Making Sense of Solar Cells

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STUDENTS are becoming more aware of the role that solar photovoltaic arrays play in their daily lives simply by observing the increased number of solar installations in their local communities. In addition, they may have studied electric power and energy consumption in the average home in a science or technology education class. What is often missing is a way for students to "make sense" of the connection between electric power consumption during life's daily activities and an understanding of how much power a photovoltaic cell or module can produce.

After taking part in the activity described here, students will be able to make a meaningful association between the arrays they see and the electricity they use. The activity makes that connection real by having students take measurements of the voltage and current produced by a photovoltaic (PV) module when connected to a load resistance and then calculate the resulting power.

Photo 1—Small PV array with eight modules produces 1,840 W.

Background

The specification label for a commercial solar module illustrates an important idea about measuring the power of electrical sources. Using this information, it is easy to show that the maximum power (P_{max}) agrees with the calculation of power, $P = V \times I$ using the rated voltage (V_{pmax}) and rated current (I_{pmax}). What is implicit in this information is that these data were obtained during test conditions with a load resistance connected.

Photo 2—A PV module label provides useful information.

Connecting a voltmeter to a PV module in sunlight provides a measure of "open circuit" voltage (V_{OC}). Since typical voltmeters in use today have resistances of many megaohms, the current that flows during this measurement is negligible. Connecting an ammeter to a PV module in sunlight provides a measure of "short circuit" current (I_{SC}). Ammeters have very low resistance and the voltage across the source during this measurement is near zero.

So, although V_{OC} and I_{SC} provide useful data about an operating PV module, these values are not appropriate for calculating meaningful power production. A goal of this activity is to model real-world testing conditions where a calculation of meaningful power requires that a load be connected to the PV module. For this lab or demonstration, a 50 Ω, 5 W resistor is used. ►

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Several logical extensions of this activity include understanding how large amounts of power can be produced by connecting multiple modules in series and parallel, identifying energy transformations in various load devices, and relating the concepts of electric power and energy.

What Students Will Learn

As a lab exercise, this activity provides a contextual way to address a number of generic engineering and technology performance indicators. For example, after completing this work, students should be able to:

- Solve math problems involving power, current, and voltage;
- Design a circuit using a power source, load resistance, voltmeter, and ammeter;
- Select appropriate meters (or range/function settings on a digital multimeter) to make circuit measurements of voltage and current;
- Collect, organize, and manipulate real-world data;
- Explain the factors that affect the power production of a photovoltaic cell or module.

Measuring Current and Voltage Produced by a PV Module

Students should have a basic understanding of how to construct a simple series circuit and how to connect meters in series and parallel for measuring current and voltage. As an introduction or review for this, the instructor can draw pictorial and schematic representations of the circuit and explain the connections and placement of various components in it.

Since this is a direct current (dc) circuit, students should be able to identify and mark correct polarity for the PV module, ammeter, and voltmeter. The PV module shown here has connections that make it possible to work with 1.5, 3.0, and 4.5 V outputs depending on how jumper wires are connected. This is a handy feature as it makes it possible to collect several sets of current and voltage data. Other PV cells or modules could be used for this lab, but they should have similar voltage and current characteristics if connected in series and parallel.

What Does This Show?

Through class discussion, students should be encouraged to consider the results of these measurements in the context of their everyday lives. Many high school students are interested in the batteries that power their portable music and communication devices—particularly when they need to be recharged! A typical cell phone charger operating from 120 Vac uses 24 W of power. This is approximately 80 times more power than the tested PV module produced.

The measurements show that by increasing the number of cells, in this case always in series connections, the power is also increased. From this, students can begin to understand that the way to produce "useful" amounts of electricity from solar PV cells is to design and build larger panels combining many cells. This provides them with a foundation for understanding the operation of large systems, or arrays.

Extensions

Several related extension activities give students an opportunity to apply what they learned while making measurements and calculating photovoltaic power.

- **Area and power scaling—**Once the power-producing capability of the module is determined, making measurements and calculating the

Equipment and Materials

Photovoltaic cell or module. (The one used here is from the Elenco SK-40 Solar Deluxe Educational kit and is rated approximately 4.5 V and 100 MA maximum output).

Ammeter (200 mA range)

Voltmeter (0-10 V). Two digital multimeters having appropriate dc voltage and current ranges can also be used here.

