

A photovoltaic systems laboratory activity plan for Taiwanese senior high schools

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ABSTRACT: In this article, the author presents a laboratory activity plan for photovoltaic systems and an outline for student evaluation. A laboratory curriculum is developed in order to assist teachers in achieving the teaching goal for this activity. The laboratory teaching activity includes an introduction to photovoltaic energy, testing photovoltaic cells and activity evaluation. The photovoltaic cell test covers seven topics: experimental set-up, operating instruments, constructing photovoltaic cells, irradiance activity, light activity, temperature change activity and data summary. The laboratory activity was first offered in the first semester of the 2006 academic year at a senior high school in Taiwan.

INTRODUCTION

Renewable energy is an important and economical energy source for electricity generation. Major sources of renewable energy include hydro, biomass, geothermal, solar and wind. Due to the monumental growth in renewable energy use for electricity generation and in the interest of keeping students abreast of current engineering developments and trends, it is necessary and timely to develop an instructional course for students on renewable energy [1].

Education is an important first step in promoting renewable energy technologies. Renewable energy is an ideal topic for classrooms. A unit on renewable energy can be used to teach basic scientific principles: the sun as the source of the Earth's energy, energy conversion from one form to another, or electricity generation [2].

Solar photovoltaic technologies provide an attractive renewable energy solution for growing world energy demands. Solar energy is clean, efficient, renewable and inexhaustible. Because the light source is the sun, photovoltaic cells are often called *solar cells*. The word photovoltaic comes from *photo*, meaning light, and *voltaic*, which refers to producing electricity. Photovoltaic cells are often referred to as *PV* and is a technology for converting light directly into electricity. Most PV cells have two layers of semiconductor material: the same material used in computer chips. When light hits the photovoltaic cell, electrons travel from one layer to the other, creating voltage that can power an electrical device.

Teachers are often expected to design instructional activities that integrate theoretical knowledge and promote students' creative thinking [3]. Interview details have shown that constructivist learners tended to explore deeply the involved concepts of laboratory activities, resulting in a richer understanding [4]. This study developed several laboratory

activities that provide a convenient and flexible way for senior high school students in Taiwan to learn about photovoltaic systems. The key areas covered in these laboratory activities are: experimental set-up, operating instruments, constructing photovoltaic cells, irradiance activity, light activity, temperature change activity and data summary. These laboratory activities assist students to gain an overview of solar photovoltaic energy systems. Another related experiment has students determine the overall efficiency of the photovoltaic power system [5]. A technology instructional design module development and validation process is also presented [6].

The early laboratory activity steps introduce students to photovoltaic systems and instruments. Later steps concentrate on the environmental effects of solar photovoltaic systems. The final laboratory activity section helps students develop an understanding of solar electricity and the criteria used in case studies. Teachers or educators try to design learning activities that facilitate the development of these attributes [7]. These laboratory activities have been developed to give students information about the important problems connected with PV from the photovoltaic effect, cell construction and technology to applications, including operating conditions, economical and ecological problems. In order to provide all students with some opportunities to conduct the laboratory work within a set time, it is required to reduce the session hours for laboratory experiments. Students will be able to complete an actual laboratory activity in the shortest possible time, as they will not be required to spend more time to become familiar with the laboratory equipment and the basic theory involved [8]. Thus, a two-hour laboratory session can be reduced to one hour without compromising the quality of education.

HOW A PHOTOVOLTAIC CELL WORKS

The PV cell was developed in the 1950s as part of the space programme. When light enters the cell, some of the photons

from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer to flow through an external circuit and back into the positive layer. This flow of electrons produces electric current. Figure 1 shows a typical photovoltaic cell. The fun begins when the two semiconductor types are intimately joined in an NP-junction, and the carriers are free to wander. Being of opposite charge, they move towards each other and may cross the junction, depleting the region they came from and transferring their charge to the new region. This produces an electronic field called a gradient, which quickly reaches equilibrium with the force of attraction from excess carriers. This field becomes a permanent part of the device, a kind of slope that makes carriers tend to slide across the junction when they get close [9].

