EE 330/330L Energy Systems (Spring 2012)
Laboratory 2 Single-Phase Transformer

Introduction/Background

In this laboratory, you will determine the equivalent circuit parameters for a small single-phase transformer. In addition, the efficiency and voltage regulation of a single-phase transformer will be examined with a load attached to the transformer.

Experiment 1- Low side (secondary) transformer tests

1) Record the nameplate data for the transformer being tested. Based on the nameplate data, determine and record the rated current $I_{rated,120}$ for the side of the transformer rated for 120 V_{rms}.
2) Configure the transformer in a 240/120 (primary/secondary) configuration by connecting the high voltage coils (H2-H1 & H4-H3) in series, i.e., tie jack H2 to H3, and the low voltage coils (X2-X1 & X4-X3) in parallel, i.e., tie jack X1 to X3 and jack X2 to X4, as shown in Figure 1.

Top View

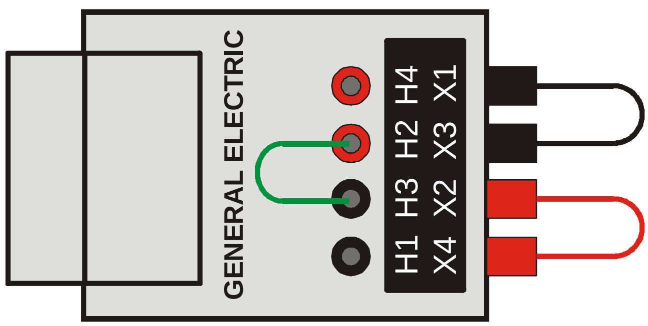

Figure 1 Transformer connections for 240/120 configuration.

3) Using an ohmmeter (multimeter), measure and record the dc wire resistance $R_{w,120}$ of the low voltage coils (i.e., the resistance between jacks X1/X3 and X2/X4) and the dc wire resistance $R_{w,240}$ of the high voltage coils (i.e., the resistance between jacks H1 and H4).
4) Perform the rated-voltage open circuit test on the low (120 V_{rms}) side of the transformer. A block diagram of the necessary connections, including wattmeter, voltmeters, and ammeter, is shown in Figure 2. Do **NOT** plug in the three-phase power cord until all connections have been made, wattmeter has been zeroed, variac set to zero, and three-phase breaker set to 'off'. After plugging in the three-phase power cord and setting the three-phase breaker to 'on', slowly raise the applied voltage to ~120 V_{rms} using the variac. Then, measure and record $V_{oc,120}$, $I_{oc,120}$, and $P_{oc,120}$. In addition, measure and record $V_{oc,high}$. Using the variac, reduce the applied voltage to zero, set the three-phase breaker to 'off', and unplug the power cord. Do NOT disconnect any wires.
5) Next, the rated-current short circuit test will be performed on the low (120 V_{rms}) side of the transformer. Replace the voltmeter connected across H1 and H4 with a short circuit (i.e., a jumper wire). The remaining connections remain the same. After verifying that both the wattmeter and variac are zeroed, plug in the three-phase power cord and set the three-phase breaker to 'on'. Then, **slowly** raise the applied voltage using the variac until the ammeter reads ~$I_{rated,120}$. Then, measure and record $V_{sc,120}$, $I_{sc,120}$, and $P_{sc,120}$. Using the variac, reduce the applied voltage to zero, set the three-phase breaker to 'off', unplug the power cord, and remove the short circuit (jumper wire).

