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Design and Implementation of an Experiment Setup on Solar Electricity

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Abstract

PV module price has fallen 75% to below $1/w since 2008. There are over 17,500 MW of cumulative solar electric capacity operating in the U.S., enough to power more than 3.5 million average American homes, 36%, over 49,000 installations, of all new electric capacity is from solar in 2014. It means that a new solar project has been installed every 3 minutes. The growth of solar industry boosts the economy and creates 174,000 jobs in the U.S. As a part of PV system, module-level, string, and central power electronics are well developed and the market for global PV micro-inverters and power optimizers will more than triple in the coming years, rising to more than $1 billion in 2018. In order to train the workforce to meet the future demand, solar-energy related courses are developed at the University of Bridgeport. One course, Sustainable Energy lab, was offered to facilitate the education in renewable energy. One of experiments is focused on the PV system and it consists of solar position calculation, site survey, VI curve measurements, buck-booster converter and energy storage. Finally, a stand-alone PV system, is setup to deliver DC and AC power to the loads. Through this experiment, the students are expected to understand the working principles of the PV system and the function of each component.

1. Introduction

PV module price has fallen 75% to below $1/w since 2008 [1, 2]. There are over 17,500 MW of cumulative solar electric capacity operating in the U.S., enough to power more than 3.5 million average American homes, 36%, over 49,000 installations, of all new electric capacity is from solar in Q3 2014. This means that a new solar project has been installed every 3 minutes. As a part of PV system, module-level, string, and central power electronics are well developed and the market for global PV micro-inverters and power optimizers will more than triple in the coming years, rising to more than $1 billion in 2018. The growth of solar industry boosts the economy and creates 174,000 jobs in the U.S. [3]. In order to maintain this growth and meet the future demands of this industry, a skilled workforce is necessary. Therefore, solar-electricity related courses are offered by more and more universities.

At the University of Bridgeport, one course, EE479 Solar Energy and Solar Cells, is offered once a year and it covers the fundamental theories on solar cells and the PV system. Since 2010, a lab, EE492 Sustainable Energy Lab, has been developed and it covers solar electricity, fuel cells, rechargeable batteries, and power electronics. Because there is no a well-designed experiment available, we designed our experiment on the solar electricity and we updated it every year. The purpose of the paper is to share our work with the community in the solar electricity experiment.

2. Objectives of the experiment

The experiment in the solar electricity will facilitate the understanding of the theories obtained through the course, Solar Energy and Solar Cells, in the following aspects:

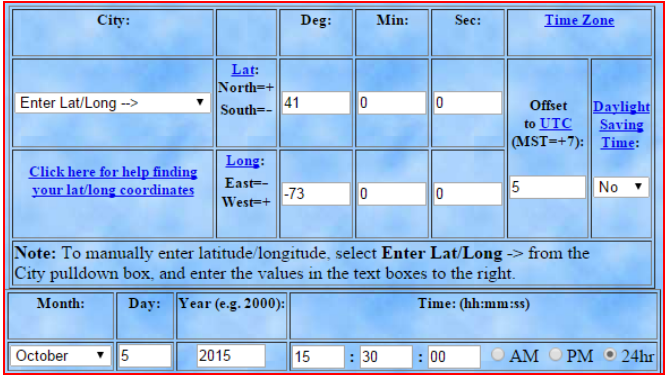
- calculate and measure the solar position
- conduct site survey

- o understand the shading effects
- o measure the current-voltage (IV) curve

3. Experiment design

3.1 Solar Position and site survey

Table 1 The interface for the calculation of solar position from NOAA

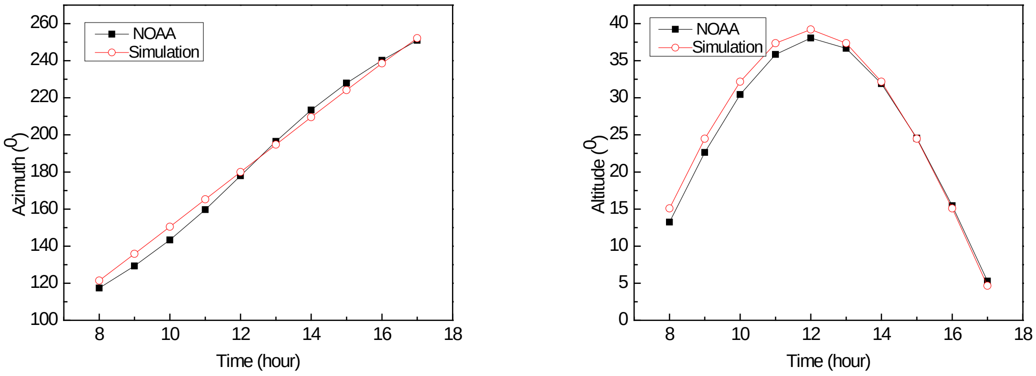


City:		Deg:	Min:	Sec:	Time Zone	
Enter Lat/Long --> ▼	Lat: North=+ South=-	41	0	0	Offset to UTC (MST=+7):	Daylight Saving Time:
Click here for help finding your lat/long coordinates	Long: East=- West=+	-73	0	0	5	No ▼

Note: To manually enter latitude/longitude, select **Enter Lat/Long** -> from the City pulldown box, and enter the values in the text boxes to the right.