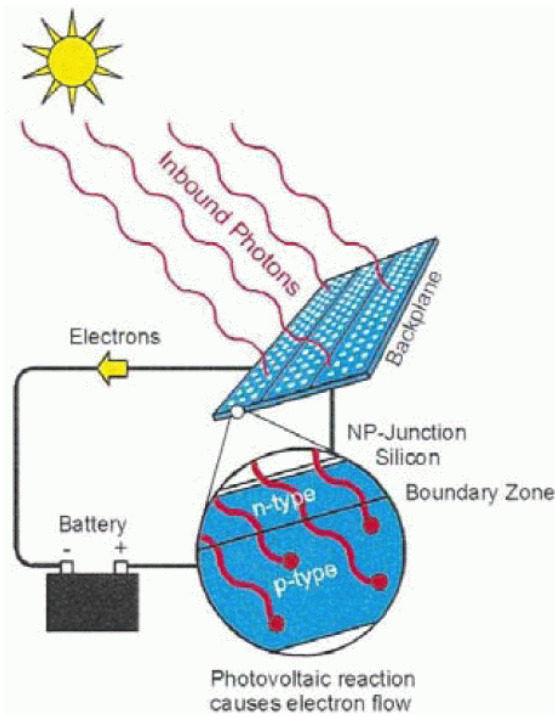


Figure 1: A typical photovoltaic cell.

LABORATORY ACTIVITY: TESTING PHOTOVOLTAIC CELLS

The purpose of this activity is to construct a photovoltaic system using a PV cell and instruments to learn how the environmental effects of light affect electricity generation. The students also learn how PV systems are connected to produce different voltages. Finally, students study how temperature affects PV cell efficiency. The defined activities have been closely related to the needs of senior high school students in Taiwan. Experts (eg university professors, experienced researchers) examined and used these activities, concluding that these teaching materials and experimental equipment were suitable for students.

TOPIC 1: SETTING UP FOR THE EXPERIMENTS MODULE

Before launching into the laboratory activities, students must first understand what is involved in the set-up for all experiments. After reading this section, students come away with a much better appreciation of how the system is structured for successful experimental execution. This experimental module combines PV cells, simulated solar light, digital multi-meter and a light meter used to construct a solar energy generator. The experimental module is shown in Figure 2.

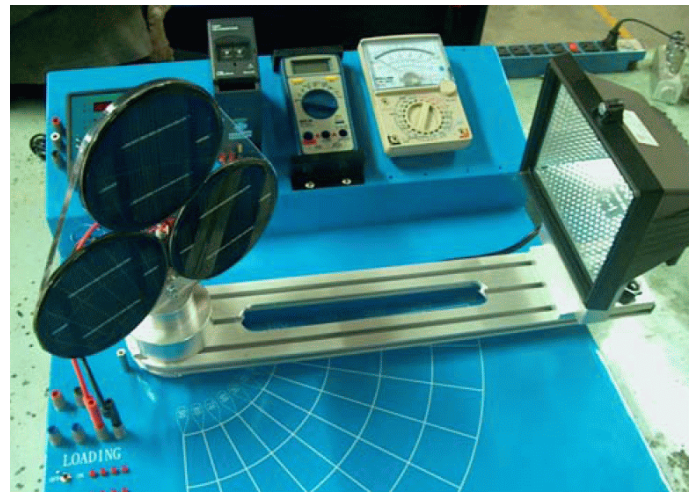


Figure 2: The experimental module.