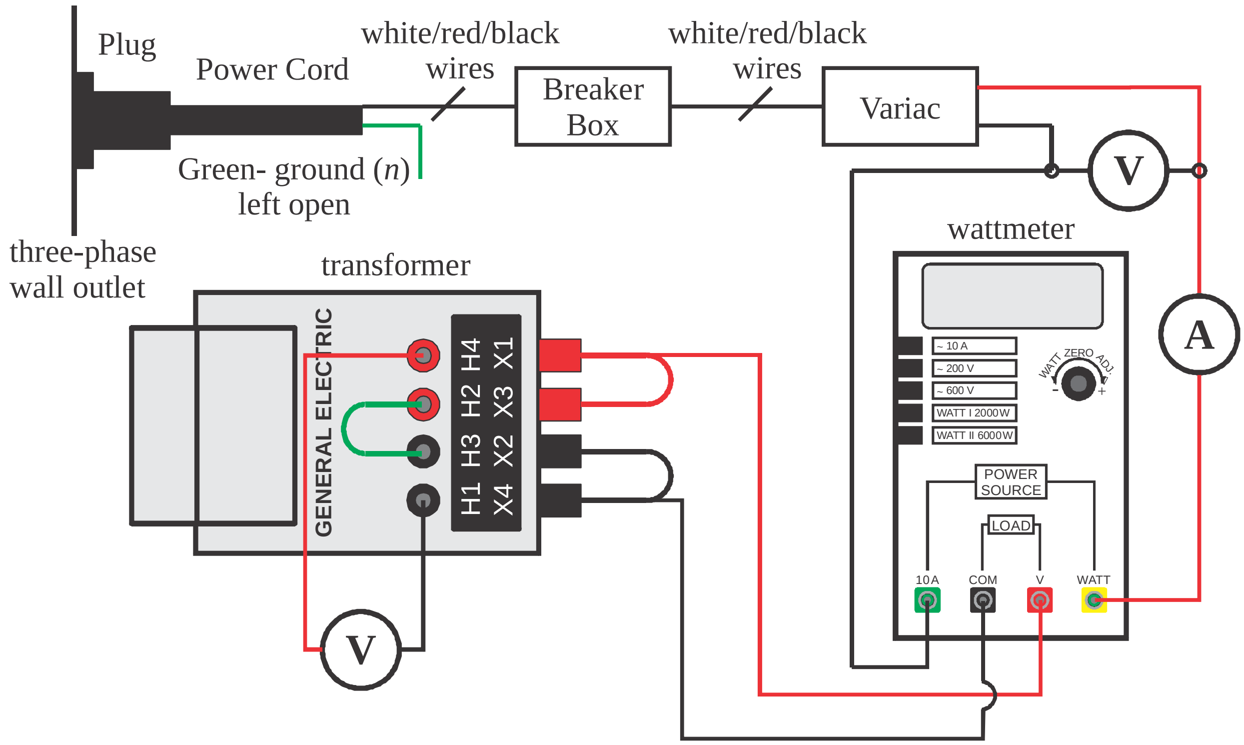

Figure 2 Connections for rated-voltage open circuit test on the low (120 V_{rms}) side of the transformer.

<u>Experiment 2- High side (primary) transformer tests</u>

1) Based on the nameplate data, determine and record the rated current $I_{rated,240}$ for the side of the transformer rated for 240 V_{rms}.

2) As the line-to-line three-phase wall voltages are ~208 V_{rms}, performing the rated-voltage open circuit test on the high (240 V_{rms}) side of the transformer will require some circuit modifications. To achieve the rated voltage, another transformer will be used to step-up the voltage coming from the variac. A block diagram of the necessary connections, including wattmeter, voltmeters, and ammeter, is shown in Fig. 3. Do **NOT** plug in the power cord until all connections have been made, wattmeter has been zeroed, variac set to zero, and three-phase breaker set to 'off'. After plugging in the three-phase power cord and setting the three-phase breaker to 'on', slowly raise the applied voltage using the variac to ~240 V_{rms}. Then, measure and record $V_{oc,240}$, $I_{oc,240}$, and $P_{oc,240}$. In addition, measure and record $V_{oc,low}$. Using the variac, reduce the applied voltage to zero, set the three-phase breaker to 'off', and unplug the power cord. Do NOT disconnect any wires.

3) Next, the rated-current short circuit test will be performed on the high (240 V_{rms}) side of the transformer. Replace the voltmeter connected across X1 and X4 with a short circuit (i.e., jumper wire). The remaining connections remain the same. After verifying that both the wattmeter and variac are zeroed, plug in the three-phase power cord and set the three-phase breaker to 'on'. Then, **slowly** raise the applied voltage (won't take much), using the variac, until the ammeter reads ~$I_{rated,240}$. Then, measure and record $V_{sc,240}$, $I_{sc,240}$, and $P_{sc,240}$. Using the variac, reduce the applied voltage to zero, set the three-phase breaker to 'off', unplug the power cord, and remove the short circuit (jumper wire). Do NOT disconnect any other wires as the next experiment will require only small modifications to the test set-up.

