

EXPERIMENT Transformer Waveforms

Steady-State Testing and Performance of Single-Phase Transformers

Waveforms

OBJECTIVE

The voltage regulation and efficiency of a distribution system are affected by the electrical and magnetic characteristics of the transformers operating in the network. The design of such a distribution system must consider these effects. The experiment studies the excitation current, magnetization current, and core-loss current. And the effect of load current and load power factor on the transformer currents.

The transformer model used for this experiment is the equivalent circuit from the Transformer Model experiment, except we are using only one 120V primary winding and only one 120V secondary winding.

REFERENCES

1. "Electric Machinery", Fourth Edition, Fitzgerald, Kinglsey, and Umans, McGraw-Hill Book Company, 1983, Chapter 1.
2. "Electromagnetic and Electromechanical Machines", Matsch, Leander W., Intext Educational Publishers, 1972.
3. "Electromechanical Devices for Energy Conversion and Control Systems", Del Toro, Vincent, Prentice-Hall, Inc., 1968.

BACKGROUND INFORMATION

The basic theory of transformer operation is adequately explained in Reference 1. For our purposes here we will concentrate on the test methods and the experimental set-up of Figure 5

Figure 1 shows the traditionally accepted electrical equivalent circuit for a power transformer in steady-state. This particular equivalent circuit's parameters are referred to side 1. All relevant impedances, voltages, and currents are shown in the figure.

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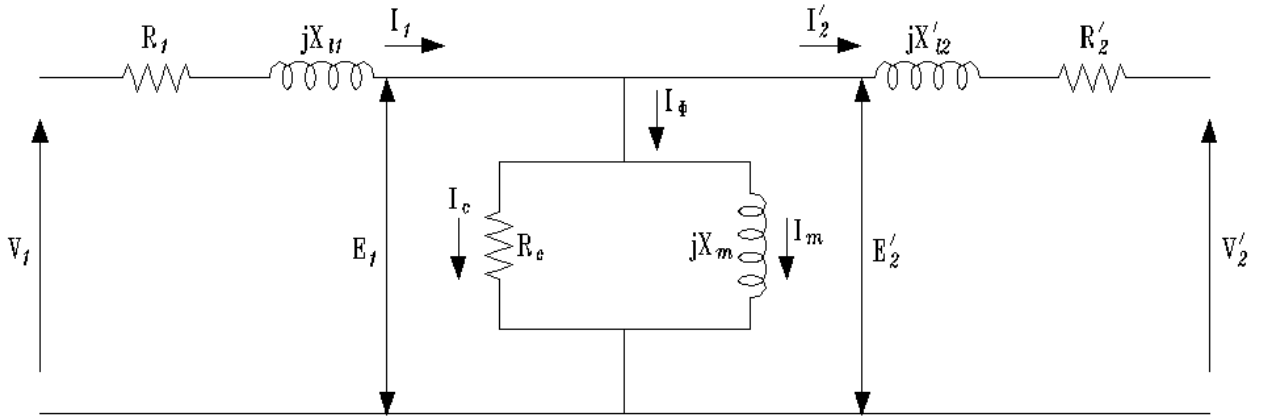


Figure 1: Steady-state equivalent circuit for power transformer.

It is important to note that for a typical power transformer the ratio of the parallel combination of the common leg impedances to the total impedance of either winding will exceed 200. Algebraically, this can be described as

$$\frac{|R_c // X_m|}{|R_1 + jX_{l1}|} > 200$$

(2.1)

