Experiment 4
Topic: Solar Panels
Week A Procedure

Laboratory Assistant: Shirui Luo
Email: Sluo1@nd.edu
Office/Hours 12/03 – 12/06 from 5:00 pm to 6:00 pm in Fitzpatrick B14
E-4 Website: http://www.nd.edu/~jott/Measurements_lab/E4/

Overview

In Week 1, you will characterize the solar panel circuits (as shown in Figure 1) with respect to load and distance from light source using a halogen lamp as a light source in a laboratory setting. Note the solar panel is a non-ideal power supply and has an internal resistance R_S. The results from this week will provide a firm foundation for an independent field test of the solar panel in Week B.

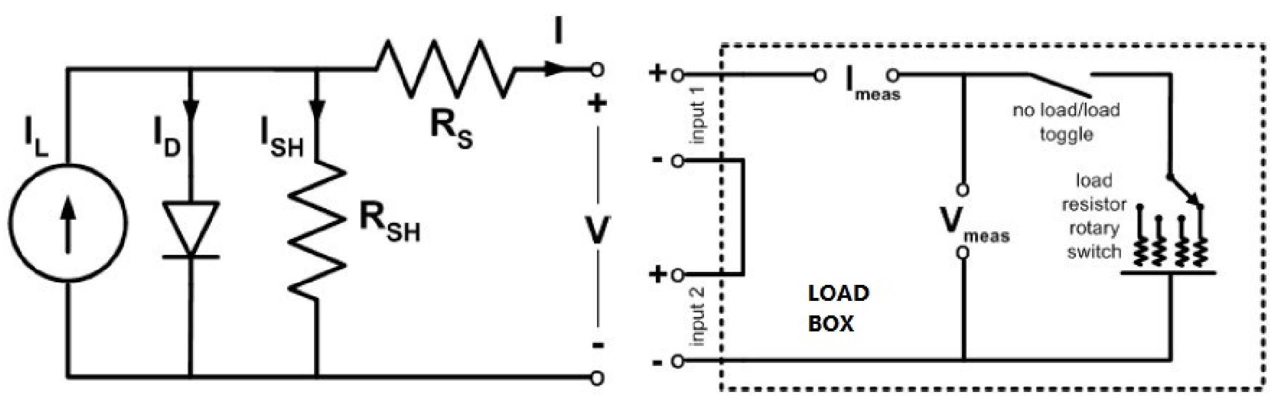

Figure 1: Solar Panel Circuitry

Performance Characterization

The student will measure the power output of a single solar panel while varying the following parameters:

(a) load level (varying of electrical resistance and power intensity)
(b) separation distance of panel to light source

Power, in a direct current (DC) circuit, is the product of current and voltage: $P = I\ V$. Therefore, at each measurement, a closed circuit current and closed circuit voltage with an input impedance is required. In exercise (a), the student will determine the proper input impedance (resistance) for maximum power output; the irradiance will be measured to determine true power input in exercise (b).

Laboratory Equipment

Please record the laboratory equipment being used and all of the following tables and parameters in their lab notebooks.

Solar Panel:

Solar Panel Bar Code: ____

Active Surface Area: ____

Lamp:

Light Bulb Type: ____

Wattage: ____

Diameter: ____

Experimental Setup

1. Set the toggle switch to "*Short*"(load toggle in Figure 1) and insert a shorting pin in "*Input B*"(input 2 in Figure 1).
2. Connect the leads of the solar panel into "*Input A*" (input 1 in Figure 1).
3. Connect the "*Voltage*" (V_{meas} in Figure 1) leads to the top Sensor Interface Box meter and connect the Irradiance Sensor leads to the bottom Sensor Interface Box meter.
4. To measure the current, use a multi-meter set to the 200mA range. Do not use 10A jack.
5. Locate the **Irradiance Sensor**. It has twelve different settings that can be chosen for sensitivity and scaling of the voltage output. Setting (9) is recommended for this laboratory exercise. Professor Patrick Dunn has created a document that explains how to determine the irradiance in $\mu W/cm^2$. This document can be found on the E4 website. Ignore the loose green wire.

NOTE: Alignment of the solar panel is important; care should be taken in centering it directly under the lamp for accurate measurements.

Part I: Load Level

To record the effect of resistive loads on output power of the solar panel, center a single panel on five wooden blocks beneath the light source. Be sure the resistance knob is turned counterclockwise and record the currents and voltages in Table 1.

