LABORATORY 4

SINGLE PHASE TRANSFORMERS

OBJECTIVES

1. To determine the transformer turns ratio
2. To perform the no-load and short circuit tests
3. To calculate the transformer's equivalent circuit

INFORMATION

A single-phase transformer will be investigated in this lab. It is a step-up transformer 110/220V with the rated power of 1000VA and rated frequency of 60 Hz.

1. Ideal Transformer

A transformer is a device used to change voltages and currents of AC electric power. In the simplest version it consists of two windings wrapped around a magnetic core; windings are not electrically connected, but they are coupled by the magnetic field, as it shown in Figure 4.1. When one winding is connected to the AC electric power, the electric current is generated. This winding is called the primary winding. The primary current produces the magnetic field and the magnetic flux links the second winding, called the secondary winding. The AC flux through the secondary winding produces an AC voltage, so that if some impedance is connected to the terminals, an AC electric current is supplied.

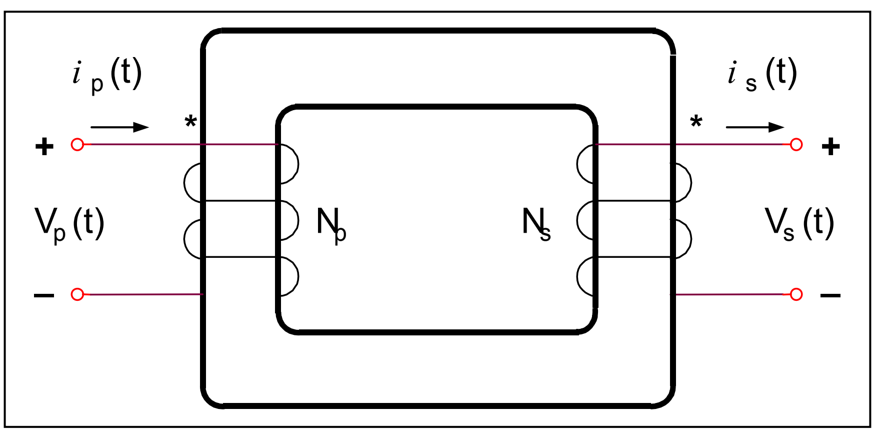

Figure 4.1. Sketch of an ideal transformer.

Figure 4.2 shows the schematic symbols of a transformer.

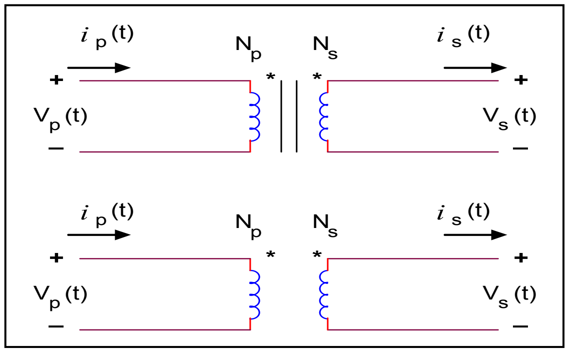

Figure 4.2. Schematic symbols of a transformer.

The simplest model of the transformer is called the ideal transformer and it neglects any power losses and leakage magnetic fluxes. Assuming that the primary winding has N_p turns of wire, and the secondary winding has N_s turns, the relationship between the primary voltage and the secondary voltage is

$$\frac{V_p(t)}{V_s(t)} = \frac{N_p}{N_s} = a \qquad \text{Equation (4.1)}$$

where ***a*** is the turns ratio in the primary and secondary windings

$$a = \frac{N_p}{N_s} \qquad \text{Equation (4.2)}$$

Similarly, for the primary and secondary currents

$$\frac{i_p(t)}{i_s(t)} = \frac{1}{a} \qquad \text{Equation (4.3)}$$

For AC power the same can be also expressed in the phasor notation

$$\frac{V_p}{V_s} = a \quad \text{and} \quad \frac{I_p}{I_s} = \frac{1}{a} \qquad \text{Equation (4.4)}$$

2. Real Transformer

The ideal model of the transformer is sufficient for approximate analysis of the electric circuits only. For full analysis a more complete model is needed and it should include: core losses, winding losses, magnetising current and all leakage magnetic fluxes. It can be shown that the equivalent circuit in Figure 4.3 fully represents all these effects.