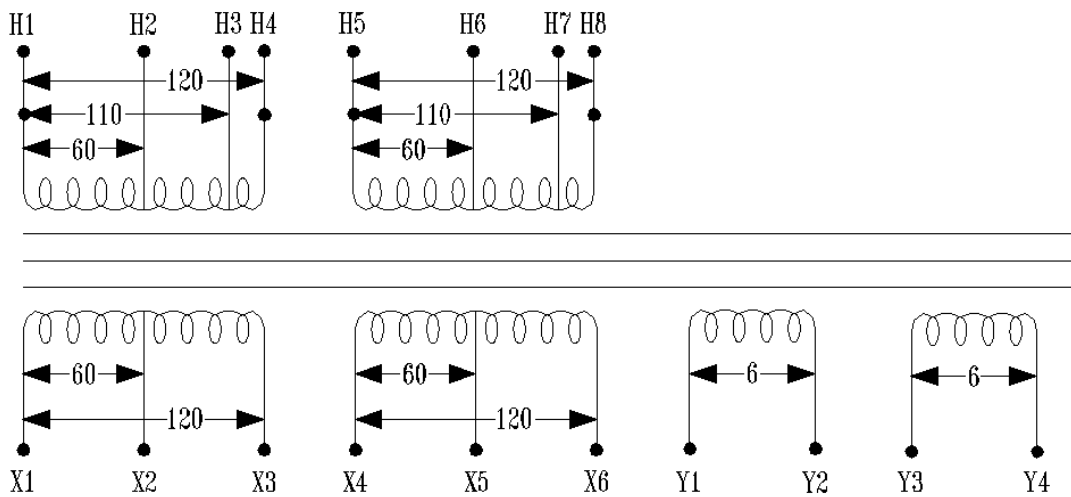


Figure 2: Winding configuration of laboratory transformers.

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We will now focus our attention on designing a system for observing the waveshapes and interactions of the various currents and fluxes in the transformer. Figure 2 shows the configuration of the transformers used in the laboratory. Using Figure 1 as an equivalent circuit for the transformer shown in Figure 2, we can designate side 1 (primary) as any of the windings labeled with “H” terminals and side 2 (secondary) as any of the windings labeled with “X” or “Y” terminals. An important point is that the induced voltages E_1 and E_2' are exactly in phase. Figure 3 shows the phasor diagram of the voltages and currents of the transformer. Note that current I_c is in phase with E_1 and that current I_m is phase-shifted by 90° . From transformer theory, we recall that current I_c represents power losses in the transformer core, and that current I_m represents the current required to produce the magnetic flux.

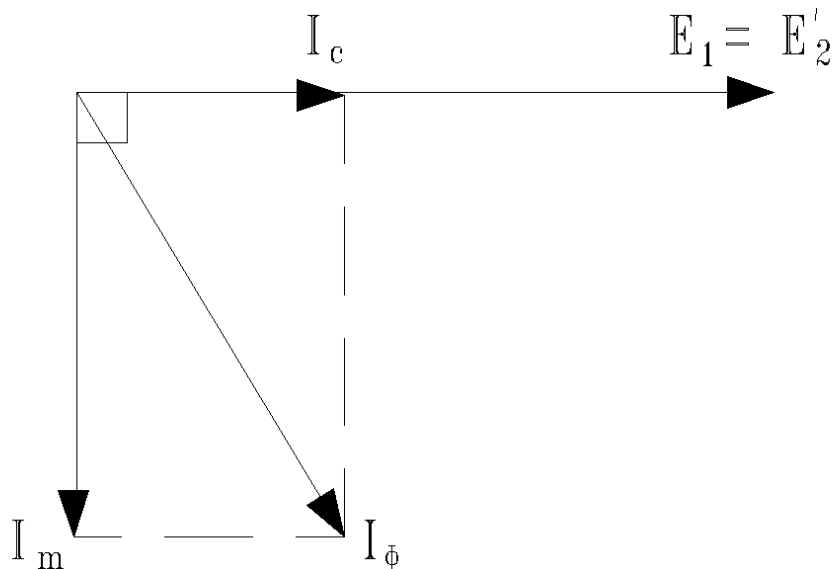


Figure 3: Phasor diagram of voltages and currents of transformer.

