EXPERIMENT 1

TITLE: SINGLE PHASE TRANSFORMERS - TRANSFORMER REGULATION

OBJECTIVES

1) To determine the voltage regulation of a transformer with varying loads and to discuss capacitive and inductive loading on transformer regulation.

2) To produce load regulation curves based on voltage and current measurements.

EQUIPMENTS

EMS Workstation Model 8110, Single Phase Transformer Model 8341, Resistive Load Model 8311, Inductive Load Model 8321, Capacitive Load Model 8331, Power Supply Model 8821 and Data Acquisition Interface Model 9062.

INTRODUCTION

The load on a large power transformer in a sub-station will vary from a small value in the early hours of the morning to a very high value during the heavy peaks of maximum industrial and commercial activity. The transformer secondary voltage will vary somewhat with the load, and because motors, incandescent lamps and heating devices are all quite sensitive to voltage changes, transformer regulation is of considerable importance. The secondary voltage also depends upon whether the power factor of the load is leading, lagging or unity. Therefore, it should be known how the transformer will behave (its voltage regulation) when connected to a capacitive, an inductive or a resistive load. Transformer voltage regulation in percent determined with the following formula:

\[
\text{Voltage Regulation} \% = 100 \times \frac{E_{NL} - E_{FL}}{E_{FL}}
\]

where \( E_{NL} \) is the no-load secondary voltage and \( E_{FL} \) is the full-load secondary voltage.

The result (a percentage value) obtained gives an indication of transformer behaviour under load. The smaller the voltage regulation percentage, the smaller the secondary voltage variation with the load and the better the voltage regulation. Note that \( E_{NL} \) is measured with the secondary winding open while \( E_{FL} \) is measured when nominal current flows in the secondary winding.

Several factors affect a transformer’s operation. The resistance and inductive reactance of its winding cause internal voltage drops that vary with the amount of current flowing in the windings. If the secondary is lightly loaded, current through the winding resistance and reactance is small and the internal voltage drops are
not significant. As the load increases, current and internal voltage drops increase. If a transformer were perfectly ideal, its windings would have neither resistance nor inductive reactance to cause the voltage drops. Such a transformer would have perfect regulation under all load conditions and the secondary voltage would remain absolutely constant. But practical transformer coils are made of real wire and thereby have resistance and inductive reactance. Therefore the primary and secondary windings have an overall resistance $R$ and overall reactance $X$. The simplified equivalent circuit of a practical transformer with a 1:1 turns ratio can be approximated by the circuit shown in Figure 1.1. The actual transformer terminals are $P_1$, $P_2$ on the primary side and $S_1$, $S_2$ on the secondary side.

![Figure 1.1 Simplified Equivalent Circuit of a Practical Transformer](image)

In this equivalent circuit, the practical transformer is shown to be made up of an ideal transformer in series with impedance consisting of $R$ and $X$ that represents the imperfections of the transformer. When a load ($Z$) is connected to the secondary winding terminals (terminals $S_1$ and $S_2$), a series ac circuit consisting of the secondary winding of the ideal transformer $R$, $X$, and $Z$ is obtained. Analysis of this series ac circuit shows that when the load is either resistive or inductive, the load voltage decreases continuously as the load increases (as the secondary current increases). Furthermore, when the load is capacitive, the load voltage increases to a maximum as the load increases from zero (no load condition) and then the load voltage decreases as the load continues to increase.

**PROCEDURE**

**CAUTION**

High voltages are present in this laboratory exercise! Do not make or modify any banana jack connections with the power on unless otherwise specified!

1. Install the Power Supply, Data Acquisition Interface, Single-Phase Transformer, Resistive Load, Capacitive Load and Inductive Load modules in the EMS Workstation.

2. Make sure that the main switch of the Power Supply is set to the O (OFF) position, and the voltage control knob is turned fully counter clockwise. Set the voltmeter select switch to the 4-N position.
3. Ensure that the DAI LOW POWER INPUT is connected to the main Power Supply, set the 24V-AC power switch to the I (ON) position.

4. Display the Metering application.

5. Set up the transformer loading circuit shown in Figure 1.2. Ensure that all switches on the Resistive, Capacitive and Inductive Load modules are open and connect E1, E2, I1, I2 as shown in the figure. Different load values will be used to examine how the secondary (load) voltage changes as transformer loading changes.

