Microcontroller-based Experiment Setup for Learning the Basic Concepts of Solar Photovoltaic

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Abstract- In this article, we describe the construction and operation of a low-cost experimental system to demonstrate the fundamental concepts of solar photovoltaic cells. The major goal of this project is to provide students with basic instrumentation and methodologies to learn fundamental concepts of solar photovoltaic cell and its application. The system runs under the Windows operating system and is composed of an Arduino UNO ATmega328p data acquisition board as well as current and voltage sensing elements. A software written under the open-source programming language platform was used to program the microcontroller while the sun path simulation software was used for tracking the sun. The site location coordinates were determined by using a Google maps application. The experiments were performed throughout the day and the current and voltage data were automatically captured and graphically presented in an excel spreadsheet. It was found that the fill factor and power conversion efficiency of the solar photovoltaic cells were calculated to be 0.68 and 5.68% respectively.
Keywords – Arduino UNO, Engineering Education, Open Circuit Voltage, Short Circuit Current, Solar Photovoltaic

I. INTRODUCTION

Fossil fuels, such as oil, natural gas, and charcoal are still the world's main sources of energy. However, due to the side effect of carbon based materials, they tend to pollute the environment and contribute to the greenhouse effect. One of the solutions to overcome this problem is to use renewable energy such as the energy from the sun. Solar energy is one of the most abundant sources of clean energy that can be utilized to generate electrical energy by the photovoltaic effect. As a result, a renewable energy policy to encourage industries and individuals to utilize renewable-energy resources in power applications has been initiated [1]. On the other hand, school is the best place to start nurturing future generations to create awareness on the importance of clean energy production through renewable energy application. Teaching at the school level should emphasize on integrating science, technology and engineering knowledge and skills to enable the students to appreciate the modern socio-technical systems [2,3]. This paper elucidates the design and development of electronics engineering education microcontroller-based experiments to study the electrical energy properties produced by a polycrystalline solar PV panel.

II. EXPERIMENTAL METHODOLOGY

2.1 Location Selection and Sun path diagram

The coordinates of any location on earth can be easily obtained through internet software such as Google maps. The position selected by this application can be converted to latitude and longitude coordinate format. These data serve to determine the position of the sun for the location of study. Universiti Pendidikan Sultan Idris (UPSI) Proton City campus in the district of Tanjong Malim, Perak state of Malaysia was selected as a location to carry out this experiment. According to Google maps it is located at 3.72096°N latitude and 101.5243°E longitude. A preceding requirement for the installation of solar photovoltaic panels is the information about optimum orientation and tilt surface at which maximum solar radiation can be collected. This angle depends on the daily, monthly and yearly path of the sun [4]. Latitude and longitude data generated by Google maps application are used to determine the position of the sun at a certain time and date. It allows students to determine the position of the sun based on the location, date and time. The position of the sun and its path are constantly changing based on the change in position of the earth around the sun throughout the year. The sun path diagram is a visualization of the sun's path through the sky and formed by plotting azimuth and elevation angles of the sun in a given day. Since sun path data for Tanjong Malim is not indicated by the software, the nearest city, Kuala Lumpur (3.12°N latitude and 101.55°E longitude) was selected [5].

2.2. Design Concept and Specification

The Arduino microcontroller-based experiment kit was designed and set up to measure the electrical power generated by the solar panel. The power measurement is based on the DC voltage and current produced by the solar panel at a specific load. Figure 1 shows the power measurement system block diagram of a solar photovoltaic (PV). Solar PV panel absorbs the photons and convert them into electron-hole pair carriers. The current and voltage generated by the solar panel was sensed by the current and voltage sensors respectively. These inputs were processed and interpreted by an Arduino microcontroller and displayed on the computer. The field performances of solar PV panel were characterized by measuring the relationship between panel voltage, current, and power output.