The input current I_2' can be directly displayed on an oscilloscope by measuring the voltage across a 1Ω resistor placed in series with the current. Note that the measurement is a voltage signal that is dependent upon the current. Referring to Figure 5, resistor R_1 is used to measure the current I_1 . Similarly, resistor R_3 in Figure 5 is used to measure current I_2' . It is not so easy to measure the currents I_c and I_m , but we can derive a voltage signal that is in phase with I_c . The no-load voltage across terminals Y_1 and Y_2 is

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$$V_{Y1-Y2} = N_Y \frac{d\phi}{dt} \quad (2.9)$$

which corresponds to E_2' from Figures 1 and 4. Thus, we have a voltage signal that is in phase with I_C . The resistor R_2 in Figure 7 provides an adjustable signal that is in phase with I_C , yet the resistor is large enough to prevent excessive loading of the circuit. The requirement for an adjustable signal becomes clear as the experiment is performed.

We now have access to signals representing three currents. It is seen from Figure 1 that

$$I_1 = I_C + I_m + I_2' \quad (2.10)$$

and, clearly

$$I_m = I_1 - I_C - I_2' \quad (2.11)$$

Thus, we have signals for the three terms on the right side of Eq. 2.11, which means we should be able to measure the unknown by some differential means. Figure 4 shows a voltage source equivalent for the system of Figure 5 and clearly indicates a synthesis of Eq. 2.11. Therefore, the voltage signal that remains after the sources interact is representative of I_m .

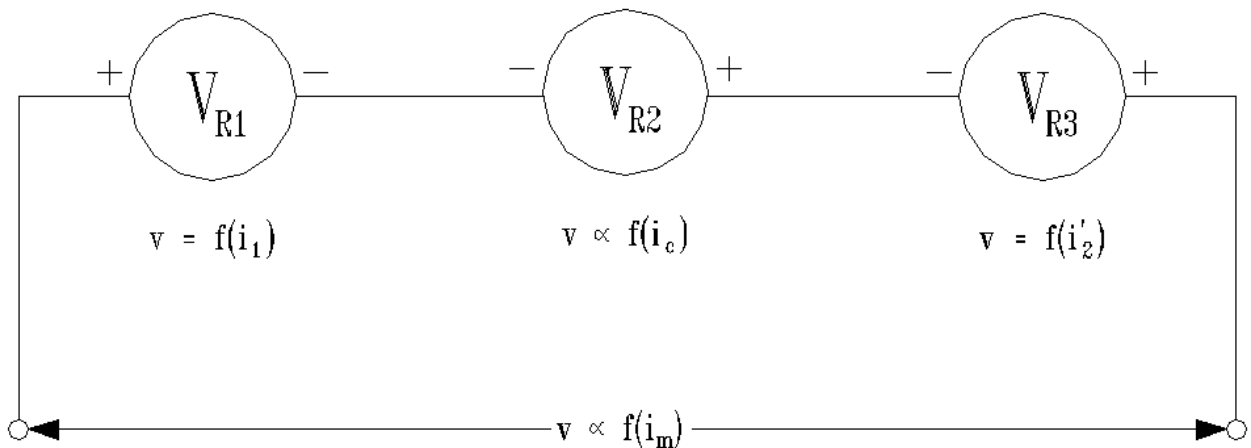


Figure 4: Voltage source equivalent of Eq. 2.11.

NOTE: The voltage signals used above are adequate for waveshape analysis and phase relationships. They are not accurate for magnitude comparisons and should not be used for this purpose.

SUGGESTED PROCEDURE

The transformers used for this experiment are rated 120V-120V, 0.6kVA. There are three of them on each set of wall shelves we need 2 transformers. One is used for isolation; the other is the transformer under test. The set of windings connected to the source side of the transformer are the primary windings, and those connected to the load are the secondary windings. To achieve a 600 volt-ampere rating, these two sets of 120V main primary and secondary windings must be in parallel. We will use only one set of 120V primary windings so it will a 300 volt-ampere rating. The other two “Y” windings are information (instrumentation) windings and are **not designed to support a load**.