TOPIC 2: OPERATING INSTRUMENTS

Two kinds of instruments are used in the experimental module. The operation procedures for these instruments are as follows:

1. Light meter operating procedure:

- Turn the meter ON or OFF with the ON/OFF key;
- Press the Lux/Fc key to select the unit of measure for light intensity;
- With the lens cap completely covering the light sensor, zero the meter by adjusting the screw on the right side of the meter for an LCD reading of 0.0;
- Remove the lens cap to allow the sensor to collect light;
- Read the light intensity measurement on the LCD;
- For over-range conditions, the *OL* icon will display. Select a higher range by pressing the *Range* key until a valid reading replaces the *OL* display;
- For the 20,000 range, multiply the displayed reading by a factor of 10.

2. Digital multi-meter (DMM) operating procedure:

2.1 DC voltage measurements:

- Insert the black probe into the black *Ground* jack and the red probe into the red jack;
- Always start in the highest range of the function being measured and work down from there. Note that these selection range areas are red in colour. Be sure to match the red test probe jack to the matching insert and the black jack to the black insert. Caution: to avoid possible electric shock, instrument and/or equipment damage, do not attempt to take any voltage measurement if the voltage is above 200V DC or if the voltage is unknown. The *Ground* jack potential should not exceed 500V measured to ground;
- Apply the test probes to the two points at which the voltage reading is to be taken. Be careful not to touch any energised conductors with any parts of your body;
- Turn the dial to the next lower range for a more accurate reading only if the reading is within that next lower range;
- When measurements are completed, disconnect the test probes from the circuit under test.

2.2 DC current measurements:

- Always start at the highest range of the function to be measured and move down from there;
- Insert the black probe into the black *Ground* jack, and the red probe into the blue *10A* only jack;
- Adjust the dial to the blue *10A* position. Note this area of the selection range is blue in colour to match the colour of the jack in which the red test probe should be inserted for this type of measurement only;
- Confirm the circuit in which the current is to be measured. Place the meter in series with the conductor carrying the current to be measured;
- If the reading is less than 200mA, you can move the dial to a lower selection for greater accuracy. Caution: before changing ranges, always confirm the circuit. Failure to do so could damage the meter or equipment under test and void the warranty;
- The mA ranges are fuse protected. To avoid possible electrical shock, meter damage and/or equipment damage, do not attempt to take mA current readings on circuits having more than 500mA of current flow.

TOPIC 3: CONSTRUCTING THE PHOTOVOLTAIC CELLS

The simplified equivalent circuit of a PV cell consists of a diode and a current source that are switched in parallel. The current generates the photo current, which is directly proportional to the solar irradiance. When two cells are wired together in series, their voltage is doubled while the current stays constant. When two cells are wired together in parallel, their current is doubled while the voltage stays constant.

1. Follow the safety instructions given by the teacher and attach the red wire from the PV cell to the red lead of the DMM meter (either clip or wrap the wires together);
2. Similarly, attach the black wires from the PV cell to the black lead of the DMM meter;
3. Use the simulated solar light on the PV cell to see if the voltage is read. If the DMM meter shows no voltage, check the wire connections;
4. Use the simulated solar light on the PV cell to see if current is read;
5. Use the simulated solar light on the series PV cell to see if voltage is read greater than single PV cell;
6. Use the simulated solar light on the parallel PV cell to see if the current read is greater than a single PV cell.

TOPIC 4: PERFORMING THE IRRADIANCE ACTIVITY

By increasing the irradiance level the number of electron-hole pairs separated increases and the induced photo current increases. The photo current is therefore proportional to the irradiance, thereby increasing the output power. The PV cell will be held at distances of 5 cm, 10 cm, 15 cm and 20 cm from a directional light source. The solar cell should be held facing directly at the light source. Record the voltage generated for all three distances from the light source in Table 1.

Table 1: Influence of irradiance.

Distance of Light Source	Voltage
5 cm	
10 cm	
15 cm	
20 cm	

TOPIC 5: PERFORMING THE ACTIVITY FOR LIGHT

1. Keeping the light constant (or the light source at a constant distance), cover the PV cell with a piece of coloured transparency film. Repeat with the other colours of transparency film and then use just direct light alone (or a light substitute). Record the voltage generated for all colours tested and for direct light in Table 2;

Table 2: Influence of colour on cell voltage.

