1 Experiment No. 8

2 Experiment Title

Determinations of Transformer Equivalent Circuit Parameters.

3 Objective

The objectives of this lab are as follows:

- To perform the open-circuit and short-circuit tests on a transformer.

- To determine the equivalent circuit parameters of a transformer.

4 Theory

4.1 The Equivalent Circuit of a Transformer

The losses that occur in real transformers must be accounted for in any accurate model. The major items to consider in the construction of such a model are:

1. **Copper (I^2R) losses:** These are resistive heating losses in the primary and secondary windings of the transformer, proportional to the square of the current in the windings.

2. **Eddy current losses:** These are resistive heating losses in the core of the transformer, proportional to the square of the voltage applied.

3. **Hysteresis losses:** Associated with the rearrangement of magnetic domains in the core during each half-cycle, hysteresis losses are a complex, nonlinear function of the applied voltage.

4. **Leakage flux:** The fluxes Φ_{LP} and Φ_{LS} that escape the core and pass through only one of the transformer windings are leakage fluxes. These produce self-inductance in the primary and secondary coils, which must be accounted for.

4.2 Transformer Model

It is possible to experimentally determine the values of the inductances and resistances in the transformer model. These values can be approximated using two tests: the open-circuit test and the short-circuit test.

4.2.1 Open-Circuit Test

In the open-circuit test, the transformer's secondary winding is open-circuited, and its primary winding is connected to a full-rated line voltage.Under these conditions, all the input current flows through the excitation branch of the transformer. The series elements R_p and X_p are too small compared to R_c and X_M to cause a significant voltage drop, so essentially all the input voltage is dropped across the excitation branch.
Full line voltage is applied to the primary of the transformer, and the input voltage, input current, and input power to the transformer are measured. From these measurements, it is possible to

determine the power factor of the input current, which provides the magnitude and angle of the excitation impedance.

The easiest way to calculate the values of R_c and X_M is by first looking at the admittance of the excitation branch. The conductance of the core-loss resistor is given by:

$$G_C = \frac{1}{R_c}$$

The susceptance of the magnetizing inductor is given by:

$$B_M = -\frac{1}{X_M}$$

The excitation admittance, Y_E, can be expressed as:

$$Y_E = G_C - jB_M$$

where G_C is the conductance of the core-loss resistor, and B_M is the susceptance of the magnetizing inductor.

The magnitude of the excitation admittance (referred to the primary circuit) can be found from the open-circuit test voltage and current:

$$|Y_E| = \frac{I_{\text{oc}}}{V_{\text{oc}}}$$

where I_{oc} and V_{oc} are the open-circuit test current and voltage, respectively.

The angle of the admittance can be found from the knowledge of the circuit power factor. The open-circuit power factor (P_f) is given by:

$$P_f = \cos(\theta) = \frac{P_{\text{oc}}}{V_{\text{oc}} I_{\text{oc}}}$$

and the power-factor angle θ is given by:

$$\theta = \cos^{-1}(P_f)$$

The power factor is always lagging for a real transformer, so the angle of the current always lags the angle of the voltage by θ degrees. Therefore, the admittance Y_E is given by:

$$Y_E = \frac{V_{\text{oc}}}{I_{\text{oc}}} \angle - \theta$$

where

$$\theta = \cos^{-1}(P_f)$$

By comparing Equations, it is possible to determine the values of R_c and X_M directly from the open-circuit test data.

4.2.2 Short-Circuit Test

In the short-circuit test, the secondary terminals of the transformer are short-circuited, and the primary terminals are connected to a fairly low-voltage source. The input voltage is adjusted until the current in the short-circuited windings reaches its rated value. It is important to ensure that the primary voltage remains at a safe level, as applying excessive voltage could damage the transformer's windings during the test.

During the test, the input voltage, current, and power are measured. These values are then used to determine the parameters of the transformer's equivalent circuit, similar to the process in the open-circuit test.

Since the input voltage is so low during the short-circuit test, negligible current flows through the excitation branch. If the excitation current is ignored, then all the voltage drop in the transformer can be attributed to the series elements in the circuit. The magnitude of the series impedances, referred to the primary side of the transformer, can be calculated using the measured values of voltage and current during the short-circuit test.

The series impedance Z_s can be expressed as:

$$|Z_s| = \frac{V_{\text{sc}}}{I_{\text{sc}}}$$

where V_{sc} is the input voltage during the short-circuit test, and I_{sc} is the current measured during the test. The short-circuit power factor (P_f) is given by:

$$P_f = \cos(\theta) = \frac{P_{\text{sc}}}{V_{\text{sc}} I_{\text{sc}}}$$

and the power-factor angle θ is given by:

$$\theta = \cos^{-1}(P_f)$$

This impedance can be further split into its real and imaginary components, representing the series resistance R_s and reactance X_s, respectively:

$$Z_s = R_s + jX_s$$

The values of R_s and X_s are determined from the magnitude of the impedance and the power factor measured during the short-circuit test.