Month:	Day:	Year (e.g. 2000):	Time: (hh:mm:ss)
October ▼	5	2015	15 : 30 : 00 ○ AM ○ PM ● 24hr

The solar position can be found through the website of National Oceanic and Atmospheric Administration (NOAA). Table 1 shows the interface for the solar position from NOAA. In our calculation, the inputs include the local altitude, day, and time. So the Julian Day, declination angle, and hour angle can be calculated [4]. Furthermore, the solar altitude and azimuth angle can be determined. In the lab, LabView is extensively used for the simulation and data acquisition. Figure 1 shows the comparison of the solar altitude and azimuth between the calculation and the data from NOAA. This comparison indicates that the calculation is quite accurate.



(a) (b)

Figure 1 Azimuth (a) and solar altitude (b) on Feb. 20, 2014in Bridgeport, CT [5]

For a site survey, a solar PathFinder is used to evaluate the shading of the surrounding building or trees and other factors that will affect the PV system production. Figure 2 (a) shows that the students are working on the Solar PathFinder and Figure 2 (b) shows the result on the sunpath diagram. In addition, the students can also find the information from the Solmetric website to determine the best optimal azimuth and tilt angles for the solar panels [6].


(a) (b)

Figure 2 The experiment on site survey (a) and the result on the Solar PathFinder (b)

3.2 Shading Effects

In order to understand the shading effect on the PV output, one 250W solar panel is set up for testing as shown in Figure 2 (a) with the tilt angle fixed as 10^{o}. In this testing, the students cover the PV panel in two different ways: one row as in Figure 3 (a) and one column in Figure 3 (b).

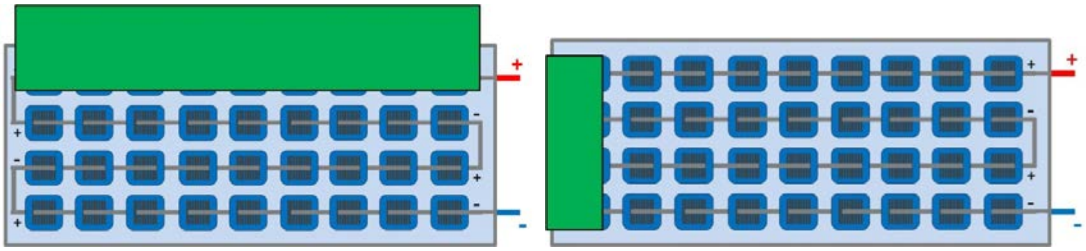
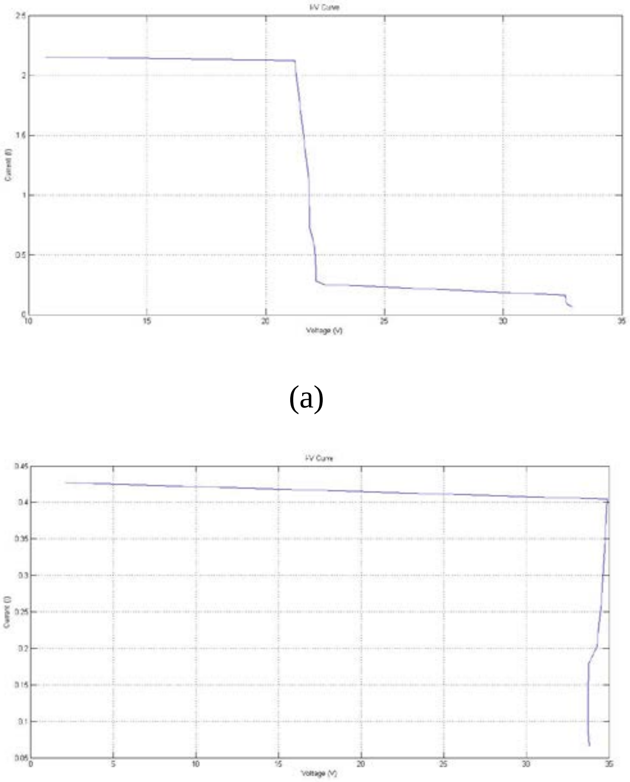

(a) (b)

Figure 3 the covering of one row (a) and one column (b) for shading effect experiment

For the measurement of IV curve, a programmable DC electronic load is connected to the panel and the power to the electronic load is from a rechargeable lead acid battery through an inverter. Figure 4 (a) and (b) shows the two results corresponding to the two different shading. The students are required to explain these results with bypass diodes in the solar panel.