Colour of Transparency Film	Voltage
Red	
Yellow	
Green	
Blue	
Violet	

2. Shade $\frac{1}{4}$ of the PV cell with a piece of cardboard or paper and take a reading. Shade $\frac{1}{2}$ of the PV cell and then cover the entire PV cell. Record the readings in Table 3;

Table 3: Influence of shading on cell voltage.

Amount of Shade	Voltage
No shade	
$\frac{1}{4}$ shade at one corner	
$\frac{1}{2}$ shade at one corner	
Entire shade	

3. Place the PV cell directly pointed at the light source. Using a protractor to determine the angle, slant the PV cell at 30° intervals away from the direct perpendicular position. Record the voltages generated at every 30° change in Table 4;

Table 4: Influence of tilt angle on cell voltage.

Amount of Tilt Angle	Voltage
No tilt	
30 degrees	
60 degrees	
90 degrees	
120 degrees	
150 degrees	

4. Take a magnifying glass and concentrate the light source on the PV cell. Measure the new voltage and record;
5. Take a piece of aluminium foil and design a light reflector for PV cell to concentrate the light shining on it. Measure the new voltage with the reflector attached and record.

TOPIC 6: PERFORMING THE ACTIVITY FOR TEMPERATURE CHANGES

1. Take a PV cell that is connected to the DMM meter and shade the PV cell directly under a lamp so that the cell becomes warm. Record this new reading in Table 5;
2. Place some crushed ice in a zip-lock bag, then set the PV cell on top so the cell becomes cold. Take four readings over a five-minute interval. Record the readings in Table 5.

Table 5: Influence of temperature on cell voltage.

Temperature	Voltage
Full light	
On ice after 5 minutes	
On ice after 10 minutes	
On ice after 15 minutes	
On ice after 20 minutes	

TOPIC 7: DATA SUMMARY

At the end of these topics, summarise the data by answering the following questions:

1. Which distance from the light source can get the most electricity?
2. Which colours allowed the most electricity to be generated?
3. What happens when the PV cell is shaded entirely?
4. Which degree allowed the most electricity to be generated?
5. What happens when the PV cell is cooled?

EVALUATION

In a continuing effort to improve the laboratory activity programmes, the teacher would appreciate students to take a few minutes to complete the following evaluation for the laboratory activity in Table 6. Open-ended comments are also asked of students to provide. These evaluation items are also examined by experts meeting for students to complete.

CONCLUSIONS

This laboratory activity was first offered in the fall of 2006 to 30 students. In keeping with the advances in photovoltaic system conversion technologies and the continued growth in renewable energy along with its impacts on electrical power systems, it is important and timely to develop photovoltaic system laboratory activities. Students were generally excited and receptive about these activities. Since this was the first offering of these activities future improvements are planned. These improvements include additional exercise problems and laboratory sessions on simulation models. The latter is

particularly desired since simulation enhances the understanding of fundamental concepts presented in the classroom.

The materials presented herein can be used as the starting point for other teachers or instructors considering offering a similar course on other renewable energy sources.

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Table 6: Evaluations for the laboratory activity.

Items	Evaluations	Strongly Agree	Agree	No Comment	Disagree	Strongly Disagree
1. The activity guide was organised						
2. The activity guide was east to follow						
3. The activity goals were clear						
4. The activities were more interesting						
5. The activities were appropriate for your level						
6. The background information was useful in understanding the content area						
7. The background information was clearly written						
8. The key terms were explained, understandable and useful						
9. The rubrics provided easy-to-measure guidelines						
10. The materials were well supplied						
11. The materials were helped in the teaching of the activities						
12. The assessments, overall, provided useful feedback on your progress						
13. The activities, overall, were useful and motivating						