A New Angle on PV Efficiency
Student Investigation Guide

In this experiment, you examine how the orientation of a photovoltaic (PV) panel relative to the sun affects its efficiency. Using sunshine (or a lamp) and a small PV panel connected to a digital multimeter, vary the angle of the solar panel and record the resulting current output. Then, you'll plot the data.

Real-World Applications

Solar energy generation is becoming one of the most widespread solutions to address energy costs and global climate change. PV panels are used around the world for many applications because they are adaptive to so many buildings, sites and purposes. One of the largest factors in determining a PV panel's efficiency is the angle at which the solar radiation hits its surface. The ideal orientation of a solar panel varies, depending on the season and location on the planet. To design PV arrays with the highest efficiency (energy output) possible, engineers must understand how these factors affect the power output of solar panels.

Installing a solar PV array as roof shingles.

Introduction

Photo means "light," and voltaic means "electric." A photovoltaic (PV) panel is a device that turns light into electrical energy. PV panels have been used on satellites and for power needs in remote areas for years, and are becoming more popular for providing energy to homes and buildings because they are more environmentally-friendly than conventional power solutions. You may have seen a solar panel on a home or know how they work already, but what if I gave you a PV panel to put on your own home and proposed that the person who could create the most energy over the course of the year would win $1,000! What would you do to ensure that your PV panel produced the most energy possible?

PV panels do not all make the same amount of energy when the sun shines on them. Even two identical solar panels might make completely different amounts of energy depending on some very simple differences in how they are installed. Would you like to know the secrets to designing a PV system so that it is as efficient as possible at converting sunlight to energy?

Okay, let's start with one of the most important factors that affects a PV panel's efficiency; this is also one of the easiest factors to control. Let's pretend that I gave you a PV panel for the competition, but because you are so busy with homework and studying, you decide to hire someone else to install the PV panel on your roof. When you come home from school you look up and you see that it is up-side down, so that the light-sensitive material is facing the roof. Do you think this set-up will win the competition of making the most energy possible? No! Okay, so that's an obvious error, but what if it was installed flat against your roof so that it had the same slope as the roof? Is that the best way to install it? Would it be better for it to lie horizontally and point straight up into the sky? Or, should it stand up on its edge, vertically? What is the best angle to install the PV panel so that you can generate the most energy possible over the course of the year? Engineers who design photovoltaic systems for buildings and other spaces must consider all of these questions when creating their designs.

While there is no contest or prize money for installing the world's most efficient solar panel, maximizing the energy output of each installed panel saves its owner the maximum amount of money over the lifetime of the PV panels. Let's do some experiments to see how the angle at which sunlight hits a PV panel affects its current output, which is directly related to its overall power output and efficiency.

Materials List

Each group needs:

- mini PV panel
- multimeter and 2 wires with alligator clips
- sunlight (or 100-watt lamp incandescent lamp)
- 2 pieces of cardboard, each about the same size as the panel
- protractor
- ruler or string
- duct tape
- *Investigation Worksheet*, one per person

Safety Tips

Be gentle when handling your PV panel – the panel surface and its wire connections are fragile!

Be careful with the lamp – it can become extremely hot!

Troubleshooting Tips

If you are outside, you may need to use the 10A setting on the multimeter.

Make sure that the wire connections are tight. If you do not get a reading on the multimeter, look for a bad connection or loose alligator clamp.

Make sure that the conductive pieces, especially the ends of the wires or leads of both the PV panel and the multimeter, are not touching any other conductive materials, such as a metal table.

The panels do not work well under fluorescent lights due to their reduced light spectrum. When setting up the circuit, use direct sunlight or an incandescent lamp to test the circuit and panel.

Experimental Set-Up

1. Take all materials outside, or if inside, secure the lamp to a desk or shelf.
2. To support the solar panel during the experiments, tape two pieces of cardboard that are roughly the size of the panel to opposite sides of the solar panel to create an adjustable support triangle, as shown in the experimental set-up in Figure 1.