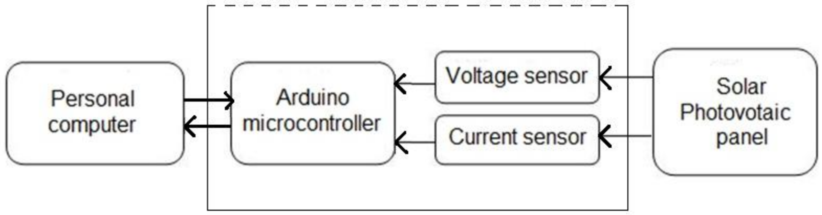

Figure 1 Flowchart of Arduino microcontroller solar PV power measurement system

2.3. Software and Hardware Integration

Arduino microcontroller is an open-source electronics based on easy-to-use hardware and software. The Arduino Software (IDE) runs on Windows, Macintosh OSX, and Linux operating systems. On the contrary, most other microcontroller systems are limited to the Windows platform only. Arduino board is completely open-source, empowering users to build them to their particular needs [6]. The motherboard, as shown in Figure 2, has several input ports which are used to measure the voltage and current generated by the solar panel. These data will be fed to a computer through an output port where output power will be computed.

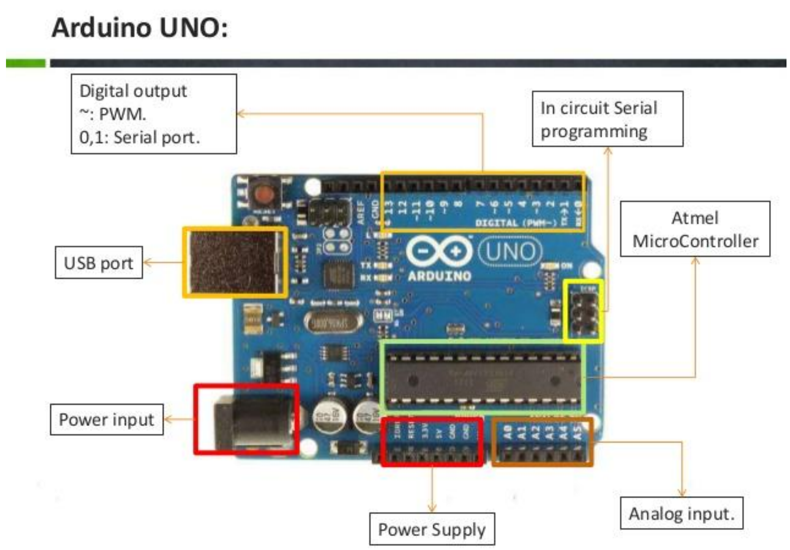

Figure 2 Arduino microcontroller board

III. EXPERIMENT AND RESULTS

3.1 Experimental Procedures

To run the experiment, several steps have been set as follows:

First step: Locate the position of the desired location for solar installation. Explore on longitude and longitudinal concepts on the world map using Google maps application [7].

Second step: Determine the sun position for specific date and time based on the latitude and longitude point of selected location using the available internet application [4].

Third step: Measure the angle of zenith or declination angle of the sun path at a specific date. The maximum value of declination angle is 23.450 [4,8,9]. Figure 3 shows the elevation angle position (as refer to the horizontal axis) for a selected date of a year. In this experiment, the solar panel declination or angle tilts (θT) was fixed to 13o which is the solar declination on the day of the experiment.

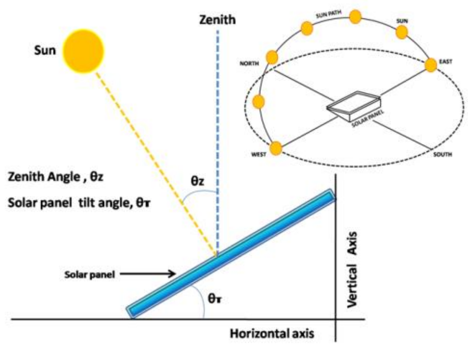

Figure 3 Solar panel tilt angle. The insert is the sun path diagram

Fourth step: Prior to making the connection of voltage and current sensors to the microcontroller, write the IDE Arduino software programming coding using a PC.

Fifth step: Determine the position of the sun based on the location information, time and date and jot down the data in a standard table format. The azimuth and elevation angles of the sun on the day of the experiment are as shown in Table 1.

