Chemistry: Bulgarian Journal of Science Education | Volume 28 Number 6, 2019 | Природните науки в образованието

Education: Theory and Practice
Науката за образованието: теория и практика

Physics is an ever young science, Varna, October, 27 – 29, 2017
Физиката – вечно млада наука, Варна, 27 – 29 октомври 2017 г.

ELABORATION OF A LAB EXERCISE TO ANALYZE THE CHARACTERISTICS OF PHOTOVOLTAIC PANELS THROUGH A V-I ELECTRONIC UNIT

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Abstract. A lab exercise has been developed to teach students how to monitor and analyze basic characteristics of a photovoltaic (PV) panel. The exercise configuration is based on an electronic unit, previously constructed and reported by the authors. It is applied to measure and record the PV panel voltage at different current loads. Then the Volt-Ampere (V-I) and the output (P-V) characteristics of a PV panel are analyzed. The procedures are done for different light sources and different filters. The analysis and the visualization is executed by a software, developed previously by the authors.

Keywords: lab exercise; photovoltaic panel; current vs. voltage characteristic; power output vs. voltage characteristic

Introduction

Photovoltaic and solar-thermal panels generate free electricity by converting sunlight into electricity or transferring the sun's heat to heating and ventilation systems. The usage of solar panels to produce energy offers many benefits, which include reductions in the costs associated with generating electricity. Solar panels also offer pollution-free power sources and allow new levels of independence to energy clients. Nations that have to obtain oil and other fuel sources from other countries are beholden to their suppliers. Such countries may find it necessary to compromise their national safety or principles in order to maintain trade with their suppliers. Communities and nations who use renewable energy systems reduce or eliminate their dependence on foreign fuel sources. That is why it is important for universities to prepare highly qualified specialists in the field of renewables, including photovoltaic (PV) panels.

The need for innovative laboratory exercises on the newly discovered specialty "Eco-Energy Technologies" at the Faculty of Physics and Technology of Plovdiv University "Paisii Hilendarski" motivated us to develop a system, analyzing the main characteristics of photovoltaic panels. The main objective is to acquaint students with the characteristics of modern panels and under what conditions they produce maximum power. For this purpose, it is necessary to present the two main relations, the voltage current (IV) known as the volt-ampere characteristic, on which basis the power characteristic of photovoltaic panels is calculated and presented in graphical form. This general goal of this paper is to present a lab exercise, elaborated by us and presented here, using the PV power analyzer system (*PV-PA 1A*), including a software and hardware parts (Sotirov et al., 2016a; 2016b), previously developed by the authors to explore the characteristics of photovoltaic panels.

Theoretical basis of PV cells

A solar (photovoltaic) cell is an electrical device that converts the energy of light directly into electricity through the photovoltaic effect, which includes both physical and chemical processes (Shockley & Queisser, 1961). The photovoltaic effect is closely related to the photoelectric effect (Serway, 1990). In either case, light is absorbed, causing excitation of an electron or other charge carrier to a higher-energy state, specifying that for the photovoltaic effect the excited charge carrier is still

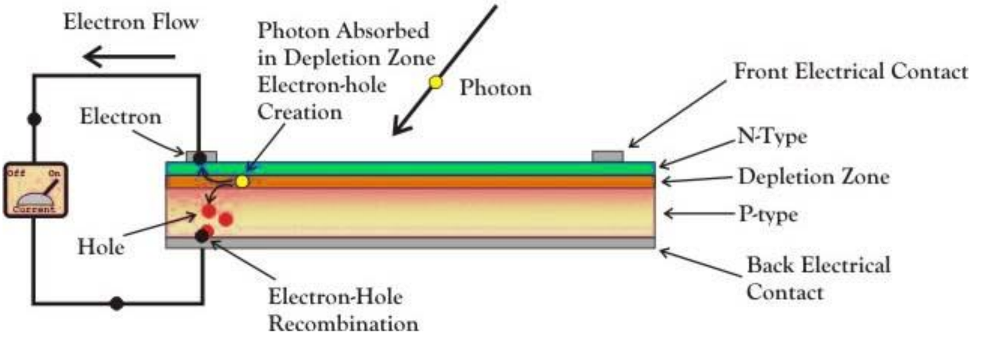


Figure 1. Characteristics of the PN junction

confined within the material.