5 Required Apparatus

1. **Transformer**

   (a) Power (P): 760 VA

   (b) Primary Voltage (U_1): 230 V

   (c) Secondary Voltage (U_2): 400 – 230 V

   (d) Frequency (f): 50 Hz

   (e) Primary Current (i_1): 3.7 A
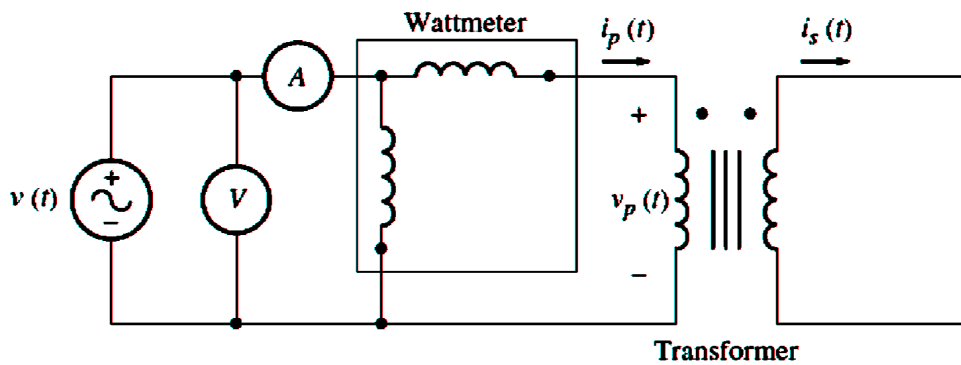
   (f) Secondary Current (i_2): 1 – 1.7 A

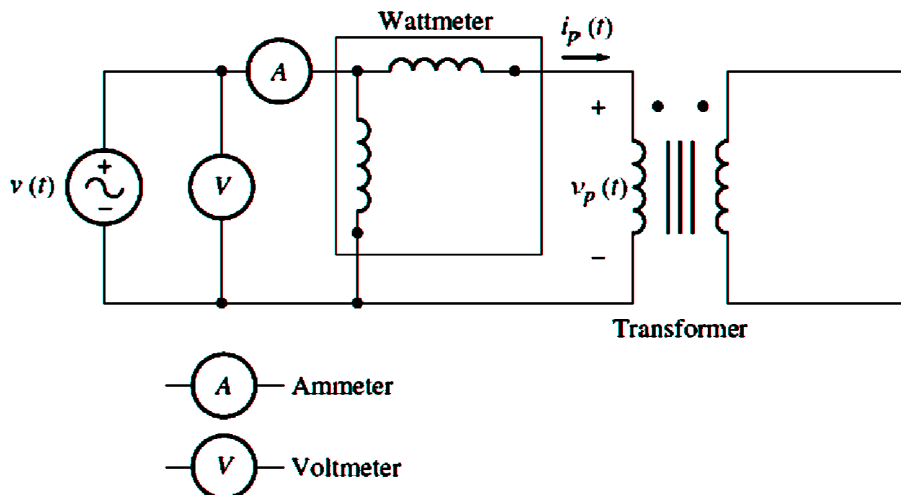2. **Voltmeter:** 500 V AC rms MAX

3. **Ammeter:** 5 A MAX

4. Digital Multimeter Display

5. Connecting Wires

6 Circuit Diagrram

(a) Connection for transformer short-circuit test.

(b) Connection for transformer open-circuit test.

7 Data Table

Table 1: Table for Short Circuit Test

SI No.	Voltage, $V(V)$	Current, $I(A)$	Power, $P(W)$	Power factor, P_f	$\|Z\| = \frac{V}{A}$	$\theta = cos^{-1}(P_f)$	$R_s,$ Ω	$X_s,$ Ω
1.	19.7	3.74	72.9	0.991	5.267	7.69	5.22	0.705

Table 2: Table for Open Circuit Test

SI No.	Voltage, $V(V)$	Current, $I(A)$	Power, $P(W)$	Power factor, P_f	$\|Z\| = \frac{V}{A}$	$\theta = -cos^{-1}(P_f)$	$R_c = G^{-1},$ Ω	$X_m = B^{-1},$ Ω
1.	230	0.241	28.1	0.507	1.048×10^{-3}	-59.53	1881.82	1107.42

8 Calculations

8.1 Short Circuit Test Calculations

From data table:

1. Impedance magnitude, $|Z|$:

$$|Z| = \frac{V}{I} = \frac{19.7}{3.74} = 5.267\,\Omega$$

2. Phase angle, θ:

$$\theta = \cos^{-1}(P_f) = \cos^{-1}(0.991) = 7.69°$$

3. Resistance, R_s:

$$R_s = |Z| \times P_f = 5.267 \times 0.991 = 5.22\,\Omega$$

4. Reactance, X_s:

$$X_s = |Z| \times \sin(\theta) = 5.267 \times \sin(7.69°) = 0.705\,\Omega$$

8.2 Open Circuit Test Calculations

From data table:

