EE 330/330L Energy Systems (Spring 2012)
Laboratory 4 Synchronous Generator

Introduction/Background

In this laboratory, you will measure the open-circuit characteristic (OCC) and short-circuit characteristic (SCC) for a synchronous generator. The armature and field winding resistances will be measured. Then, an equivalent circuit model for the generator will be determined. In addition, the voltage regulation will be determined when a load is attached to the synchronous generator.

Experiment 1- Open Circuit Test

1) Record the nameplate data for the synchronous machine (generator) being tested. Based on the nameplate data, determine the number of poles in this synchronous generator.

2) With the switch in the "synch run" position, measure the field resistance R_f (between '+' and '-' terminals at top). Determine the value of the applied dc field voltage V_f required to achieve the rated field current, $I_{f,\mathrm{rated}}$. Measure the dc armature resistance for all three phases (i.e., R_{A1}, R_{A2}, and R_{A3}). Assume armature winding 1 is between terminals 1 & 4, armature winding 2 is between terminals 2 & 5, and armature winding 3 is between terminals 3 & 6.

3) Connect the synchronous generator and induction motor (prime mover) as shown in Figure 1, leaving the coupler off/out (i.e., do not want the synchronous generator spinning yet). Ensure that the three-phase breaker and dc power supply are off.

4) Turn on the three-phase breaker to start the induction motor (dc power supply is off). Measure the total electrical power P_{motor} supplied to the unloaded induction motor using the powers P_1 and P_2 measured by the two wattmeters (shown in Figure 1). Turn off the three-phase breaker.

   Note: Using the two-wattmeter method (refer to circuits text), the total power to any three-phase load is equal to the sum of the readings of two properly connected wattmeters. An individual reading (i.e., P_1 or P_2) may be negative. Therefore, $P_{\mathrm{motor}} = P_1 + P_2$.

5) Next, complete the set-up shown in Figure 1 by inserting the coupler (i.e., want the synchronous generator spinning with dc power supply off). Turn on the three-phase breaker to start the induction motor. If necessary, adjust the position(s) of the synchronous generator/induction motor so they both turn smoothly. Measure the total electrical power $P_{\mathrm{motor+sync}}$ supplied to the loaded induction motor using the powers P_1 and P_2 measured by the two wattmeters. Repeat with $I_{f,\mathrm{rated}}$ applied to the synchronous generator to measure $P_{\mathrm{motor+sync\_If}}$.

6) Perform an open circuit test on the synchronous generator. Start by adjusting both voltage knobs to zero (all the way CCW) on the dc power supply and adjusting the current limit knobs to maximum (all the way CW). Turn on the dc power supply. In a table, measure and record the field current I_f (A), electrical frequency f_e (Hz), mechanical rotation velocity n_m (RPM), and the three open-circuit armature voltages V_{A1} (terminals 1 & 4), V_{A2} (terminals 2 & 5), and V_{A3} (terminals 3 & 6). Next increase the dc power supply voltage (try to keep both sides roughly balanced), and repeat the measurements for $I_f \approx 0.1$, 0.2, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, and 0.6 A. Reduce the dc power supply voltages to zero and turn off the dc power supply, set the three-phase breaker to 'off', and unplug the power cord. Do NOT disconnect any other wires before reading next experiment.

Notes:
- Use an optical tachometer to measure n_m.
- Many of the multimeters have built-in frequency counters. Simply toggle the multimeter 'Hz' after measuring one of the armature voltages