In the case of a p-n junction solar cell, illuminating the material creates an electric current as excited electrons and the remaining holes are moved in different directions by the built-in electric field of the depletion region.[1)] A solar cell is in fact a PN junction with a large surface area. The N-type material is kept thin to allow light to pass through to the PN junction (Fig.1).

The depletion region is the area around the PN junction where the electrons from the N-type silicon, have diffused into the holes of the P-type material. When a photon of light is absorbed by one of these atoms in the N-Type silicon it will dislodge an electron, creating a free electron and a hole. The free electron and hole has sufficient energy to jump out of the depletion zone. If a wire is connected from the cathode (N-type silicon) to the anode (P-type silicon) electrons will flow through the wire. The electron is attracted to the positive charge of the P-type material and travels through the external load (meter) creating a flow of electric current. The hole created by the dislodged electron is attracted to the negative charge of N-type material and migrates to the back electrical contact. As the electron enters the P-type silicon from the back electrical contact it combines with the hole restoring the electrical neutrality.

To make it clear what the photo elements (cells) are, we'll look at the three options that are encountered. The first-generation photoelements consist of a single-layer silicon p-n diode (p-n transition diode) with a large area which, in the presence of sunlight, is capable of generating electrical energy. Second-generation photoelements are based on multilayer p-n diodes (Jeon et al., 1992). Each layer is designed to absorb light waves with increasing wavelength (decreasing energy). This absorbs much of the solar spectrum and increases the amount of energy absorbed. Third generation photo elements do not use the traditional p-n transition. These include organic polymer batteries, photoelectrochemical batteries, and semiconductor nanocrystalline solar batteries. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels.

Performance characteristics of a PV panel

The industry standard against which all PV modules are rated and can be compared is called Standard Test Conditions (STC). STC is a defined set of laboratory test conditions which approximate conditions under which solar panels, or PV modules, might be used. Although there are other standards that offer better real-world approximations, STC offers the most universal standard.

Every type of solar panel has unique performance characteristics which can be graphically represented in a chart. The graph is called an "I-V curve", and it refers to the module's output relationship between current (I) and voltage (V) under prevailing conditions of sunlight and temperature. The curve looks like a seated person's leg (Fig. 2 – red curve).

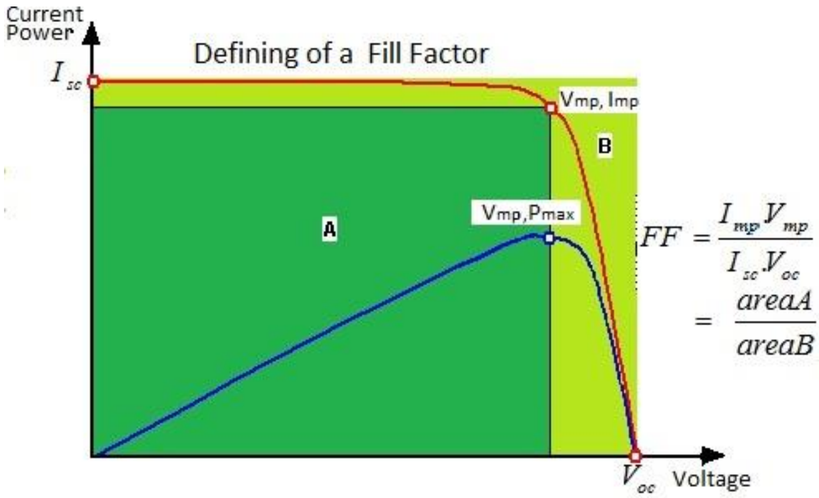


Figure 2. I-V curve (red) and P-V characteristic (blue) of a PV panel of maximum 5W

Theoretically, every solar panel has multiple I-V curves one each for all the different combinations of conditions (Ibrahim, 2011) that would affect the STC rating parameters above: temperature, air mass, irradiance etc.

The ideal position on any I-V curve – the sweet spot where we can collect the most power from the module, is at the “knee”. That’s the maximum power point (MPP).