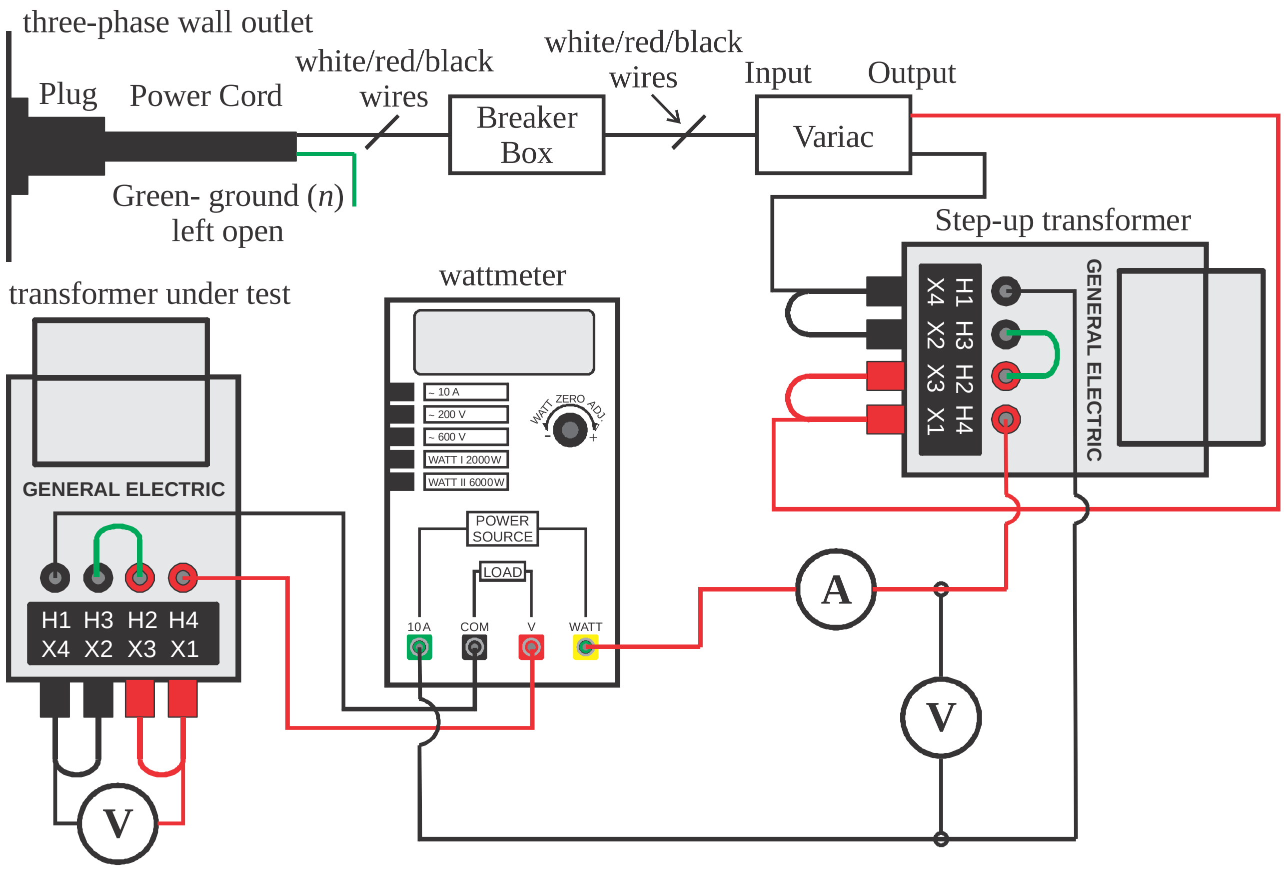

Figure 3 Connections for rated-voltage open circuit test on the high (240 V_{rms}) side of the transformer.

Experiment 3- Load

1) In this test, a resistive-inductive load will be connected to the low side (~120 V_{rms}) of the transformer. A block diagram of the necessary connections, including wattmeters and ammeters, is shown in Fig. 4. Connect the 100 Ω rheostat so the resistance may be adjusted (i.e., use left two terminals) and adjust for maximum resistance (verify with ohmmeter). Do **NOT** plug in the power cord until all connections have been made, wattmeters have been zeroed, variac set to zero, and both breakers set to 'off'. After plugging in the three-phase power cord and setting the three-phase breaker to 'on' (leave single-phase breaker 'off'), slowly raise the applied voltage (w/ variac) until the low side is ~120 V_{rms}. Measure and record the voltages on the high $V_{NL,high}$ and low $V_{NL,low}$ sides.