6. Turn on the main Power Supply and adjust the main voltage control to obtain the value of Es given in Figure 1.2. With no load on the transformer (all switches open on the load module), click the Record Data button to enter the measurements for E_PRI, I_PRI, E_SEC and I_SEC in the Data Table.

7. Adjust the switches on the Resistive Load module to successively obtain the resistance values given in Table 1.1. For each resistance value, record the measurements as in step 6. When all data values have been recorded, rotate the voltage control fully counter clockwise and turn off the Power Supply.

8. Display the Graph screen, select E2 as the Y-axis parameter and I2 as the X-axis parameter. Click the Line Graph button to observe the curve of secondary voltage versus current. What happens to the secondary voltage as the resistive load increases, i.e. load resistance decreases?
9. Calculate the voltage regulation using the no-load \((R=\infty)\) and full-load \((R=\text{minimum value})\) output voltages.

\[
100 \left( \frac{E_{NL} - E_{FL}}{E_{FL}} \right) = \text{__________}%
\]

10. Use the Clear All button in the Data Table window to clear the data and then replace the Resistive Load module in the circuit of Figure 1.2 with the Inductive Load module.

11. Turn on the main Power Supply and adjust the main voltage control to obtain the value of \(E_s\) given in Figure 1.2. With no load on the transformer (all switches open on the load module), click the Record Data button to enter the measurements for \(E_{PRI}, I_{PRI}, E_{SEC}\) and \(I_{SEC}\) in the Data Table.

12. Adjust the switches on the Inductive Load module to successively obtain the reactance values given in Table 1.1. For each reactance value, record the voltage control fully counter clockwise and turn off the Power Supply.

13. Display the Graph screen, select \(E_2\) as the Y-axis parameter and \(I_2\) as the X-axis parameter. Click the Line Graph button to observe the curve of secondary voltage versus current. How does the secondary voltage vary as the inductive load increases?

14. Use the Clear All button in the Data Table window to clear the data and then replace the Inductive Load module in the circuit of Figure 1.2 with the Capacitive Load module.

15. Turn on the main Power Supply and adjust the main voltage control to obtain the value of \(E_s\) given in Figure 1.2. With no load on the transformer (all switches open on the load module), click the Record Data button to enter the measurements for \(E_{PRI}, I_{PRI}, E_{SEC}\) and \(I_{SEC}\) in the Data Table.

16. Adjust the switches on the Capacitive Load module to successively obtain the reactance values given in Table 1.1. For each reactance value, record the voltage control fully counter clockwise and turn off the Power Supply.

17. Display the Graph screen, select \(E_2\) as the Y-axis parameter and \(I_2\) as the X-axis parameter. Click the Line Graph button to observe the curve of secondary voltage versus current. How does the secondary voltage vary as the capacitive load increases?

18. What differences do you observe between the three load curves?

19. Ensure that the Power Supply is turned off, the voltage control is fully counter clockwise and remove all leads and cables.
Name: _________________________ Matrix No.: _____________ Date: __________

CALCULATION

9. \[
100 \left( \frac{E_{NL} - E_{FL}}{E_{FL}} \right) =
\]

Instructor Approval: _______________________________ Date: __________
RESULTS

7.

<table>
<thead>
<tr>
<th>Primary Voltage (E1)</th>
<th>Secondary Voltage (E2)</th>
<th>Primary Current (I1)</th>
<th>Secondary Current (I2)</th>
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<tbody>
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<td>V</td>
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Table 1-1 Transformer with a variable resistive load

8.

Figure 1-1 Secondary voltage versus current (resistive load)
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<tr>
<th>Primary Voltage (E1)</th>
<th>Secondary Voltage (E2)</th>
<th>Primary Current (I1)</th>
<th>Secondary Current (I2)</th>
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Table 1-2 Transformer with a variable inductive load

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Figure 1-2 Secondary voltage versus current (inductive load)
Name: _________________________ Matrix No.: _____________ Date: __________

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<thead>
<tr>
<th>Primary Voltage (E1)</th>
<th>Secondary Voltage (E2)</th>
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<th>Secondary Current (I2)</th>
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Table 1-3 Transformer with a variable capacitive load

17.

![Secondary Voltage versus Current (Capacitive Load)](image)

Figure 1-3 Secondary voltage versus current (capacitive load)

18. ___________________________________________________________________
    ___________________________________________________________________
    ___________________________________________________________________

Instructor Approval: ___________________________ Date: __________