To study the characteristics of photovoltaic panels, we need to know basic dimensions; (I_{sc}) – Short circuit current; (V_{oc}) – Open circuit voltage; (I_{mp}) – Rated current; (V_{mp}) – nominal voltage; (MPP) – the point of maximum power; FF – Fill-Factor i.e. the efficiency factor of the solar element. A volt-amperage characteristic is created that gives an idea of generating the photoconduct, for which purpose the area is irradiated with light[2)] (Van Dyk, 2005).

The FF-factor is used to evaluate the properties of photovoltaic panels, also known as the efficiency factor, and should be as close as possible to one (Zhelyazova et al., 2013). It can be determined by Eq. (1):

$$F = \frac{I_{mp} . V_{mp}}{I_{sc} . V_{oc}} \qquad (1)$$

Another basic parameter of a photovoltaic panel is its efficiency coefficient, which is the ratio of the output electric power to the input radiant power (Eq. (2)).

$$\eta = \frac{P_{OUT}}{H.S}.100\% \qquad (2)$$

where η is the efficiency factor, P_{out} – output power ($I_{mp}.V_{mp}$), H – radiant energy falling on the photoelectric unit in mW / cm^2, and S – active area of the photoelectric in square centimeters.[3)]

Basic characteristics of the *PV-PA 1A* module

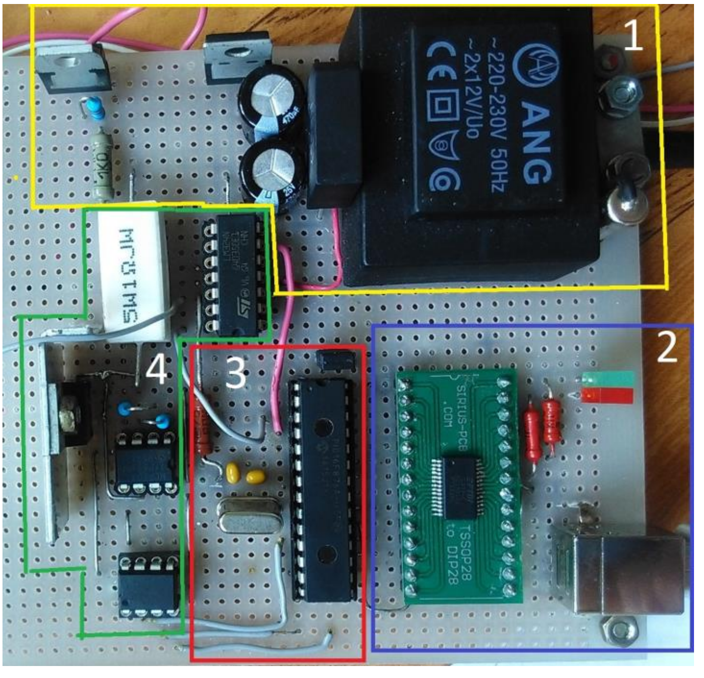


Figure 3. Basic elements of the *PV-PA 1A* module (see more in text)

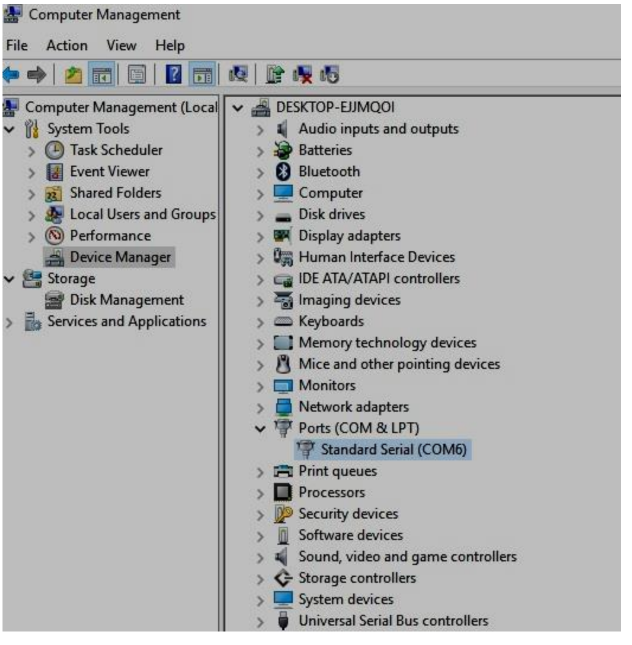
On Fig. 3 the board of the device is represented as divided into four main. Module one (marked in yellow) is the power supply unit of the device, consisting of a transformer, voltage straightening circuit, and two voltage stabilizers. Module two (blue) is the part, responsible for the RS-232 to USB interface conversion, its purpose being to make a serial connection between the PIC16F876A microcontrollers and a personal computer (Kenarov, 2006).

