Experiment A5
Solar Energy I
Procedure

Deliverables: Full Lab Report (including A6, due in two weeks), checked lab notebook
Recommended Reading: Chapter 5; Section 10.4 of the textbook

Overview

In this lab, you will measure the power output of a solar panel and use it to calculate its efficiency η. A halogen lamp will be used to simulate the sun in a laboratory setting. The electrical power produced by the solar panel will be dissipated in R_L. The solar panel is a non-ideal DC power supply with an internal resistance R_S. As a result, the output voltage, current, power and efficiency all depend on the load resistance R_L and light intensity (irradiance) E_0.

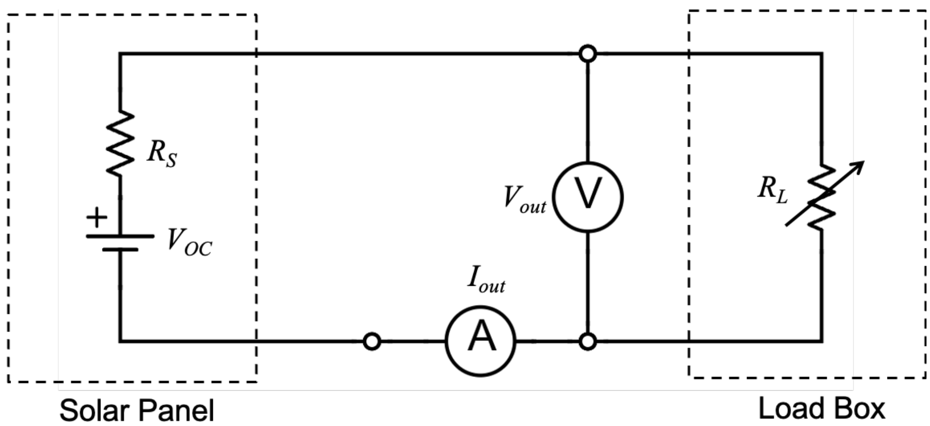

Figure 1: The circuit on the left represents the solar panel. Note that the solar panel is a non-ideal power supply with an internal resistance R_S. It is connected to the load box on the right, which is used to vary the load resistance R_L. (The arrow indicates that R_L is a variable resistor.)

Part I: Efficiency vs. Load

Background

The electrical power output by the solar panel will be dissipated via joule heating in a load resistor. You will see that the power output and efficiency of the solar panel depend on the load resistance R_L, and there is an optimal value of R_L that yields the most efficient operation. The black load box contains a switch that toggles between different values of R_L, as shown on the right-hand side of Fig. 1.

The pyranometer sensor will be used to measure the irradiance of the halogen lamp light incident on the solar panel surface. Multiplying irradiance by the solar panel area yields the total radiant power going into the solar panel.

Procedure

1. Measure the area of the solar panel. You will use the dimensions to calculate the area A_{panel}.
2. Test the black load box. Use the banana cables to connect the Extech DMM to the red and black ports on the load box, and measure its resistance. Turn the load box knobs to values between 0 – 2000 Ω. Check that the values measured by the DMM are consistent with the knob positions.
3. Sketch Figure 1 in your lab notebook.
4. You will use an Extech DMM to measure current and a second Extech DMM to measure voltage. Turn the knob to set one of them to measure voltage on the 20V DC setting, and the other one to measure current on the 200mA setting.
5. Make the connections shown in Figure 1. Be very careful to note which one is set to current and which is set to voltage. (If you mix them up, it will blow the fuse!)
   a. Solar panel red banana cable → Red banana plug on black load box
   b. Solar panel black banana cable → COM port on 200mA Extech DMM
   c. 200mA port on 200mA Extech DMM → Black banana plug on load box
   d. V port on 20V Extech DMM → Black banana plug on load box (stack the connector)
   e. COM port on 20V Extech DMM → Red banana plug on load box (stack the connector)
6. Locate the pyranometer and connect it to the CH1 port on the side of the LabQuest. The sensor data should appear on the man screen displaying irradiance units of W/m^2.

Pro-Tip: Alignment of the solar panel and pyranometer is important; care should be taken in centering them directly under the lamp for accurate measurements.

7. Measure the distance from the light bulb to the solar panel and record it in your lab notebook.
8. The BK Precision AC power supply or "Variac" is used to control the voltage across the lamp V_{IN}, which ultimately changes its brightness or "irradiance". You will measure the power output and efficiency of the solar panel as a function of the load resistance R_L for two different lamp voltages, 125V and 100V, which correspond to different irradiances E_0.
9. Plug the halogen lamp into the variac. Turn on the variac, and use it to adjust the lamp voltage to 100V. (If the circuit breaker trips and you lose power, ask the lab instructor to help you reset the breaker switch.)
10. Place the pyranometer in the center of the solar panel. Make sure the active area of the sensor (the rounded white dome) is facing upward toward the lamp.
11. As you increase the variac voltage, the lamp will get brighter. As the lamp gets brighter, the irradiance reading from the pyranometer should increase.
12. Copy Table 1 into your lab notebook. Record the irradiance in W/m^2 of the lamp that is incident on the solar panel beneath the table.
13. Take the pyranometer off of the solar panel and set it to the side, after you have recorded the value.