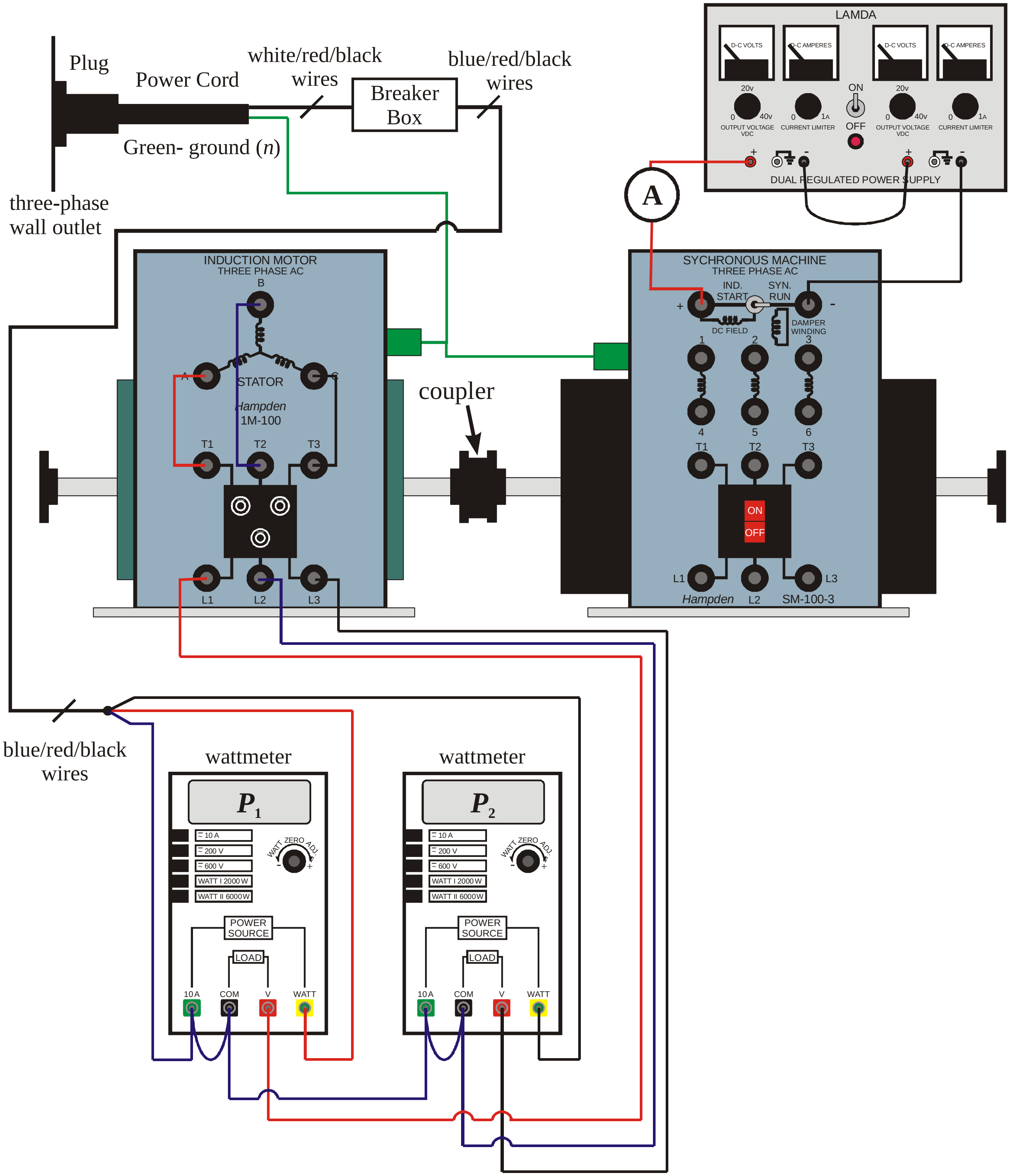

Figure 1 Set-up for open circuit test (Experiment 1).

Experiment 2- Short Circuit Test

1) Connect the synchronous generator and induction motor (prime mover) as shown in Figure 2. Note that the differences with Figure 1 are the removal of the wattmeters and the addition of three ammeters, one connected to each of the three armature windings.

2) Turn on the three-phase breaker to start the induction motor. If necessary, adjust the position of the synchronous generator so they both turn smoothly. Perform a short circuit test on the synchronous generator. Start by adjusting both voltage knobs to zero (all the way CCW) on the dc power supply and adjusting the current limit knobs to maximum (all the way CW). Turn on the dc power supply. In a table, measure and record the field current I_f (A), electrical frequency f_e (Hz), mechanical rotation velocity n_m (RPM), and the three short-circuit armature currents I_{A1}, I_{A2}, and I_{A3} (A_{rms}). Next, increase the dc power supply voltage (try to keep both sides roughly balanced), and repeat the measurements for $I_f \approx$ 0.1, 0.2, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, and 0.6 A.