(a)

(b)

Figure 4 The VI curves due to two different shading: one row covered (a) and one column covered (b)

3.3 Solar simulator and PV panel emulator

Figure 5 One 150W LED Flood Light with color temperature as 6000K

The experiment on the solar energy is significantly affected by the weather. Especially in winter, classes are often cancelled due to the snowing or raining and it is difficult to reschedule the classes. In order to mitigate the weather's effect, solar simulator is used and a PV panel emulator was developed.

Figure 5 is a daylight white LED light that can be used as a solar simulator. The color temperature is 6000K which is very close to the surface temperature of the sun. Thus, the IV measurement and the testing of shading effect on the solar panel output can be conducted indoor when weather outside is not good or unstable.

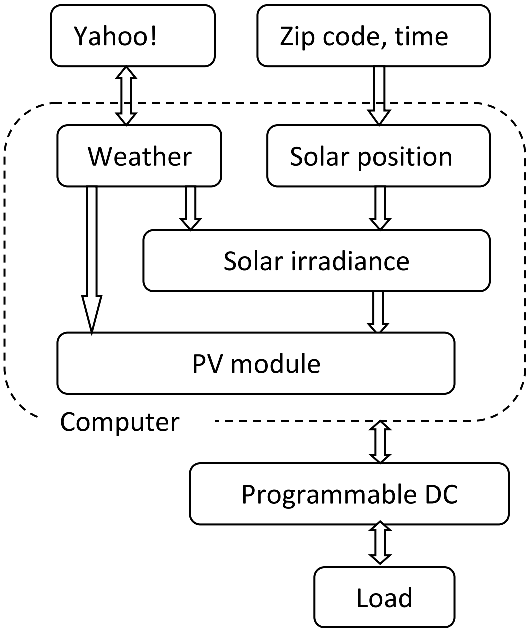
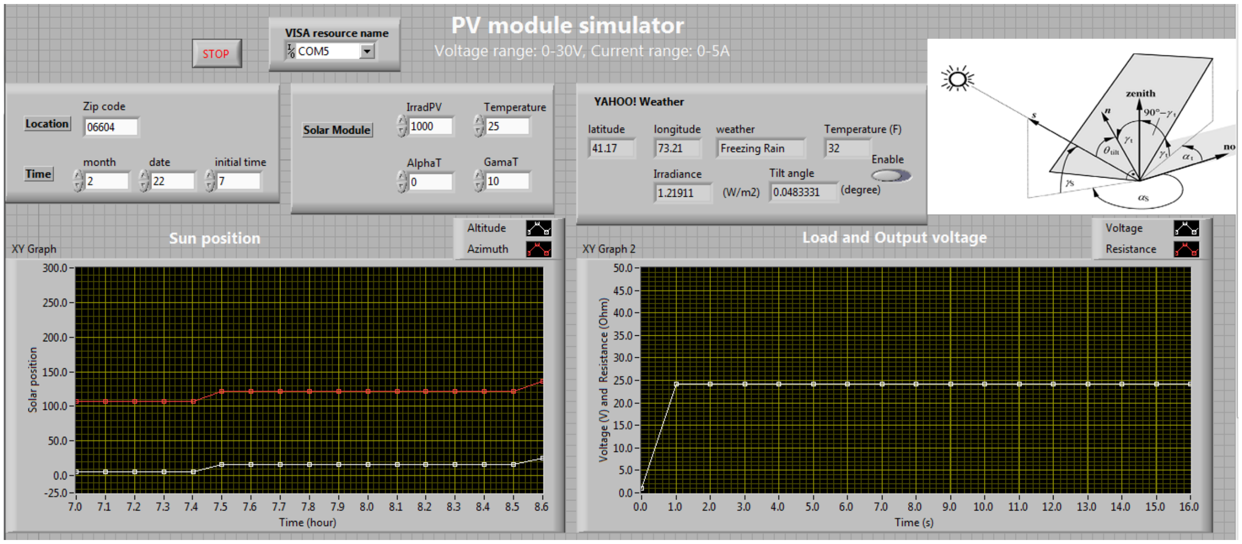


