Lesson 8: "Watt's" Your Angle?

Adopted/ Revised From
Kid Wind, Idaho National Laboratory, ScienceBuddies.org

Grade Level
6-12

Objectives
- Define and apply concepts of tilt and azimuth
- Isolate the tilt and orientation variables from one another
- Measure the energy produced by a small solar PV panel with a multimeter
- Find the optimum tilt and azimuth to maximize voltage production
- Use a sun chart to explain experimental findings
- Draw conclusions and justify them to classmates

Overview
Students compare the voltage output of a small PV solar panel at different angles and orientations to learn how solar panel location and installation are determined.

Materials (per group)
- One small (0.5V – 1 V) solar PV panel
- Multimeter
- Sun Path Chart from http://solardat.uoregon.edu/SunChartProgram.html for your location
- Thermometer
- Protractor
- Magnetic compass

Estimated Cost of Materials
$20 per group

Computer Required?
Only to download Sun Path Charts

Duration
1-2 class periods

Primer References
1.1 Forms of Energy
1.5 Energy Conversion
3.1 Solar

Related Articles
- Invert Your Thinking: Squeezing more power out of your solar panels, Scientific American Blog, August 2009

Engagement

1. What factors are important when placing a photovoltaic cell for maximum power production?
2. Why are solar panels installed at an angle?
3. Would solar panels be useful year round in Colorado as a primary source of energy? Why or why not?
4. What would be the impact if solar panels could move with the sun?
5. What might be the relationship between temperature and energy?

Investigation

DO NOT LOOK DIRECTLY INTO THE SUN!

DAY 1

1. Divide students into small groups with the materials listed.
2. Explain to students that their challenge will be to use the materials provided to generate the greatest possible voltage (you can also determine wattage if your multimeter is capable of picking up amperage). Have them find definitions for tilt and azimuth and discuss to be sure everyone understands the concepts.
3. Go outdoors and have students choose their site for their measurements.
4. Place the PV solar panel in direct sunlight with no shade, connect it to a multimeter and record how many volts are registered. Move the panel around in different combinations of tilt and azimuth and notice the results.
5. Next have students set up a systematic way to measure the effect of changes in tilt and azimuth. Remind them that changing one variable at a time is good scientific practice. *Be sure to record the date and time just before you start the measurements.* If the measurements take more than a few minutes apart, you may want to record a time with each measurement as the sun moves quite quickly some times of the year:
6. First explore the effect of changes in tilt as the azimuth is held constant at an angle that seemed to be effective in the first trials. Use the protractor to make changes in 10 degree increments.
7. Next use your compass to assess the effect of changes in azimuth while holding the tilt constant at the angle found to be most effective. Record findings on the activity sheet.
8. Give each group a sun path chart. To practice interpreting the chart, ask each group to figure out the answer to these questions:
    a. On what date or dates is the solar elevation closest to 45˚ at 12:00 pm?
    b. Where is the solar elevation on June 21 at 9 am?
    c. What is the solar azimuth (angle east/west) on March 21 at 5 pm?
    d. Would your shadow be longer on July 21 at 12:00 pm or October 21 at 12:00 pm?
9. Have the students look at the Sun Path chart to determine where the sun was when they were taking their readings on their solar panel. Make sure to discuss the concept of solar noon (see Glossary), especially if the activity is done during daylight savings time. Record the solar elevation on their data sheets. Have them compare this information to the data they collected. What do they notice?

As you get involved with solar energy, you will be very interested in the sun's movements and position because these have such an impact on your system's efficiency. You may already know that the sun is in different positions in the sky in different parts of the year. For example, on the sun path charts you saw that the sun is not nearly as high above the horizon in December 21, the winter solstice, as it is in June 21, the summer solstice. Wonder why?

At the two equinoxes, March 21 and September 21, the sun rises due east and sets due west. At solar noon on the equinoxes, the altitude of the sun is 90 minus the local latitude. For example, if you live in Denver with a latitude of 40 degrees, the altitude of the sun at noon on the equinoxes will be 90 - 40 = 50 deg. (This is why you use your latitude as the default tilt angle on stationary panels.) Day length on the equinox everywhere on earth is 12 hours. On the winter solstice, the shortest day of the year, the sun rises well to the south of east, and sets well to the south of west. The altitude of the sun at solar noon will be 23.5 degrees less than it was on the equinox -- or, 50 -23.5 = 26.5 degrees in our Denver example. This will be the lowest that the noon sun will be in the sky all year. On the summer solstice, the longest day of the year in the northern hemisphere, the sun rises well to the north of east, and sets well to the north of west. The altitude of the sun at solar noon will be 23.5 degrees more than it was on the equinox -- or, 50 + 23.5 = 73.5 degrees in our Denver example. This will be the highest that the noon sun will be in the sky all year.

The 23.5 degrees referred to above is the tilt of the earth axis of rotation relative to the plane of the earth's orbit. The summer solstice in the northern hemisphere occurs when the North Pole is tilted toward the sun, and the winter solstice when the North Pole is tilted away from the sun. Adapted from http://builditsolar.com/

DAY 2 (optional)

1. Repeat the experiment without varying the method on a different day with a significantly different temperature; this does not have to be the next day.
2. Graph the results for both days and discuss.

Class Review

1. Ask class to share some of their results of their experiments and what they might mean for solar PV installations.
2. Have students re-discuss Engagement questions as a group using the graphs to respond to those questions.