2) Next, set the single-phase breaker to 'on'. The inductors should hum and the load ammeter should read over 3 A_{rms} immediately. Adjust the variac and rheostat until the high side voltmeter reads ~$V_{NL,high}$ and the low side ammeter reads ~$I_{rated,120}$, respectively. This will be an iterative process as the high side voltage will also drop under load (remember we are using a step-up transformer). This will make the load draw near the rated apparent power of the transformer (due to voltage regulation on the low side, the load will draw slightly more than the rated apparent power). Measure and record $I_{FL,high}$, $I_{FL,low}$ (should be ~$I_{rated,120}$), $P_{FL,high}$, $P_{FL,low}$, $V_{FL,high}$ (should be ~$V_{NL,high}$), and $V_{FL,low}$.

3) Using the variac, reduce the applied voltage to zero, set both breakers to 'off', and unplug the power cord. Verify that all necessary information has been recorded before dismantling the circuit.

4) Measure and record the dc resistance of the rheostat R_{rh} and inductors (R_{wire1} & R_{wire2}). Record the labeled values of inductance (L_1 & L_2).

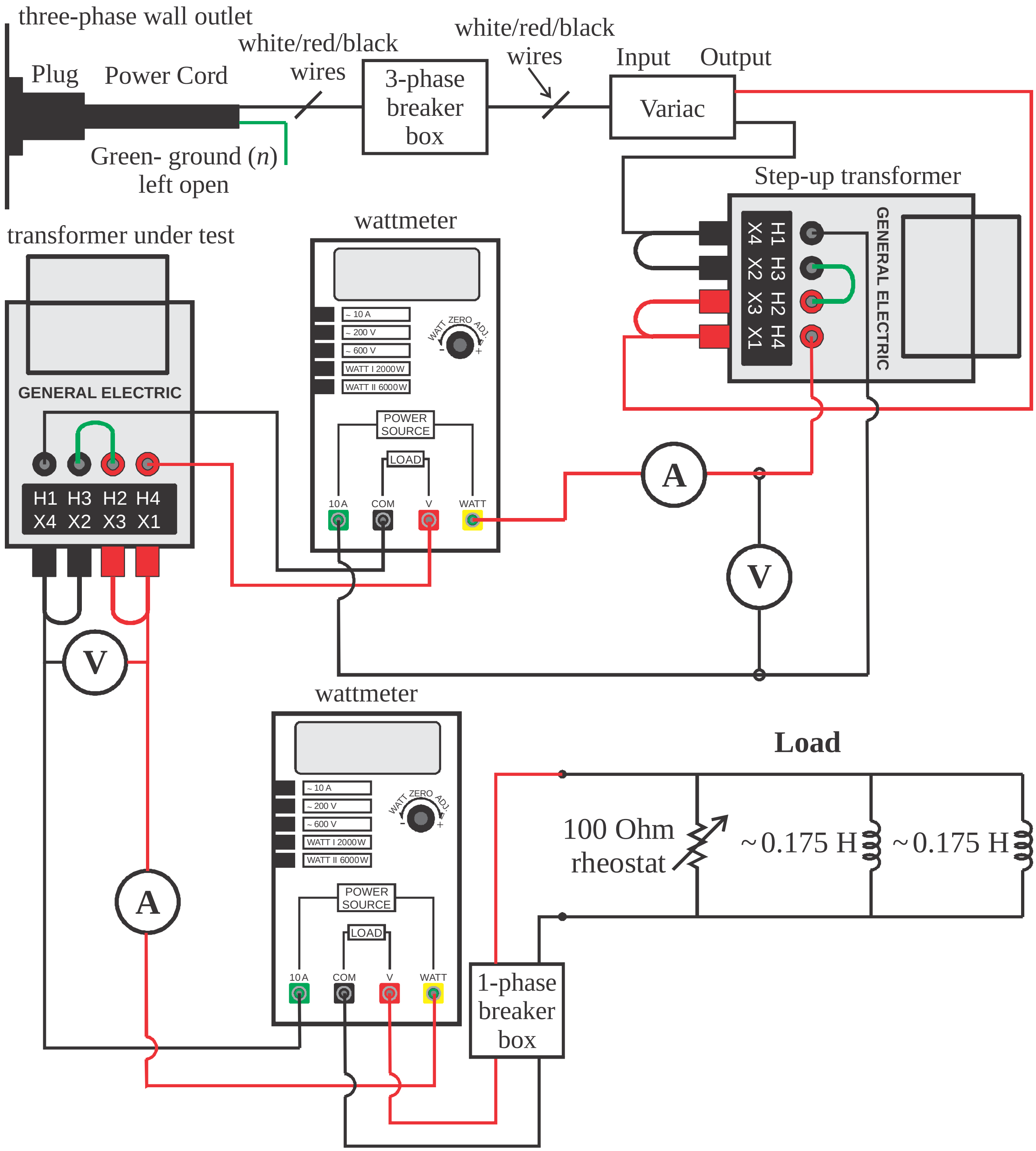

Figure 4 Transformer with load connected to low side.