Figure 1 defines the currents that are referred to throughout the experiment.

1. Figure 5 shows the connections that are used to view i_1 , i_c , i_m , and ϕ_m . The first transformer is identical to the transformer being tested and is used to help prevent ground loops between the source and the instrumentation.

Channel 1 displays current, Channel 2 displays Flux or Voltage (Part 3). Set the fluke current meters manual range to amps not mA with the up and down arrow key.

The oscilloscope is connected so that many different signals can be displayed. The undesired signals are eliminated by pressing the ground button next to their scope connection. Referring to Figure 5, pressing the ground button on the upper (positive) input of (channel 1) causes the i_1 **signal is displayed**. Releasing both ground buttons of the diff amp causes the i_m **signal to be displayed** on scope (channel 1). Obviously, pressing the bottom (Negative) ground button causes the sum of the $-i_2$ **and** $-i_c$ **signals to be displayed**.

For initial tests, the load is left disconnected and R_3 is set to zero. Slowly increase the voltage from the Single-Phase AC Source until 120 V AC is registered on the voltmeter

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(V1). The signals across R_1 (1Ω) and R_2 are proportional to i_1 and i_c , respectively. From Figure 1, it is seen that $i_m = i_1 - i_c - i_2$. Adjust R_2 to eliminate the i_c component from the display. Perhaps the easiest way to minimize i_c is to display ϕ_m (channel 2) versus i_m on (channel 1) the scope and adjust R_2 until the hysteresis goes away.

When R_2 is properly adjusted, i_m is observed when both differential amplifier inputs for channel 2 are used, i_c when only the upper input is used, and the total i_1 when only the lower input is used.

Grounding push buttons of Diff Amp	Signal displayed
Both inputs ungrounded	i_m
Positive (upper) input grounded	i_1
Negative (lower) input grounded	$-i_c - i_2$

Differential amplifier Channel 1 of the scope

At the transformer's rated voltage, **record scope waveforms** i_1 , i_c , i_m , and ϕ_m versus time (4 waveforms), the hysteresis loop(ϕ_m versus i_1 ,) (1 XY plot) and the AC saturation curve (ϕ_m versus i_m)(XY plot) . Note that i_m is very symmetrical when correct cancellation of i_c is obtained. Now, vary the primary voltage from zero to 120 V and describe in the report the changes in each i_1 , i_c , i_m , ϕ_m and saturation.

NOTE: The signal being observed as i_c , is voltage from the 6V winding, but this signal has the same waveform as i_c . Also, the ϕ_m signal is an integrated voltage signal having the waveform of ϕ_m .

2. Add a secondary resistive load by connecting the circuit of Figure 6 to the transformer load connection of Figure 5 and set input voltage to 120 V AC and maintain it **constant**. Adjust R_3 to remove the load current from the oscilloscope display. R_2 may

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also need to be readjusted slightly. Observe the AC saturation curve (ϕ_m channel 2 versus i_m channel 1) as the load current is varied between 0, 1.0, 1.5, 2.0 and 2.5 AMPS. Describe in the report the change in the peak-to-peak magnitude of flux as the load resistance is changed.

For different primary voltages $120V_{RMS}$, $90V_{RMS}$, and $60V_{RMS}$, record the changes in the waveforms and curves of i_1 , i_c , i_m , ϕ_m and saturation as the load is varied. From this information, comment on the transformer's performance at different voltages.