Figure 6 The structure of the PV module simulator



Voltage range: 0-30V, Current range: 0-5A

VISA resource name: COM5

Zip code: 06604

month: 2
date: 22
initial time: 7

IrradPV: 1000
Temperature: 25
AlphaT: 0
GamaT: 10

latitude: 41.17
longitude: 73.21
weather: Freezing Rain
Temperature (F): 32
Irradiance: 1.21911 (W/m2)
Tilt angle: 0.0483331 (degree)

Figure 7 The front panel of the LabVIEW program

In order to get the IV curve from the panel and test or develop power electronics, a solar panel simulator was developed with the model shown in Figure 6. The inputs include the zip code, date, and initial time. The output is the power to the load. The software controlling the system includes four modules: the weather module, the solar position module, the solar irradiance module, and the PV module. The power output generated is from programmable DC power source which communicates with the software.

$$X_{ambient} = \left[\alpha\left(T_{STC} - T_{ambient}\right) + 1\right] X_{OC,rated}$$

The PV module simulated is close to real one, Ameresco Solar BP 90 Watt [7]. The temperature effect on the module is considered in the following equation,

Here, α is a temperature coefficient and X is open-circuit voltage, short–circuit current, voltage at MPP, or current at MPP.

The four blocks in Figure 6 are implemented as a LabVIEW program with the front panel shown in Figure 7. The system can run in two modes: real-time weather and constant weather. In the first mode, the system power output is affected by the local weather. While in the second one, the solar irradiance is set as any constant.

The hardware, in the system implementation and testing, includes a Programmable DC Power Supply (BK Precision 1788 with voltage range 0-32V and current range 0-6A) and a Programmable DC Load (TekPower 3711A). Since the voltage and current are unstable when the load from the Programmable DC load is less than 4Ω, 10W ceramic resistors are used.

Figure 8 shows the current-voltage curves from the system and the calculation under 1000, 800, and 200 W/m^2. As the solar irradiance drops, the IV curve shifts to the lower left. The pairs of curves indicate that the real output is close to the one from calculation.

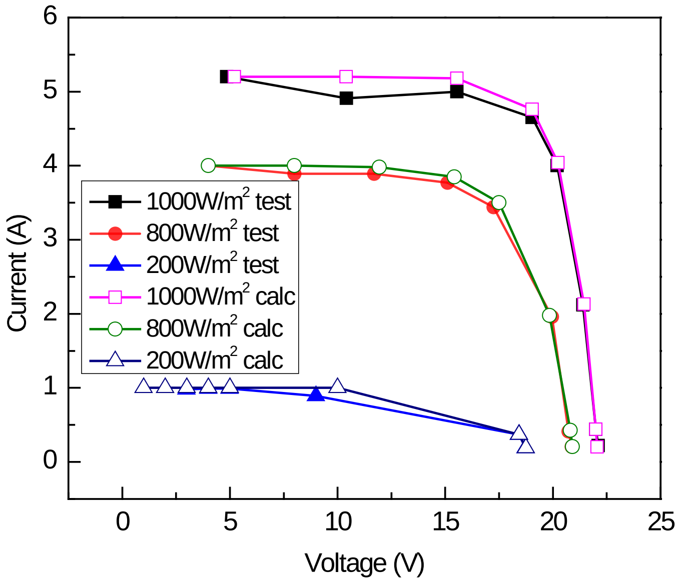


Figure 8 The current-voltage curves from the system and calculation under different irradiance

3.4 Power electronics

Figure 9 The power-pole board and Arduino UNO board

One maximum power point tracker (MPPT) is developed through a buck-boost converter with the setup shown in Figure 9. In the power-pole board developed by the University of Minnesota, the inductance and the capacitance of the buck converter are 100 μH and 697 μF, respectively. An Arduino UNO board is used to generate PWM wave, the duty ratio is adjusted based on the converter's output voltage and current.

With the rechargeable batteries and the components discussed above, a stand-alone dc power system is set up and the students can further do experiments on the power flow management and system control.

The student outcomes for this experiment were to make the student more aware of solar electricity techniques and the role they will played as engineers. Student outcome assessment was performed through their group lab reports with the questions: How does the solar position changes with the altitude and the date? How do we measure the IV curve of a solar panel? How does the shading affect the solar panel output? According to the lab report, it indicates that the experiment helps the students understand the theories in the lectures; they also obtain certain skills in the testing, system design and implementation of the solar electricity; they have more interested in a renewable energy career. The experiment also makes the students realize that the engineers are not only familiar with solar panels but also the balance of system, such as power electronics.

4. Conclusion

The solar energy experiment is designed for the students to comprehensively understand the energy conversion and get hands-on experience to measure, test, and set up the PV system. Some components are introduced or developed to conduct the experiment indoor if the weather is not good. The stand-alone PV system can also be used as a platform for the graduates' research.

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