Load resistor. Data shown in Table 1 were obtained using a 50 Ω resistor.

Bright sunlight or an incandescent lamp of 60-75 W

Table 1—Typical Data

Trial # (Light Conditions = Filtered Sun)	Voltage (V) (measured)	Current (mA) (measured)	Power (mW) (calculated)
#1 Group of 3 series cells	1.5	26	39
#2 Group of 6 series cells	3.0	50	150
#3 Group of 9 series cells	4.0	80	320

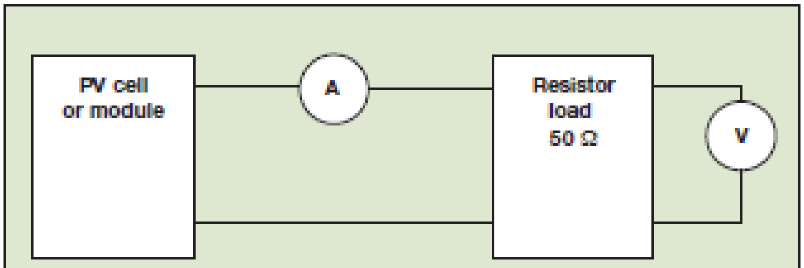

Fig. 1—Block diagram illustrating circuit setup

area of the active PV material (silicon) provides the information needed to determine the power density, measured in W/m², for the device. Using this information, students can solve problems relating the physical size of a PV array and power output. A sample question might be:

A commercially available PV module has an area of 1.6 m² and can produce 240 W in full sun conditions. How much surface mounting area would be needed to provide a power output of 10 kW?

10 kW/240 W per module
= 42 modules
1.6 m²/module × 42 modules = 67 m²

• **Energy transformations**—The fundamental energy transformation taking place with photovoltaic cells is the conversion of light or electromagnetic energy into electrical energy. Students can easily demonstrate a number of conversion processes by connecting various load devices to a PV module. A motor illustrates conversion of electrical energy to mechanical energy and a lamp (incandescent, "flashlight" type, or LED) used as a load illustrates conversion into light energy.

Another interesting load is a small, battery-powered radio or greeting-card-type sound module. Although this energy conversion is basically an example of electrical energy to mechanical energy (motion of the speaker diaphragm or piezoelectric crystal), the production of sound waves in the air is a good extension and topic for discussion. It's a worthwhile assignment to have students observe and record/describe the various energy transformations that take place with technological devices they use every day.

• **Calculating energy**—Students often have difficulty understanding the difference between power and energy. Using the definition of energy as: energy = power × time, they can illustrate and determine the amount of energy that the lab PV module will provide during some time period of operation. When working with small quantities such as time intervals in seconds and power in watts, the energy units are joules. 1 W × 1 second = 1 joule.

For example: With the PV module providing a power of 320 mW (0.32 W) for one minute, the energy transferred to the load resistor is:

$$E = P \times t$$
$$= 0.32\ W \times 60\ s$$
$$= 19.2\ joules$$

For longer time intervals and larger amounts of power—for example when calculating the energy used by the average household—kilowatts are used for power and hours for time. The resulting energy unit is: kilowatt × hour = kilowatt-hour, or kWh. A small PV array giving 1,840 W of power for two hours produces 3.68 kWh of energy.

Photo 3—Lab setup models a working PV array.

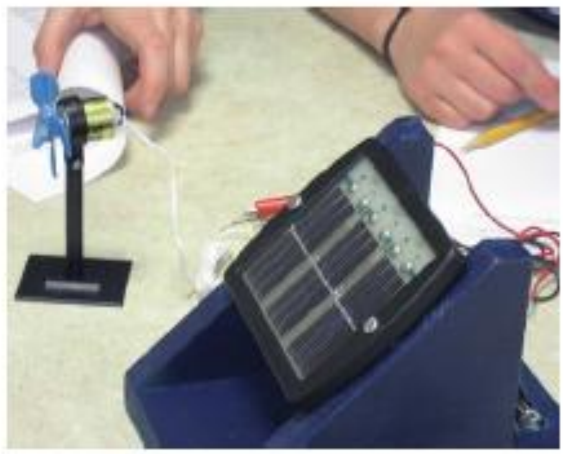

Photo 4—Energy conversions can be illustrated with basic equipment.

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