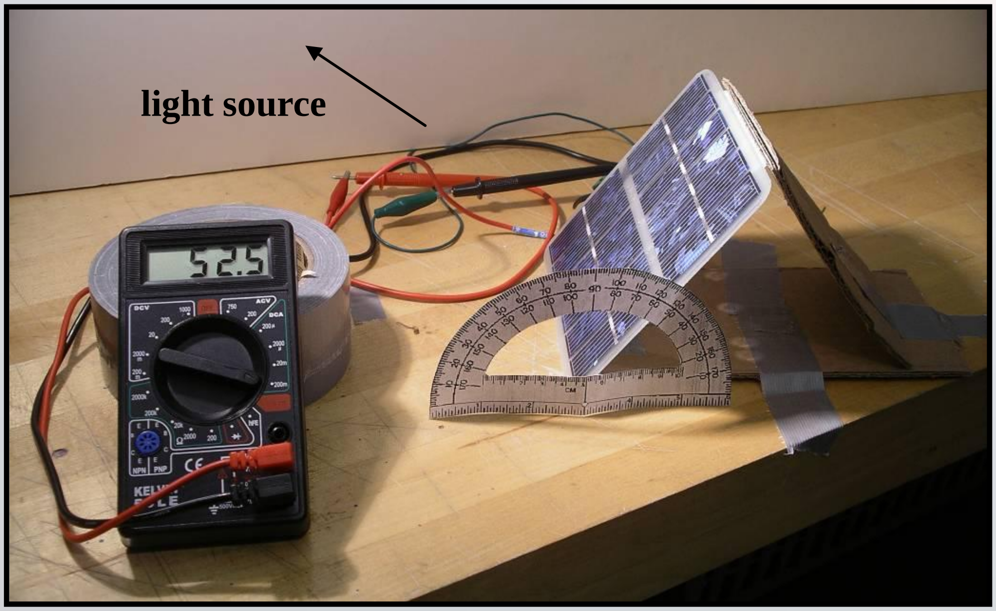

Figure 1. Solar angles experimental set-up.

3. Connect the negative and positive pins on the multimeter to the corresponding wires on the PV panel (the red pin should be connected to the red wire).
4. Turn the multimeter to the direct current amps (DCA) setting for 200m. Place the panel one to two feet from the lamp. (Tips: The reading on the multimeter should be positive; if it is not, the wires are backwards. If you see only a “1” on the screen, the panel is producing more current than the multimeter can read at that setting. In this case, back the panel away from the lamp a little or move the multimeter dial to a higher current setting.)
5. Point the PV panel directly at the light/sun and tape its triangle base to the table to prevent movement during the experiment. (The panel angle remains adjustable using the other cardboard piece.) Also be sure the lamp is secured.
6. Measure the zenith angle, θz, of the sun and record it on the worksheet. Do this by placing the protractor at the front edge of the panel. Use a ruler or string pointed at the light source to help increase your accuracy in reading the angle of the light source. (Optional: Place the light source so the zenith angle is equal to the latitude of your location.)

Experimental 1: Vary the Collector Slope Beta, β

7. Lay the panel completely flat. Measure the current and record it in the first spot on the worksheet (0º).
8. Make sure that the protractor is centered at the front edge of the PV panel. (If the angle is measured with the protractor in an incorrect position, it skews the data.)
9. Vary the slope of the PV collector in 10º increments and record the resulting current measurements on the worksheet. (Note: If you notice a higher current reading at an angle other than the zenith angle, it may be due to the reflectance of your table surface. Take this into account when answering worksheet questions.)

Experiment 2: Vary the Azimuth Angle of the Panel, γ

10. Set the panel to the optimal slope from Experiment 1 and secure the cardboard support triangle so the panel remains at this angle.
11. Remove the tape from the base. Rotate the base slightly until the current is at its maximum. Record this as the 0º reading.
12. Tape the protractor to the table at the front edge of the panel so that the center of the protractor lines up with the center of the panel. Rotate the base of the panel by 10º increments to the left or right, keeping the center of the panel at the center of the protractor. Record the resulting current measurements on the worksheet. (Be sure to rotate the panel about its center and not to slide it forward or backwards during the experiment.)

Create a Plot and Interpret the Results of the Experiments

13. Plot the data on the graphs provided on the worksheet.
14. Answer the questions on the worksheet to demonstrate your understanding of the data.