop across the primary winding resistance, R1, assuming that it is negligible. Furthermore we can assume that the current flowing through X1, leakage reactance in the primary coil of our transformer, and R2, the secondary winding resistance, is approximately 0A and so we can further reduce the circuit to the parallel combination of Rc, resistance for total core loss due to Eddy currents and hysteresis in transformer, and Xm, magnetising reactance in the primary coil of our transformer.

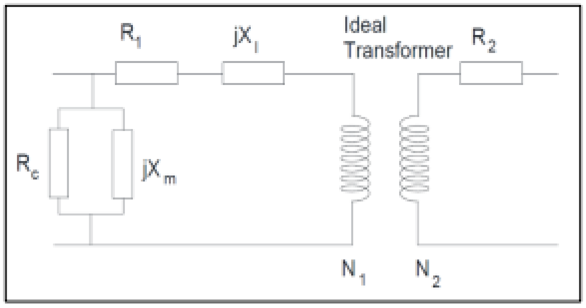

Figure 3

Using the following equations we can now determine these values.

$$P = \frac{V^2}{R_c}$$

$$I = \frac{V}{R_c} + \frac{V}{jX_m}$$

$$|I| = \frac{V}{R_c X_m}\sqrt{R_c^2 + X_m^2}$$

P = Power
V = Voltage across the parallel combination or V_1
I = Current through the elements or I_1

Short Circuit Test

Using this test we can measure X_1. To do this we must now short circuit the secondary side of the transformer. By doing this we can simplify the circuit to the equivalent circuit shown below in Figure 4.

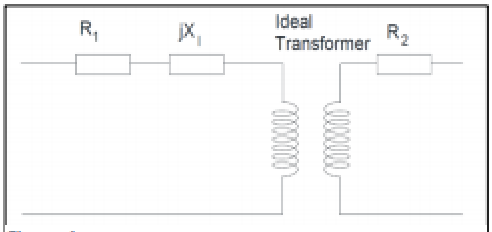

Figure 4

Using the formula below we will consider the loss due to R_1 and R_2:

$$P = I_1^2 R_1 + \ I_2^2 R_2$$

If we take R_2 over to the primary side we get:

$$P = (R_1 + \left(\frac{N_1}{N_2}\right)^2 R_2)$$

Then let:

$$R_w = R_1 + \left(\frac{N_1}{N_2}\right)^2 R^2$$

Then we can say that:

$$P = R_w I_1^2$$

We can now calculate R_w and find X_1. If we consider the voltage dropped across the primary side we find that:

$$V = R_w I_1 + jX_1 I_1$$

If we then solve for I_1 and take the absolute value we obtain the equation:

$$|I_1| = \frac{V}{\sqrt{R_w^2 + X_1^2}}$$

We can now calculate a value for X_1 now which we need to build our real transformer model.

Procedure

DC Winding Resistance

- Demonstrator applied around 8.5A to each the primary and secondary windings.
- We then measure the voltage in each side.
- We then calculate the winding resistances using Ohm's Law.

Open Circuit Test

- We set up the circuit as in Figure 3 with the primary voltage at 220V.
- Then we measure the secondary voltage using the bench voltmeters.
- Measure the current on the primary side using the bench ammeters.
- With the wattmeter we calculate the power ensuring that its voltage and current sensors aren't overloaded.
- Using the formulae above we calculate R_c and X_m.

Short Circuit Test

- Set up the circuit as show in Fig. 5.
- Use the Current Transformers to ensure that neither the wattmeter nor the ammeter are damaged by running the wire through an appropriate number of times.
- Calculate the rated current for the transformer.
- Read the voltage for the primary side and the rated current and read off the power on the wattmeter.
- Ensure to account for the turns used in the CTs when calculating X1.

Findings (evidence)

DC Winding Resistance

The demonstrator applied 8.5A of DC current to the primary side and measured a voltage drop of about 1.99V. Using Ohm's Law we get:

$$R_1 = \frac{V}{I} = \frac{(1.99)}{(8.5)} = 0.2341\Omega$$

They then proceeded to apply 10A to the secondary side of the transformer and the voltage drop was about 0.273V. Again using Ohm's law we get:

$$R_1 = \frac{V}{I} = \frac{(0.273)}{(10)} = 0.0273\Omega$$

Open Circuit Test

Our measured data was:

V_1=220V
V_2=56V
I_1=1.25A
P=65W

Using our turns ratio or N_1/N_2, we get:

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{220}{56} = \mathbf{3.93}$$

We calculate Rc using the power as follows:

$$\mathrm{Rc} = \frac{V^2}{P} = \frac{220^2}{65} = 744.62\Omega$$

And rearranging our equation for the absolute value of I we can find Xm:

$$X_m = \sqrt{\frac{V^2}{\left(I^2 + \frac{V^2}{R_c^2}\right)}} = \sqrt{\frac{220^2}{\left(1.25^2 + \frac{220^2}{744.62^2}\right)}} = 171.28\Omega$$

Short Circuit test

Knowing that the rated kVA of the transformer is 5kVA wefind the rated current for the transformer using our 220V on the primary side:

$$IV = I(22) = 5000 \therefore \mathrm{I} = 22.72\mathrm{A}$$

We know that the Current Transformer (CT) has a turns ratio of 24 though this will change depending on the number of turns we use. The measured values we found are summarised below, accounting for the CTs.

I1 (Rated) = 22A
I2 = 84A(3.5x24)
V1 = 86V
P = 480W (100 x 4.8 which was(120/5x5))

We compare $I2/I1$ to the turns ratio found in the open circuit test and we find $I2/\ I1$ = 86/ 22 = 3.9 which is in strong agreement with the turns ratio of 3.93 that we found earlier for the transformer. We now calculate Rw as follows:

Rw = $P/\ I_1{}^2$ = 480/ 22^2 = 0.99Ω

Rearranging the equation for I1 we can find an explicit equation for XL:

XL = √ $V2\ /I_1{}^2 - R_w{}^2$ = √ $480^2/\ 22^2 - 1.488^2$ = 3.78Ω

Conclusions

Using the ideal model of the transformer we cannot accurately model our transformer like we can once we take into account the non-ideal parameters. This allows for fer more accurate predictions to be made on the use of a real transformer.