The variable AC transformer (Variac) is used to control the voltage across the lamp V_{IN}, which ultimately changes its brightness. You will measure the efficiency of the solar panel as a function of the "load" resistance for three different Variac settings: 120V, 110V, and 90V.

Please fill out the tables below. Each clockwise click on the knob increased the resistance by 200 Ω. Continue measuring and recording in Table 1 to a resistive value of 2000 Ω. You will calculate the last column at a later time.

NOTE: Care should be taken to insure that the proper resistance is set on the knob.

Table 1a: Variac voltage V_{IN} = 90V

Load [Ω]	I_{out} **[mA]**	V_{out} **[V]**	$P = I\,V$ **[mW]**
Short circuit current, I_{SC}			
Open circuit voltage, V_{OC}			
200			
400			
600			
800			
1000			
1200			
1400			
1600			
1800			
2000			

Irradiance Voltage:______________________________________

Irradiance Sensor Setting:________________________________

Variac Voltage:____

Table 1b: Variac voltage V_{IN} = 110V

Load [Ω]	$\boldsymbol{I_{out}}$ **[mA]**	$\boldsymbol{V_{out}}$ **[V]**	$\boldsymbol{P = I\,V}$ **[mW]**
Short circuit current, I_{SC}			
Open circuit voltage, V_{OC}			
200			
400			
600			
800			
1000			
1200			
1400			
1600			
1800			
2000			

Irradiance Voltage:_______________________________________

Irradiance Sensor Setting:_________________________________

Variac Voltage:____

Table 1c: Variac voltage V_{IN} = 120V

Load [Ω]	I_{out} [mA]	V_{out} [V]	$P = I\,V$ [mW]
Short circuit current, I_{SC}			
Open circuit voltage, V_{OC}			
200			
400			
600			
800			
1000			
1200			
1400			
1600			
1800			
2000			

Irradiance Voltage:____

Irradiance Sensor Setting:___________________________________

Variac Voltage:____

Calculating the Efficiency

The efficiency of the solar panel is the amount of electric power generated divided by the total power from the incident light. That is, you can calculate the efficiency by dividing the power dissipated in the load resistor by the power measured by the Irradiance Sensor:

$$\eta_{panel} = \frac{I_{out} V_{out}}{E_0 A_{panel}} \tag{1}$$

where I_{out} and V_{out} are the current and voltage through the load resistor, A_{panel} is the area of the solar panel, and E_0 is the light intensity calculated from the Irradiance Voltage (see the “Irradiance Measurement” document on the lab website).

Part II: Separation Distance

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

Vary the distance of the irradiance sensor to the light source to see how this affects the power input. Use wood blocks underneath the irradiance sensor to change the distance, while taking care to keep the sensor centered. Set the separation distance (from the bulb lens to the sensor) with the sensor centered on the table to 91.4 cm. Each block lowers the distance this by 3.8 cm. The students should choose at least 8 different distances, with one of the distances being 91.4 cm (the maximum allowable distance due to laboratory setup).

At each distance, change the variable AC transformer to the same values as those used above. Record these values in Table 2.

Table 2: Separation Distance

No. Blocks	Distance [cm]	Irradiance Voltage		
		Variac V_{in} = 90 V	**Variac V_{in} = 110 V**	**Variac V_{in} = 120 V**
	91.4			

Block Thickness: _______ cm

Part III: Practical Implementation of Solar Energy

In this portion of the lab you will create your own "Solar Microgrid". The microgrid consists of the solar panel, a 12V lead acid battery, and a charge controller. Solar panels obviously do not produce energy at night, so the 12V battery is used to store energy produced during the day. Directly connecting ~20V DC output of the solar panel to charge the 12V battery would damage it, so the charge controller is used to step down the 20V DC to 12V DC. Additionally, the charge controller contains two 5V USB outputs for charging various consumer electronics.

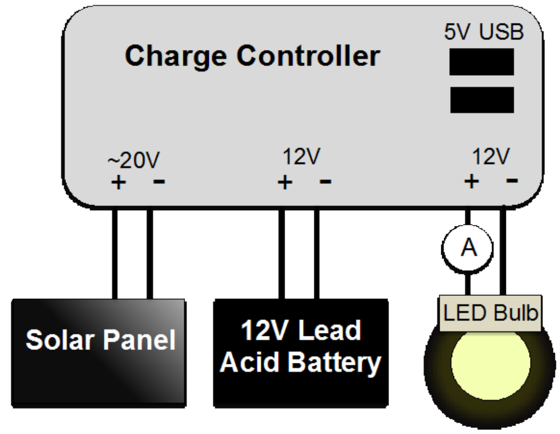

Figure 2: A schematic of the Solar Microgrid.