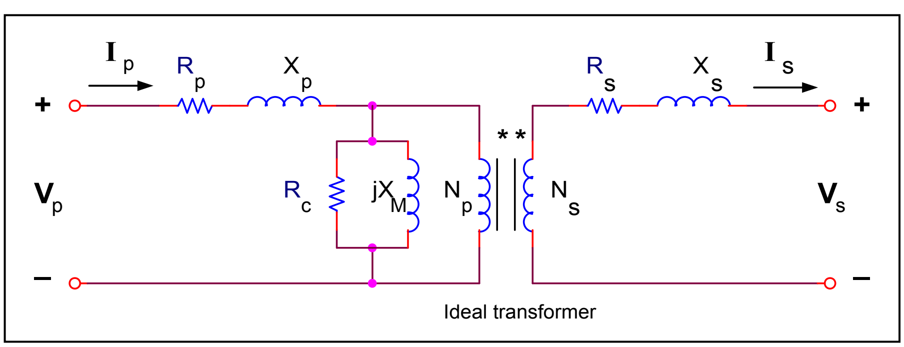

Figure 4.3. The model of a real transformer.

The resistance R_p represents the ohmic resistance of the primary winding and R_s – of the secondary winding. The reactance X_p and X_s model the leakage flux of the primary and secondary windings, respectively. The resistance R_c is responsible for the core losses due to hysteresis and eddy currents, and X_M for the generation of the main flux (magnetising reactance).
All impedances on the secondary side of the transformer can be recalculated for the primary side. This is also know as the referring to the primary side and results in the equivalent circuit shown in Figure 4.4.

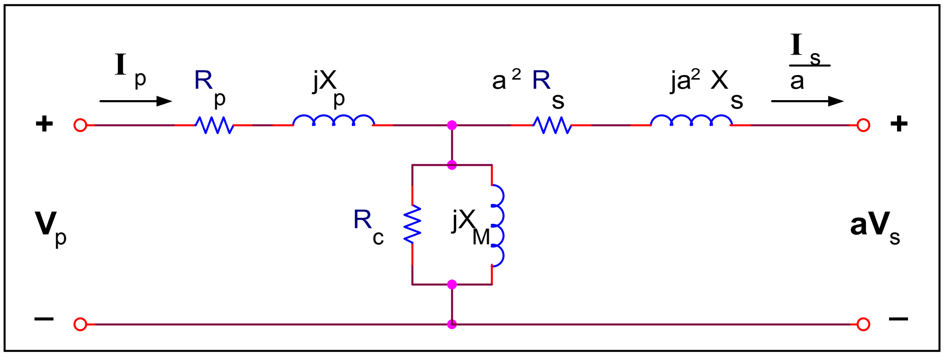

Figure 4.4. The transformer model referred to the primary voltage level

3. Determining Equivalent Circuit

Experimental determination of all elements in the transformer equivalent circuit involves three tests:

- measurement of the primary resistance
- open-circuit test
- short circuit teat

3.1 Measurement of the Primary Resistance

A DC ohmmeter should be connected across the primary terminals and R_p should be recorded.

3.2 Open-Circuit Test

The transformer's secondary should be open-circuited and primary winding supplied with a full rated voltage (Figure 4.5). The input voltage (V_{oc}), primary current (I_{oc}) and power (P_{oc}) are measured.

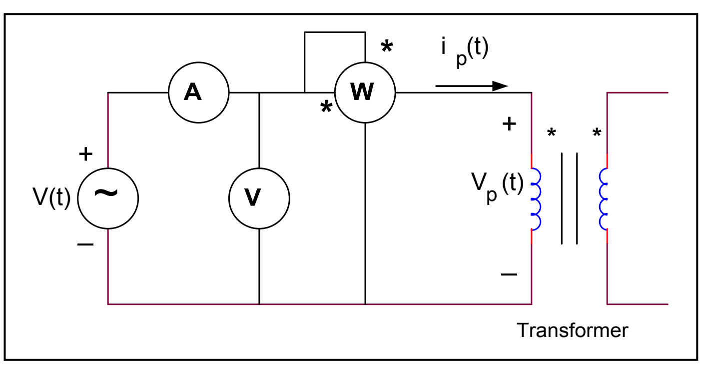

Figure 4.5. Connection for transformer open–circuit test.