1. Impedance magnitude, $|Z|$:

$$|Z| = \frac{V}{I} = \frac{230}{0.241} = 1.048 \times 10^{-3}\,\Omega$$

2. Phase angle, θ:

$$\theta = -\cos^{-1}(P_f) = -\cos^{-1}(0.507) = -59.53°$$

3. Core resistance, R_c:

$$R_c = G^{-1} = (5.314 \times 10^{-4})^{-1} = 1881.82\,\Omega$$

4. Magnetizing reactance, X_m:

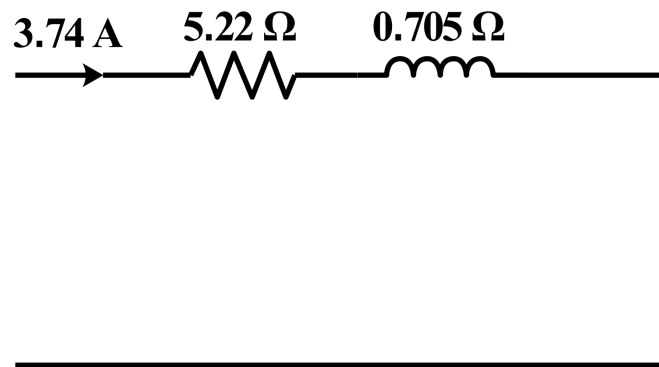$$X_m = B^{-1} = (9.032 \times 10^{-4})^{-1} = 1107.42\,\Omega$$
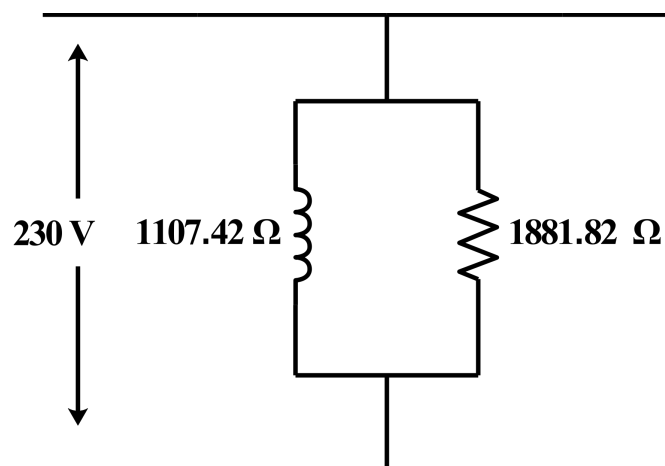
9 Result

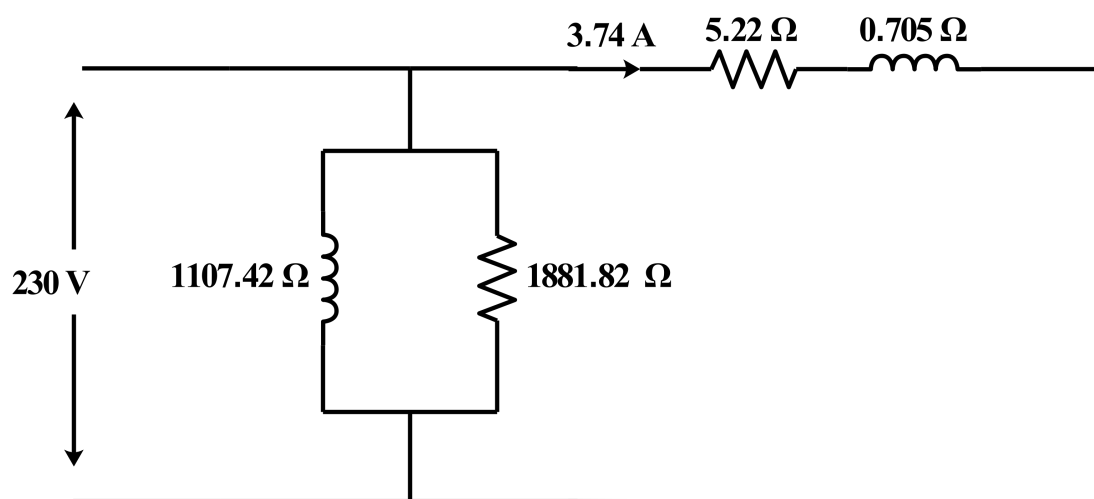Figure 2: Short-Circuit Test

Figure 3: Open-Circuit Test

Figure 4: Total equivalent circuit

10   Discussion

The experiment was conducted to determine the Transformer Equivalent Circuit Parameters.

In the short-circuit test, the secondary terminals were short-circuited, and the primary voltage was adjusted to ensure the rated current $(3.7A)$ flowed through the windings. The series impedance of the transformer was calculated by measuring the input voltage and current from the digital multimeter. The series resistance (R_s) and reactance (X_s) were then determined from the magnitude of the impedance and the power factor during the short-circuit test.

The open-circuit and short-circuit tests were performed on the transformer to determine its equivalent circuit parameters. In the open-circuit test, the primary winding was supplied with full-rated voltage $(230V)$, while the secondary winding was left open. The input current and power were measured, and from these values, the excitation impedance was calculated. The power factor and the admittance of the excitation branch were determined, allowing the values of core-loss resistance (R_c) and magnetizing reactance (X_M) to be calculated.