Table 1 - Sun Azimuth and Elevation angles

Time	Azimuth angle	Elevation angle
07:12	76.9	0.00
08:00	77.44	11.18
09.00	77.32	25.75
10.00	76.05	40.32
11.00	72.59	54.74
12.00	63	68.67
13.00	24.79	79.74
14.00	312.21	76.03
15.00	291.65	63.09
16.00	285.49	48.87
17.00	283.13	34.36
18.00	282.38	19.78
19.00	282.62	5.27
19.23	282.93	0.07

Voltage, Current and Power measurement

The microcontroller based electronic experiment set up for the student to perform the experiment is shown in Figure 4. The PV panel declination angle (θT) was set to approximately 13° to the north. The data acquired by the microcontroller during the experiment were used to calculate the power output from a solar PV panel.

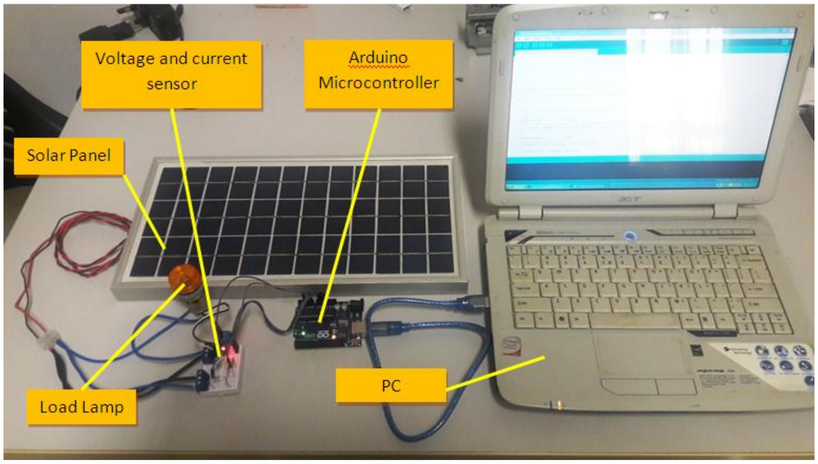

Figure 4 Arduino microcontroller-based solar PV experiment setup

The data obtained from the experiment for voltage, current and power output is listed in Table 2.

Table 2 - Voltage, current and power measurements

Time	Voltage (V)	Current (A)	Power (W)
07:15	8.8	0.025	0.22
07:30	13.7	0.025	0.34
07:45	16.2	0.020	0.32
08:00	17.8	0.029	0.52
09.00	19.2	0.039	0.75
10.00	19.0	0.019	0.37
11.00	18.9	0.010	0.18
12.00	19.6	0.010	0.19
13.00	18.3	0.034	0.63
14.00	18.6	0.025	0.46
15.00	18.8	0.035	0.65
16.00	18.6	0.010	0.18
17.00	18.6	0.030	0.55
18.00	18.2	0.020	0.36
19.00	14.6	0.014	0.21
19.15	10.1	0.014	0.15

Figure 5 shows the voltage measurement graph of the day, which was plotted using the data measured by a voltage sensor as in Table 2. As can be seen, the voltage started to increase gradually from 7.15 am to 8.30 am. Continue with a constant reading between 8.30 am to 6.00 pm that is almost 10 hours of full sunshine. Finally, the voltage readings start to decrease from 6.30 pm to 7.15 pm. The maximum voltage is 19.6V at 12.00 pm and the highest current reading is 0.039A which was captured at 9.00 am.

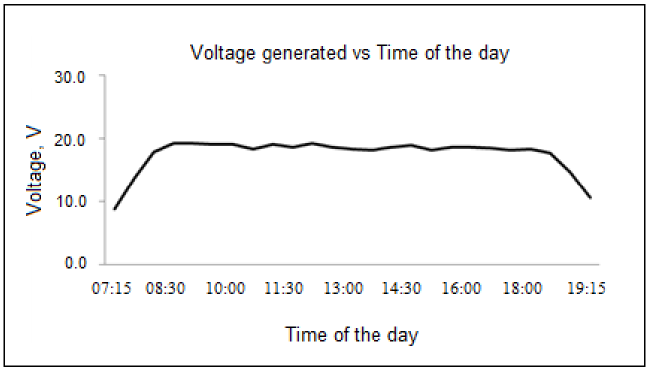

Figure 5 The voltage generated by solar PV

In order to verify the solar PV cell performance, the electrical parameters of solar cell, such as open circuit voltage (VOC), short-circuit current (ISC), maximum voltage (Vmp) and maximum current (Imp) were measured using a circuit [10,11] as shown in Figure 6. This experiment was conducted during midday to get the most solar irradiance from the sun. The solar panel was connected to a rheostat which acts as a variable load. Figure 7 shows the graphs of current and power versus voltage or better known as I, P versus V characteristic curves.