This test is sufficient to calculate the core resistance and magnetising reactance, using Equations (4.5) to (4.12). The conductance of the core-loss resistor is given by:

$$G_C = \frac{1}{R_C} \qquad \text{Equation (4.5)}$$

$$B_M = \frac{1}{X_M} \qquad \text{Equation (4.6)}$$

Since these two elements are in parallel, their admittances add and the total excitation admittance is

$$Y_E = G_C - jB_M = \frac{1}{R_C} - j\frac{1}{X_M} \qquad \text{Equation (4.7)}$$

The magnitude of the excitation admittance can be determined by the Equation (4.8)

$$|Y_E| = \frac{I_{OC}}{V_{OC}} \qquad \text{Equation (4.8)}$$

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

$$PF = \cos\varphi = \frac{P_{OC}}{V_{OC} I_{OC}} \qquad \text{Equation (4.9)}$$

and the power factor angle φ is given by Equation (4.10)

$$\varphi = \cos^{-1}\frac{P_{OC}}{V_{OC} I_{OC}} \qquad \text{Equation (4.10)}$$

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

$$Y_E = \frac{I_{OC}}{V_{OC}}\angle -\varphi = \frac{I_{OC}}{V_{OC}}\angle -\cos^{-1} PF = \frac{1}{R_C} + \frac{1}{jX_M} \qquad \text{Equation (4.11)}$$

3.3 Short-Circuit Test

The transformer's secondary terminals are short-circuited and the primary voltage is supplied with the voltage, much reduced comparing with the rated value (Figure 4.6). In practical situation, this voltage is adjusted so that the primary current is approximately rated, and the primary voltage (V_{sc}), primary current (I_{sc}) and power (P_{sc}) are measured.

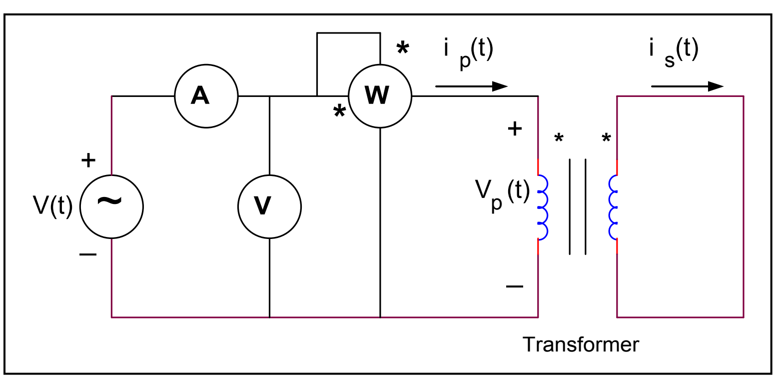

Figure 4.6. Connection for transformer short–circuit test.

The following Equations (4.12) to (4.16) can be used to calculate elements in the primary and secondary branches.
The magnitude of the series impedances referred to the primary side of the transformer is

$$Z_{SC} = \frac{V_{SC}}{I_{SC}} \qquad \text{Equation (4.12)}$$

The short circuit power factor (PF) is given by:

$$PF = \cos\varphi = \frac{P_{SC}}{V_{SC} I_{SC}} \qquad \text{Equation (4.13)}$$

and the power factor angle φ is given by Equation (4.14)

$$\varphi = \cos^{-1} \frac{P_{SC}}{V_{SC} I_{SC}} \qquad \text{Equation (4.14)}$$

Therefore,

$$Z_{SC} = \frac{V_{SC}\angle 0^{\circ}}{I_{SC}\angle -\varphi^{\circ}} = \frac{V_{SC}}{I_{SC}}\angle \varphi^{\circ} \qquad \text{Equation (4.15)}$$

The series impedance Z_{SC} is equal to

$$Z_{SC} = R_{eq} + jX_{eq} \qquad \text{Equation (4.16)}$$

EQUIPMENT

1. Single-phase transformer
2. Variable AC source
3. Two Digital multimeters
4. AC wattmeter

1. Variable AC source

The lab's variable AC source shown in Figure 4.7 is a complex device, which is designed to provide safety conditions of your experiments. It consists of single-phase transformer, variac and lamp bulb connected in series with the output.

Figure 4.7. Variable AC source

2. AC Wattmeter

Electric power is measured by means of a wattmeter. This instrument is of the electrodynamic type. It consists of a pair of fixed coils, known as current coils, and a movable coil known as the potential coil. A simplified electrodynamics wattmeter circuit is shown in Figure 4.8.

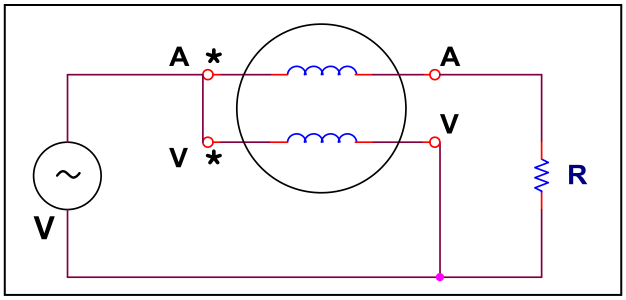

Figure 4.8. A simplified electrodynamic wattmeter circuit.