Elaboration

Now that we have seen the amount of energy generated by a solar panel in Colorado:

1. Have students read the Primer References and look at the Solar Resource Map from Appendix B using a projector, handouts, or the website.
2. Based on what they have read, the data they have collected, and the solar maps, have students determine if where they live is an ideal location to use solar as a form of energy.
3. Have students discuss how the energy from the sun is transferred to energy in the panel.
4. How does a PV cell work?
5. Is the solar PV panel by itself potential or kinetic energy?
6. If your panels are going to be stationary, what is the best choice of tilt angle and azimuth?
7. If you can move the panels, what changes would you make in the winter? What changes would you make in the summer?
8. The materials in solar cells are very expensive. Scientists and technicians have figured out how to use other materials to concentrate sunlight onto small areas. How do you think they do this?

9. Would solar panels be useful year round in Colorado as a primary source of energy? Why or why not?

Instructor Notes

- This activity needs to be done on a sunny day.
- Please caution students to not look directly into the sun.
- Doing this activity in early morning or later afternoon will enable students to see the greatest changes of solar energy production from different tilts. (Doing the experiment while the sun is at its highest point will *not* produce significant difference in the data while changing the PV angle or the solar azimuth.)
- Some multimeters won't be able to detect meaningful amps from the panels. If your multimeters can detect amperage, have the students record amps in the activity sheets in order to calculate power (watts).
- During the azimuth variable testing, instruct students to recheck their solar elevation (angle) every time they take a new azimuth measurement to avoid error.
- The panels will need to have the small alligator clips attached to their wires in order to connect them to the multimeters. See the video here. The panels and multimeter can also be connected using separate 2-end alligator clips.
- During the azimuth variable testing, instruct students to recheck their solar elevation (angle) every time they take a new azimuth measurement to avoid error.
- It may be helpful to have students read the box about sun angles and the solstices and equinoxes before they work with the Sun Path chart. Have them locate the solstices and equinoxes on the chart.

Extensions and Variations

- Have students see if they can increase the energy produced by their panels by connecting two or more together. Experiment with connecting panels in series and parallel. Which would they predict would produce more voltage? If you have a multimeter that can measure 2 amps of current or more, you can also see which arrangement produces more current. By doing the math, Power (in watts) = voltage X current (W=VI), students can determine which arrangement produces more power. For some background on the relevance of this concept, read this Related Article in Scientific American http://blogs.scientificamerican.com/solar-at-home/2009/08/26/invert-your-thinking-squeezing-more-power-out-of-your-solar-panels/
- Build a small model solar powered house and work to maximize the sunlight available and to decrease energy lost. For a lesson plan go to: http://www.talkingscience.org/2011/03/building-a-solar-house/
- Experiment with voltage output by bringing in various light bulbs or a low voltage buzzer to see if the solar panels can light them up. Use a box to provide shade for the bulb to be able to determine if there is faint glow or none at all.

References/ For More Information

The Solar Sprint PV Panel: Basic Electricity Review – just what it says and a great reference!
http://chuck-wright.com/SolarSprintPV/SolarSprintPV.html

Teach Engineering Lesson: Solar Angles and Tracking Systems
Contributed by: Integrated Teaching and Learning Program, College of Engineering and Applied Science, University of Colorado at Boulder
http://www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_pveff/cub_pveff_lesson01.xml#assoc

U.S. Department of Energy Sunshot Initiative
Good site for career information as well as a discussion on the concentration of sunlight
http://www1.eere.energy.gov/solar/sunshot/index.html

U.S. Energy Information Administration-Energy Kids- Renewable Solar
http://www.eia.doe.gov/kids/energy.cfm?page=solar_home-basics

NREL: Dynamic Maps, GIS Data & Analysis Tools
http://www.nrel.gov/gis/solar.html

<u>Watt's Your Angle?</u>

Location:
Latitude:
Longitude:

Day 1
Date:
Time of Day:
Time of Solar Noon:
Temperature:

Constant Solar Azimuth:

	PV Panel Angle	**Voltage**	**milliAmps (if detectable)**	**milliWatts (if possible)**
First Reading				
Second Reading				
Third Reading				
Fourth Reading				
Fifth Reading				
Sixth Reading				
Seventh Reading*				

Constant Tilt:

Solar Azimuth	**Voltage**	**milliAmps (if detectable)**	**milliWatts (if possible)**

* Note- Depending on the time of year it is you may have fewer then seven readings.

Day 2 (Optional)
Date:
Time of Day:
Time of Solar Noon:
Temperature:

Constant Solar Azimuth:

	PV Panel Angle	**Voltage**	**milliAmps (if detectable)**	**milliWatts (if possible)**
First Reading				
Second Reading				
Third Reading				
Fourth Reading				
Fifth Reading				
Sixth Reading				
Seventh Reading*				

Constant Tilt:

Solar Azimuth	**Voltage**	**milliAmps (if detectable)**	**milliWatts (if possible)**

Questions

1. Graph the relationship between panel angle and voltage at the constant solar azimuth:

2. Graph the relationship between solar azimuth and voltage at the constant tilt:

3. What combination of tilt and azimuth gives the optimum performance?

4. How does the optimum tilt compare to your latitude? Why is is different or the same?

5. If done on two separate days, how are the results similar and different? Was temperature a factor in the difference?