3. Bypass the integrator by reconnecting the oscilloscope leads directly to terminals Y_3 and Y_4 . Turn the calibration knob of the corresponding differential amplifier counter-clockwise until the differential amplifier is not saturated. This will prevent the amplifier from running over the maximum allowed range. Observe the relative magnitudes and phase angles of the terminal voltage (channel 2) and i_1 (channel 1) as the load resistance is varied. Magnitudes can be obtained directly from the meters on the panel. Maintain the source voltage at $120V_{L-N}$. To obtain phase angle between signals displayed, use the cursors of the scope with to find the delay time, measure between the peaks and calculate the phase angle. Determine the period of the voltage waveform because this signal is harmonic free. **Phase V_T to $I_1 = (\text{Time delay} / \text{period}) * 360^\circ$**

Without added Capacitor

Load current I_2	Voltage V_1	Current I_1	Phase V_T to I_1	PF $\text{Cos}(\Theta)$
0.0A	$120V_{L-N}$			
1.0A	$120V_{L-N}$			
2.0A	$120V_{L-N}$			
2.5A	$120V_{L-N}$			

Connect the large capacitor found on the shelf in parallel with the load resistor. Again observe the relative magnitudes and phase angles at the transformer input. The lab presently does not contain the proper inductor to try an RL load type.

With added Capacitor

Load current I_2	Voltage V_1	Current I_1	Phase V_1 to I_1	PF $\text{Cos}(\Theta)$
0.0A	120V _{L-N}			
1.0A	120V _{L-N}			
2.0A	120V _{L-N}			
2.5A	120V _{L-N}			

REPORT: things to keep in mind as you do the experiment.

1. The report must be an individual student's work (not a group's). The report must be hand written.
2. Describe the waveforms observed during Part 2 of the experiment. Pay particular attention to frequency, phase, and any distortion. Explain the causes of any frequency differences, phase changes, and distortion. Changes as the primary voltage is varied.
3. Note and explain any waveform variations caused by different loads part 2. Explain the behavior of the core flux for various loads. Changes as the primary voltage is varied.
 In order to reduce the core-loss current, what would you change in the design of the transformer? Do not change voltage or power rating of the device.
4. Explain the relationship of input voltage, current and primary side power factor as the load power factor changes, in terms of the energy relationships. Identify and comment on power factor in relationship to load current, core losses and magnetizing current.

Figure 5

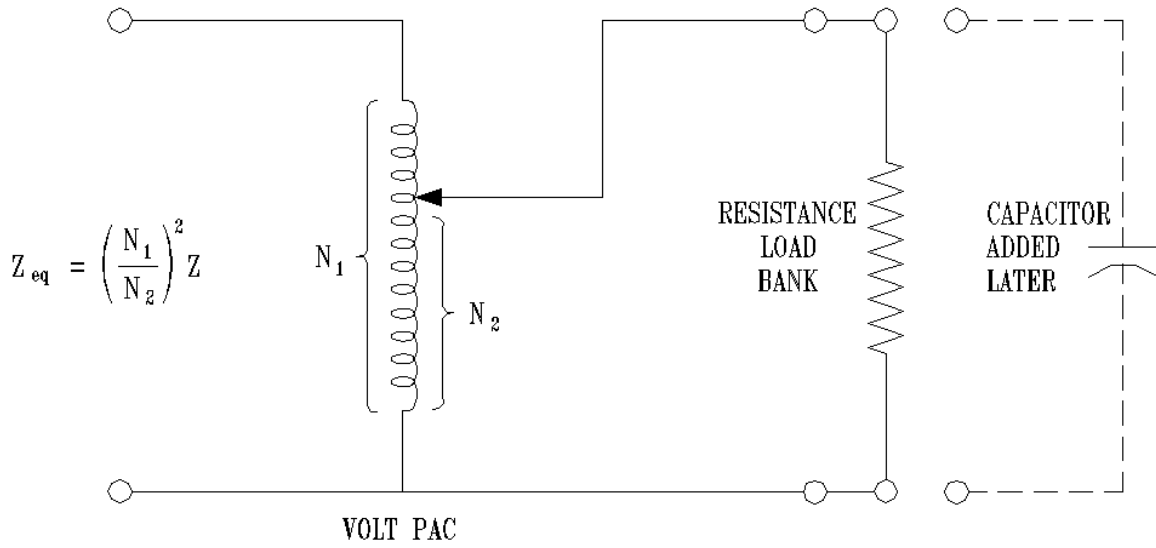


Figure 6