The current coil (stationary coil) of the wattmeter is connected **in series** with the circuit (load), and the potential coil (movable coil) is connected **in parallel** with the load. When line current flows through the current coil of a wattmeter, a field is set up around the coil. The strength of this field is proportional to the line current and in phase with it. The actuating force of a wattmeter comes from the field of its current coil and the field of its potential coil. The force acting on the movable coil at any instant (tending to turn it) is proportional to the instantaneous values of line current and voltage. That's why it is very important to perform a proper connection of the beginnings and the ends of each coil. The beginnings of the both current and voltage coils of the lab wattmeter have red connectors marked with * signs as it is shown in Figure 4.9

Figure 4.9. Lab AC wattmeter

PRE-LABORATORY PREPARATION

Read the information section of the lab manual and lab instruments description. Be ready to answer questions related to the transformer's theory and practical measurements.

PROCEDURE

1. Rated Quantities

From the transformer nameplate, note the rated values of S_1, V_1, and V_2. Calculate the rated maximum currents for the ammeters on the primary and secondary sides-do not exceed these values.

2. Resistance Measurements

Using an ohmmeter, measure the resistance of the transformer primary (R_1) and secondary (R_2) windings.

3. Turns Ratio

The turns ratio of a transformer is equal to the ratio of primary and secondary voltages at no-load

$$a = \frac{N_P}{N_S} = \frac{V_{P0}}{V_{S0}} \qquad \text{Equation (4.15)}$$

where: V_{P0} – primary voltage
V_{S0} – secondary voltage

In order to determine the turns ratio, connect the circuit as shown in Figure 4.10. The transformer is supplied with a variable voltage and both primary and secondary voltages are measured and recorded.
Do not turn the power on before your circuit has been checked by your TA!
When the layout has been completed, have your TA to check your circuit connections and get his/her signature in your log book.

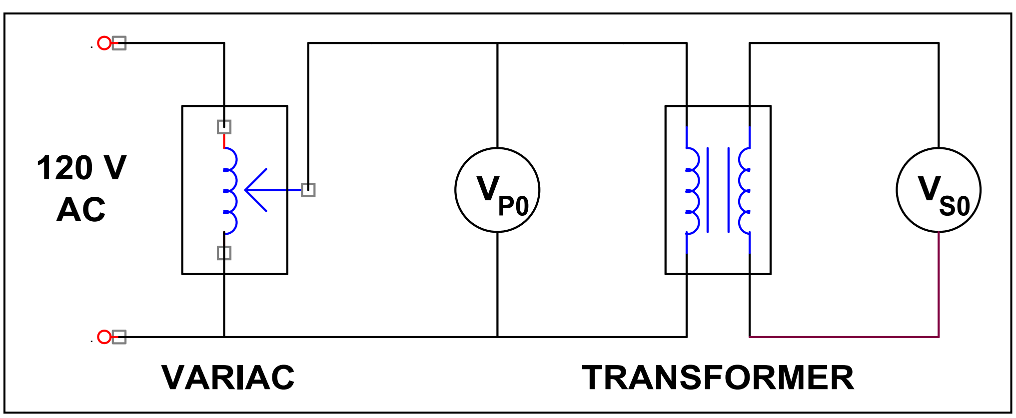

Figure 4.10. Transformer ratio measurements

Starting from V_{P0}=20V turn the variac knob and slowly increase the input voltage.

Measurements and calculations of the turns ratio should be done for V_{P0} = 20, 40, 60, 80, 100 and 120 V. Complete all the data in Table 4.1.

V_{P0} (V)	V_{S0} (V)	Turns Ratio
20		
40		
60		
80		
100		
120		
	Average Turns Ratio	

Table 4.1. Transformer turns ratio measurements and calculations

4. Open Circuit Test

4.1. Connect the apparatus as shown in Figure 4.11. Apply the rated input voltage to the primary winding and measure input voltage, current, power, and output voltage.

Do not turn the power on before your circuit has been checked by your TA!
When the layout has been completed, have your TA to check your circuit connections and get his/her signature in your log book.