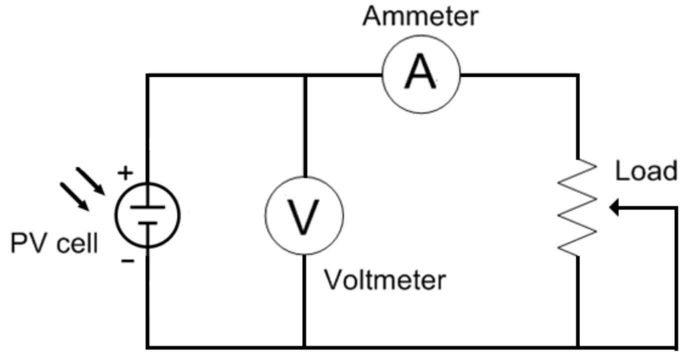

Figure 6 Experimental setup to measure the current - voltage (I-V) characteristics generated by the solar PV panel

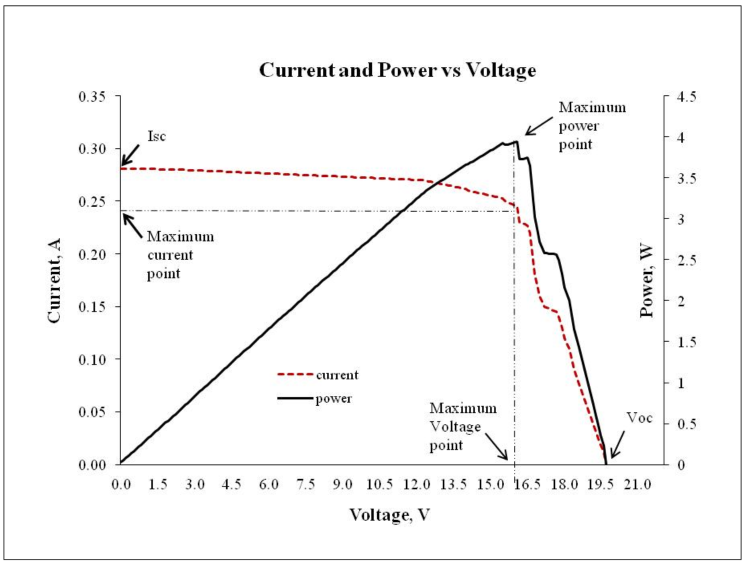

Figure 7 Current and Power vs Voltage curves for the solar PV panel

From the graph plotted in Figure 7, it can be seen that the maximum voltage and current are 16.1V and 0.245 A respectively, and the maximum power generated by the solar PV panel is 3.95 W. The fill factor and power conversion efficiency were calculated to be 0.68 and 5.68% respectively. The results obtained from the experiment were compared with the data from the manufacturer. It was found that the experimental results are very close to the manufacturer specification.

IV. CONCLUSION

We have presented, an easy to build, inexpensive educational laboratory system for high school students to study the fundamental solar photovoltaic effect. The implementation of the system is based on the Arduino UNO platform for data acquisition and control. Software written under the open-source programming language platform was used to program the microcontroller while the sun path simulation software was used for tracking the sun. The site location coordinates were determined by using a Google maps application. The system was designed to assist students in developing engineering design skills by learning the fundamental aspects of solar photovoltaic cell. By incorporating a user-friendly, low-cost microcontroller, this project is hoped to attract students' interest to perform a real-time experiment at the site in finding the power generated by a fixed tilt angle solar panel. Experiments were also done to find the electrical parameters of the solar PV panel.

V. ACKNOWLEDGMENT

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