Analysis

1) Tabulate the low side (secondary) transformer test data from experiment 1. Then, determine the measured turns ratio a_{low} and equivalent component values (e.g., $R_{c,S}$, $X_{M,S}$, $R_{\text{eq},S}$, and $X_{\text{eq},S}$), and sketch the approximate equivalent circuit referred to the secondary side. Using the measured turns ratio a_{low}, determine the component values referred to the primary side and sketch the approximate equivalent circuit.

2) Tabulate the high side (primary) transformer test data from experiment 2. Then, determine the measured turns ratio a_{high} and equivalent component values (e.g., $R_{c,P}$, $X_{M,P}$, $R_{\text{eq},P}$, & $X_{\text{eq},P}$), and

sketch approximate equivalent circuit referred to the primary side. Using a_{high}, determine the component values referred to the secondary side and sketch the approximate equivalent circuit.

3) How do the measured turns ratios a_{low} and a_{high} compare to one another and to the expected value of 240/120 = 2? What do you think is the best estimate of the true value of a_{best}? Why?

4) How do the results in parts 1) & 2) compare? Which component values (e.g., $R_{c,S}$ or $R_{c,P}$, $X_{M,S}$ or $X_{M,P}$ …) are most likely to be accurate? Why? Using a_{best} and the most accurate component values, sketch the approximate equivalent circuit referred to the secondary side. Using the transformer ratings, sketch the approximate per-unit equivalent circuit referred to the secondary side. How do the per-unit component values compare to the ranges expected for a typical power transformer?

5) Based on your answers to parts 3) & 4) and the wire resistances measured in experiment 1, estimate R_c, X_M, R_P, R_S, X_P, and X_S and sketch the equivalent circuit model for this transformer ala Figure 2-16 of the text. Instead of guessing N_P and N_S, supply the turns ratio a_{best} : 1 for the ideal transformer portion of the model.

6) Using the load transformer test data (experiment 3), determine the apparent power S_L, impedance magnitude Z_L, power factor pf_L, angle θ_L, and impedance $\bar{Z}_L$ for the load. Based on the measured resistances and recorded inductances, determine the expected load impedance $\bar{Z}_{L,\text{exp}}$. How does it compare to $\bar{Z}_L$? Also, determine the apparent power S_P, impedance magnitude Z_P, power factor pf_P, angle θ_P, and impedance $\bar{Z}_P$ looking into the high (primary) side of the transformer. Using a_{best}, refer $\bar{Z}_L$ to the primary side. How does this value compare to $\bar{Z}_P$?

7) Using the load transformer test data (experiment 3), determine the measured voltage regulation VR_{meas} and efficiency η_{meas} for the transformer.

8) Using the approximate equivalent circuit referred to the secondary side from 4), a_{best}, $I_{\text{FL,low}}$, $V_{\text{FL,low}}$, and θ_L, calculate $\bar{V}_P / a_{\text{best}}$, P_{cu}, and P_{core}. Then, calculate the voltage regulation VR_{pred} and efficiency η_{pred} expected from the approximate circuit model. (Hints: Use equations (2-62) and (2-66) and/or (2-67) from the text. See example 2-5 of the text.)

Summary and Conclusions

Summarize and discuss significant findings. How well does this transformer perform? Are your results consistent with theory? Why/why not?

Lab Report

- The results should be organized into a typed report. Where possible tabulate results.
- Unless otherwise specified, follow format guidelines contained in course syllabus.
- Include a cover page, Introduction, a body broken down into subsections/paragraphs based on the steps in assignment, and a Summary & Conclusions.
- Put **calculations**, results, and plots/figures in the body of the report in the order specified. Appendices are **NOT** to be used as a "dumping ground" for the calculations, results, and figures. However, long mathematical derivations may be attached as Appendices or done in the logbook **if referenced in the text** of the report. Your logbook is definitely a reference item.

Report and logbook due Friday, February 24, 2012 at class.