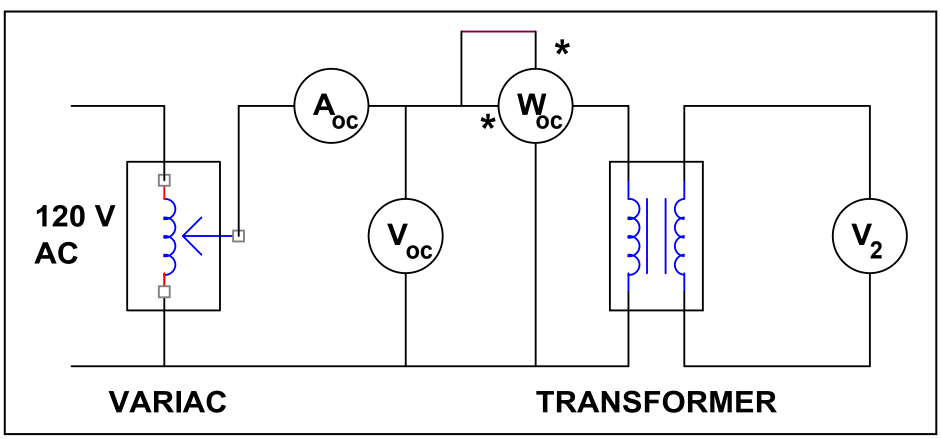

Figure 4.11. Transformer open circuit test measurements

4.2. Starting from V_{oc}=20V turn the variac knob and slowly increase the input voltage. Complete all the data in Table 4.2.
4.3. Determine the parameters of the magnetising branch using Equations (4.5) to (4.11).

V_{oc} (V)	I_{oc} (A)	P_{oc} (W)	V_{20} (V)	$\lvert Y_E \rvert$ 1/Ω	cos φ	R_{eq} Ω	X_{eq} Ω
20							
40							
60							
80							
100							
120							

Table 4.2. Transformer open circuit test measurements and calculations.

5. Short-Circuit Test

5.1. Short-circuit the secondary winding through an ammeter as shown in Figure 4.12.
Do not turn the power on before your circuit has been checked by your TA!
When the layout has been completed, have your TA to check your circuit connections and get his/her signature in your logbook.

5.2. Slowly and gradually increase the applied voltage and carefully watch the primary and secondary currents. Measurements and calculations ratio should be done for short circuit current values specified in Table 4.3.
5.3. Calculate the short circuit impedance as measured from the primary using Equations (4.12) to (4.16). Show your calculations in your lab report.
Complete all the measurements and calculations in Table 4.3.

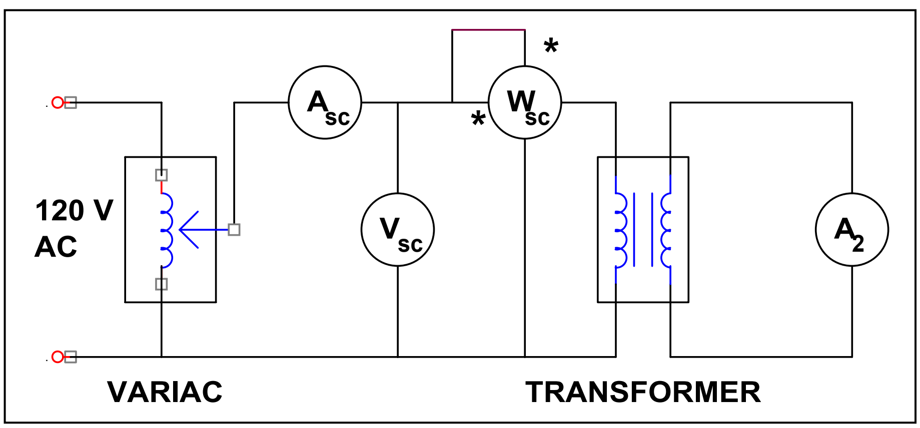

Figure 4.12. Transformer short circuit test measurements

I_{sc} (A)	V_{sc} (V)	P_{SC} (W)	I_{20} (A)	$\lvert Z_{SC} \rvert$ Ω	cos φ	R_C Ω	X_M Ω
0.3							
0.4							
0.5							
0.6							
0.7							
0.8							
0.9							

Table 4.3. Transformer short circuit test measurements and calculations.

REPORT

Record in a lab book circuit diagrams and results for all experiments
Calculate average turns ratio
Calculate parameters of the equivalent circuit

Your Lab report is due one week later. Please submit it to your TA in the beginning of your next lab session.

<u>Note</u>: **You must copy/print the Signature and Marking Sheet from your manual before coming to the lab session.**

SIGNATURE AND MARKING SHEET – LAB 4

To be completed by TA during your lab session

Student Name:____________________ **TA Name:___________________**

Student # : _____________________

Check boxes			**Task**	**Max. Marks**	**Granted Marks**	**TA Signature**
			Pre-lab completed	0		
			Turns Ratio test completed	6		
			Open Circuit Test completed	7		
			Short-Circuit Test completed	7		
			Overall Report Preparation	80		
			TOTAL MARKS	**100**		