3) Reduce the dc power supply voltages to zero and turn off the dc power supply, set the three-phase breaker to 'off', and unplug the power cord. Do NOT disconnect any other wires before reading next experiment.

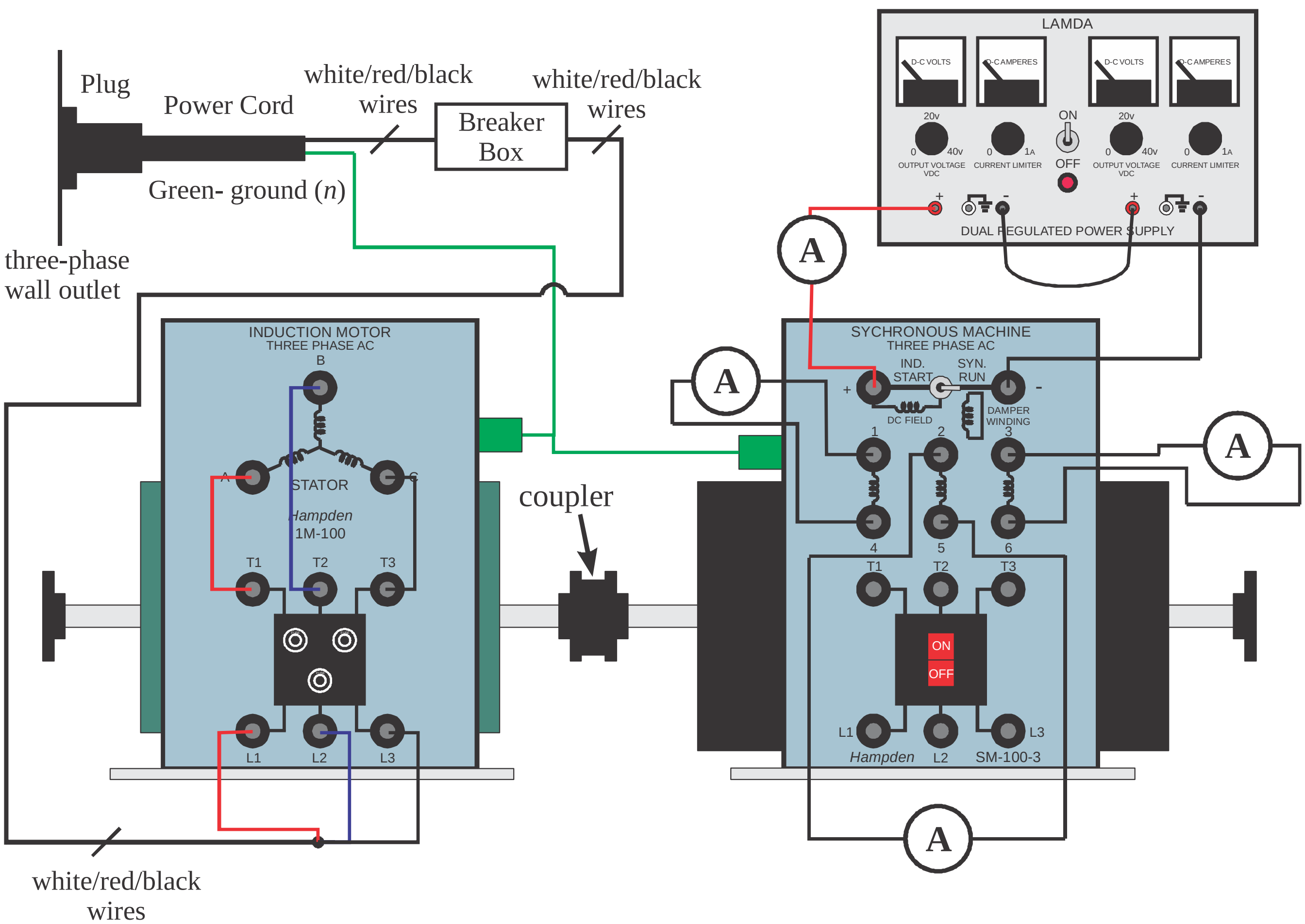

Figure 2 Set-up for short circuit test (Experiment 2).