14. A "short circuit" occurs when the load R_L is set to 0 Ω (i.e. it is replaced by a plain wire). Set the load knobs to 0 Ω, and you should see the output *voltage* drop to nearly zero (a few milliVolts). The resultant current is known as the "Short circuit current" I_{SC}. Record the short circuit current in your lab notebook.
15. An "open circuit" occurs when the load is infinite (i.e. R_L is removed from the circuit and there is nothing but air between the output terminals). Remove one set of stacked banana cables from the black load box. The resultant voltage is known as the "open circuit voltage" V_{OC}. Record the open circuit voltage in your lab notebook.
16. Reconnect the stacked banana cables to the load box. Measure the DC output voltage and current as a function of the resistive load R_L in increments of 200 Ω going all the way from 0 to 2400 Ω. Record the data in your lab notebook in a table similar to the one shown on the next page. You will use this data to calculate power and efficiency for the deliverables.

Pro-Tip: Be careful to keep the solar panel and pyranometer in the same position for each successive measurement.

17. Increase the brightness of the lamp by increasing the variac voltage to 125V, and repeat the experiment. Fill out another copy of Table 1 in your lab notebook.

Table 1: A template for the table you should put in your lab notebook.

Load, R_L [Ω]	**I_{out} [mA]**	**V_{out} [V]**
0 (short circuit)	I_{SC} =	0
200		
400		
600		
800		
1000		
1200		
1400		
1600		
1800		
2000		
2200		
2400		
∞ (open circuit)	0	V_{OC} =
Variac Voltage ________	E_0 = ________	

Calculating the Efficiency

The efficiency of the solar panel is the amount of electric power output divided by the total power from the incident light,

$$\eta = \frac{I_{out} V_{out}}{E_0 A_{panel}}, \qquad (1)$$

where I_{out} and V_{out} are the measured current and voltage through the load resistor, A_{panel} is the area of the solar panel, and E_0 is the irradiance measured by the pyranometer. The efficiency should be different for each value of load resistance.

Part II: Separation Distance

In this part of the lab, you will measure irradiance as a function of distance from the lamp and compare your data to the *inverse square law*.

Note: The Load Box and Solar Panel will not be used in this part.

1. Place the pyranometer on the lab jack such that it is centered under the lamp.
2. Copy Table 2 into your lab notebook and record the values from the pyranometer.
3. Set the lamp voltage to 90V using the variac.
4. Turn the knob on the lab jack to change the distance. Measure the irradiance as a function of distance. You should choose at least 8 different distances, starting with approximately 90 cm, ending at least half the distance to the lamp. There are also wooden blocks that may be used to vary the height.
5. Set the lamp voltage to 110V using the variac and repeat the experiment.
6. When you are all finished, **turn the variac dial back to zero and turn off the variac.** Disconnect all cables and return the lab bench to its initial state.

Table 2: The irradiance is measured as a function of gap distance and halogen lamp voltage.

	Lamp Voltage V_{AC} = 90 V	**Lamp Voltage V_{AC} = 110 V**
Distance, *r* (cm)	**Irradiance (W/m^2)**	**Irradiance (W/m^2)**

Week I Deliverables – Your results from this week and next are to be compiled in a lab report **no longer than 8 pages**. Please include the following items from this week in your report. (See the score sheet for a breakdown of the points.)

1. A plot of the solar panel output voltage V_{out} vs. load resistance R_L for the two different lamp irradiances.
    a. Use the '-o' and '-*' options in Matlab to connect the measured data points with lines.
    b. Include a legend that denotes the lamp irradiance E_0 in μW/cm^2 for each data set.
2. A plot of the solar panel efficiency η vs. load resistance R_L for the two different lamp irradiances.
    a. Use the '-o' and '-*' options in Matlab to connect the measured data points with lines.
    b. Include a legend that denotes the lamp irradiance E_0 in μW/cm^2 for each data set.
    c. Calculate the internal resistance $R_S = V_{OC} / I_{SC}$ of the solar panel for each of the lamp irradiances. Add a vertical line to the plot denoting each value of R_S.
3. A simple plot of measured irradiance E_0 vs. distance r on a *linear scale* for the two different Variac settings.
4. Show that the irradiance vs. distance obeys an *inverse square law*.
    a. Plot the logarithm of irradiance vs. the logarithm of distance, log(E_0) vs. log(r), with both data sets on the same graph. (Do NOT use the loglog() function in Matlab.)
    b. Apply a *linear* fit to each the data sets. In the caption, comment on the slopes. Are they consistent with an inverse square law?

Talking Points

- Explain how the lamp brightness (irradiance) was controlled.
- Use the terms "voltage droop" and "impedance matching" appropriately to describe your plots.
- Discuss the plot of log(E_0) vs. log(r). Is the data linear? Are the slopes what you expect for an inverse square law?

Appendix A

Equipment

- Vernier Pyranometer – PYR-BTA
- Load Box
- Solar Panel w/ 24” wire leads ending in male banana connector
- Multi-meter w/ 24” wire leads ending in male banana connector
- BK Precision AC Power Supply
- Halogen lamp Fixture w/ GE Lamp: GE 90w 1900lm M/N 66286 PAR 38
- Scissor lift
- Meter Stick
- 2 Extech handheld digital multimeters
- Keysight precision digital multimeter
- Set of 36” banana cables (1 black, 2 red)