Note: All the components used in this microgrid set-up can be purchased on Amazon.com for less than $100 total.

1. Sketch the schematic shown in figure 2 in your lab notebook.
2. Set the distance from the solar panel to halogen lamp to 91.4cm.
3. Set the variac to 120 V.
4. Check that the battery is securely connected to the screw terminals of the charge controller. **Caution: This powerful battery is NOT a toy. It can cause painful shocks and burns and even cause fires.**
5. Connect the solar panel to the banana plugs on the far left of the charge controller.
6. Using the 10A socket, connect the digital multimeter in series with the LED bulb, as shown in Figure 2. Turn on the LED bulb, and you should see a value for the current on the multimeter.
7. Measure the voltage across the screw terminals on the bottom of the LED bulbs using the voltage probes connected to the HP 3468 precision multimeter.
8. Plug the USB power monitor stick into one of the USB charging ports. Choose a device and plug it into the other end of the USB power monitor. (Possible devices include your cell phone or tablet or the rechargeable flashlight or fan provided by Prof. Ott.)
9. Copy Table 3 into your notebook. Fill it out by recording the current for the LED bulb and current and voltage for two different USB devices. (Be sure to write down the actual names of the USB devices you used, not just "USB Device 1".) Put the solar panel directly under the lamp to simulate day and turn it upside down to simulate night.

Table 3: Energy usage of various electronic devices.

	USB Device 1		USB Device 2		LED Bulb	
	Voltage	Current	Voltage	Current	Voltage	Current
Day						
Night						

Week A Deliverables – You are required to include the following items in your lab report. (See the E4 score sheet for points.)

1. A Plot of the solar panel efficiency η_{panel} vs. load resistance R_L for the three different Variac settings. (Recall the Variac controls the brightness or irradiance of the lamp.)

2. A table containing the maximum power output by the solar panel, the load resistance that yielded the maximum power, and the estimated internal resistance of the solar panel ($Rs = V_{OC}/I_{SC}$) for all three variac settings.

3. A simple plot of measured irradiance E_0 vs. distance r on a *linear scale* for the three different Variac settings.

4. The irradiance vs. distance should obey an *inverse square law*. Using one of the techniques you learned in this course, make a plot that demonstrates that the data follows an inverse square law. This plot should contain the data for all three Variac settings. (Hint: Consider the plots you made for Homework 2.)

Suggested Talking Points

- Why does the efficiency depend on the load resistance? Can you come up with an equation that predicts power vs. load resistance? (Hint: The solar panel is a non-ideal power supply with an internal resistance R_S.)

- Use the open circuit voltage and short circuit current to estimate the internal resistance of the solar panel for each power setting. Compare these to the load resistances that gave the maximum power.

- Do some research on the inverse square law and discuss your measurements of irradiance vs. distance accordingly.

- Look up the specifications of the lead acid battery. How much charge can it hold? How long would it take the USB devices and the LED light bulb to fully drain the battery?

- Was the Solar Microgrid affected by going from "day" to "night"?

Appendix A

Equipment

- Sensor Interface Box (SIB) w/ 9V power supply
- Light Sensor Box (Irradiance Sensor/Light-to-Frequency Converter) w/ 24" wire lead cable ending in snap connector to SIB input pins
- Load Box
- Shorting Pin
- Solar Panel w/ 24" wire leads ending in male banana connector
- Multi-meter w/ 24" wire leads ending in male banana connector
- Variac Transformer TDGC – 2KM
- Lab stand
- Test-tube Holder Clamp
- Lamp Fixture w/ GE Lamp: GE 90w 1900lm M/N 66286 PAR 38
- Wooden Blocks - 2" x 6" x 6" (qty. 7)
- Meter Stick
- Hewlett Packard 3468 precision digital multimeter
- Mohoo 20A Charge Controller Solar Charge Regulator Intelligent USB Port Display 12V-24V
- Eversame USB Digital Power Meter Tester Multimeter Current and Voltage Monitor, DC 5.1A, 30V
- ExpertPower EXP1272 12V 7.2 Amp-hour Rechargeable Battery
- ChiChinLighting 12v LED Bulb Daylight AC DC Compatible 7 Watts 6000k Low Voltage
- Porcelain Medium-Base Light Bulb Socket with Pull Switch, 250 Maximum Watts, 250 Maximum Volts