Experiment 3- Three-phase Load

1) In this experiment, a three-phase, Δ-connected, resistive load (i.e., lamps/light bulbs) is connected to the Y-configured synchronous generator. Note that terminals 4, 5, and 6 on the synchronous generator are tied together to create the Y-configuration. A block diagram of the necessary connections, including wattmeters and ammeters, is shown in Figure 3. Record the rated power P_{rated} (W) and voltage V_{rated} (V_{rms}) for the light bulbs.

2) Turn on the three-phase breaker to start the induction motor. If necessary, adjust the position of the synchronous generator so they both turn smoothly. Start by adjusting both voltage knobs to zero (all the way CCW) on the dc power supply and adjusting the current limit knobs to maximum (all the way CW). Turn on the dc power supply. Adjust the dc power supply voltage (try to keep both sides roughly balanced) to achieve a field current I_f (A) such that the light bulbs are supplied with their rated voltage. Measure and record field current I_f (A), electrical frequency f_e (Hz), mechanical rotation velocity n_m (RPM), and the phase current I_ϕ (A_{rms}) and line-to-line load voltage $V_{LL,L}$ (V_{rms}) supplied to the light bulb connected between terminals 1 and 2. Leaving the dc power supply voltages **in place**, turn off the dc power supply, and set the three-phase breaker to 'off'. **Do NOT** disconnect any wires before reading next step.

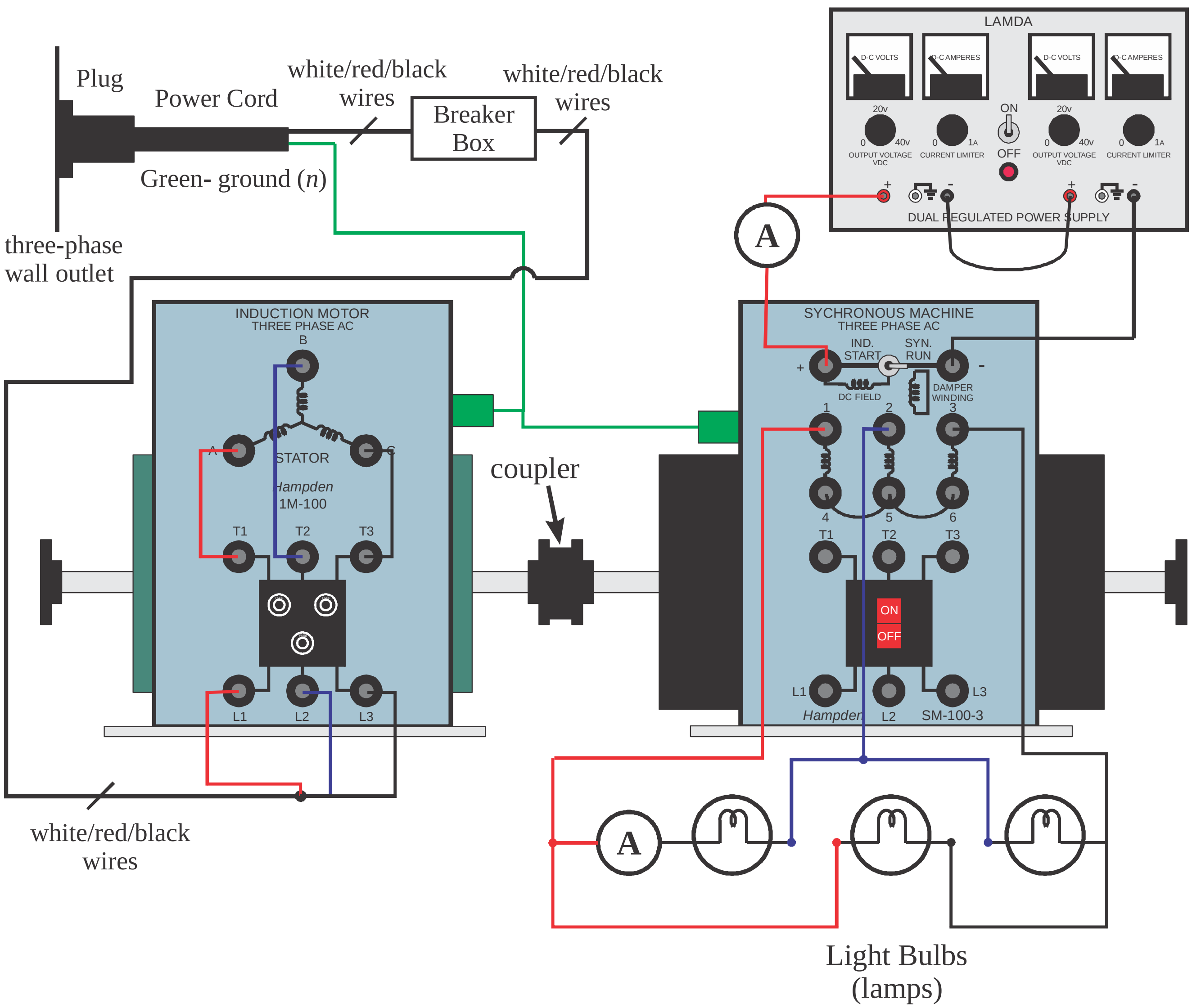

Figure 3 Set-up for three-phase load (Experiment 3).

3) Disconnect the wires leading to the light bulbs. Turn the three-phase breaker to 'on' and turn on the dc power supply. Ensure the field current I_f (A) is unchanged (adjust if necessary). Then, measure and record the field current I_f (A), electrical frequency f_e (Hz), mechanical rotation velocity n_m (RPM), and open circuit (i.e., no load) line-to-line voltage $V_{LL,NL}$ (V_{rms}) between terminals 1 and 2. What is the voltage regulation VR_{load} and speed droop SD_{load} for this load?
4) Set dc power supply voltages to zero, turn dc power supply to 'off', set three-phase breaker to 'off', and unplug power cord. Verify needed information has been recorded before dismantling circuit.

Analysis

1) Using data from experiment 1, average the open-circuit armature voltages at each I_f setting and compensate for changes in shaft speed by multiplying the average of the measured voltages by the ratio $n_m(I_f = 0) / n_m(I_f)$ to get $V_{A,\text{ave}}$ (V_{rms}). Plot the open-circuit characteristic (OCC) using $V_{A,\text{ave}}$.
2) Using data from experiment 2, average the short-circuit armature currents at each I_f setting and compensate for changes in shaft speed, i.e., multiply average of the measured currents by the ratio $n_m(I_f = 0) / n_m(I_f)$ to get $I_{A,\text{ave}}$ (A_{rms}). Plot the short-circuit characteristic (SCC) using $I_{A,\text{ave}}$.
3) Estimate the armature resistance R_A. Then, using the OCC and SCC, calculate the unsaturated synchronous reactance $X_{S,\text{unsat}}$, saturated synchronous reactance $X_{S,\text{sat}}$ at $I_{f,\text{rated}}$, and the synchronous reactance $X_{S,\text{load}}$ with the load. Take R_A into account when calculating synchronous reactances.
4) Sketch the per-phase equivalent circuit for the synchronous generator under the <u>load</u> conditions. Based on the equivalent circuit calculate the armature current $\bar{I}_A$, induced voltage $\bar{E}_A$, torque angle (δ), and voltage regulation VR_{calc}. Assume a phase angle of 0° for the terminal voltage. How does VR_{calc} compare to the measured VR_{load}?
5) Under the load conditions, calculate the rotor P_{RCL} (W) and stator P_{SCL} (W) electrical losses as well as the power out to the load P_{load} (W).
6) Estimate the friction/windage/stray and core losses using P_{motor}, $P_{\text{motor+sync}}$, and $P_{\text{motor+sync\_If}}$.
7) Under the load conditions, estimate the overall input power P_{in} and efficiency η for the synchronous generator both with and without the inclusion of P_{RCL}. Comment on the difference in the results.
8) Under the load conditions, estimate the applied torque (both N-m and ft-lbs). Should you include P_{RCL} for this calculation? Why or why not?

Summary and Conclusions

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

Lab Report

- The results should be organized into a typed short 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, <u>long</u> 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 Monday, April 2, 2012.