The red rectangle of Fig. 3 refers to the PIC16F876A microcontroller, having a 10-bit analog-to-digital converter used to convert the analog input signals into binary codes suitable for further processing in the microcontroller. The green part of the circuit board is a digitally controlled electronic load, built from the digital analogue converter, the operational amplifier, a MOFSET transistor and a resistor.

Sequence of basic steps for lab work, and layout

Task 1: Connecting a PC to the PV-PA 1A module through a USB serial interface

The FT232 Integrated Circuit is used to connect a PC to the *PV-PA 1A* module. For this purpose, a Virtual COM port is used, based on the widely used FT232 chip. Using a programmable microcontroller PIC16F876A, a two-way exchange of data between the PC and the motherboard is performed. The connection is made via a standard USB-mini USB cable. The port number is selected depending on the connection method used. Available COM ports can be viewed through WINDOW's Device Manager (Fig. 4). Select the USB serial port number (Appears after installing the FT232 chip driver).



Figire 4. PC's 'Device Manager' window after module's drivers have been installed (in our case it is COM6).

Task 2: Software application

After starting the program by clicking twice on the program icon (Sotirov et al., 2016b), several important sub-steps should be performed before the measurement. It is necessary to create a file in which to record the measurement data, this is done as follows: From the top menu on the left (Fig.5 – orange), click ’Open file’; Choose a directory and create a file; Confirm (press OK).

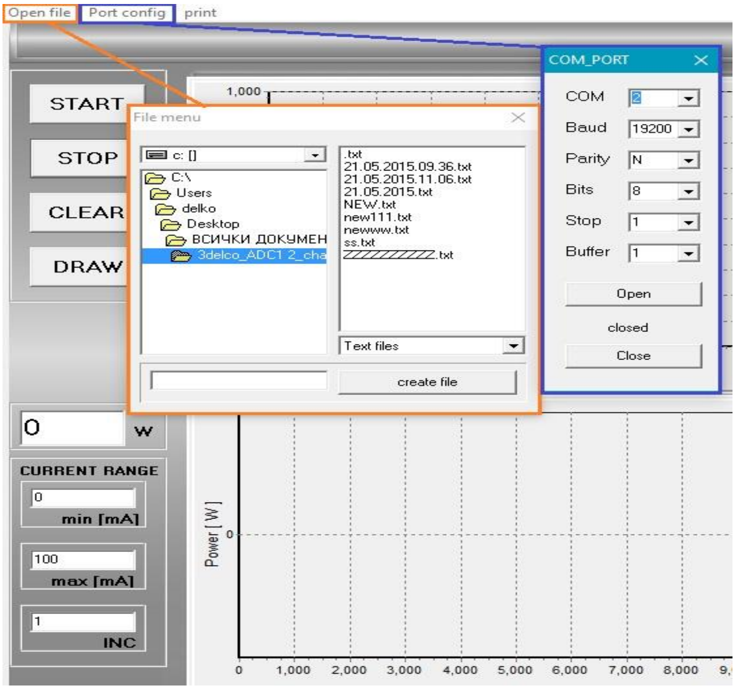


Figure 5. Setting the serial port and creating the data file

It is important to execute the sub-steps in the exact order.

The created file will be used by the program to record the measurement data. Then use the ’Port config’ option from the menu to set the port number and the transfer rate for the device (BaudRate; it should be set to 19200). The program has several more functions. The ’Current Range’ option allows us to set the range, in which the current varies (min mA – max mA), the measurement starting at a minimum current value of about 1 mA. The ’INC’ option determines how big is the step in mA, by which we change the electric current, the smallest step being 1 mA.

Task 3: Connecting the PV-PA 1A module to a PV panel

After the completion of *Task 2*, the hardware module must be connected to the output terminals of the photovoltaic panel, shown in the general picture on Fig. 6, following the correct polarity, positive pole of the device (red wire) to (+) on the photovoltaic panel and the negative pole of the device (black conductor) to (-) on the panel.

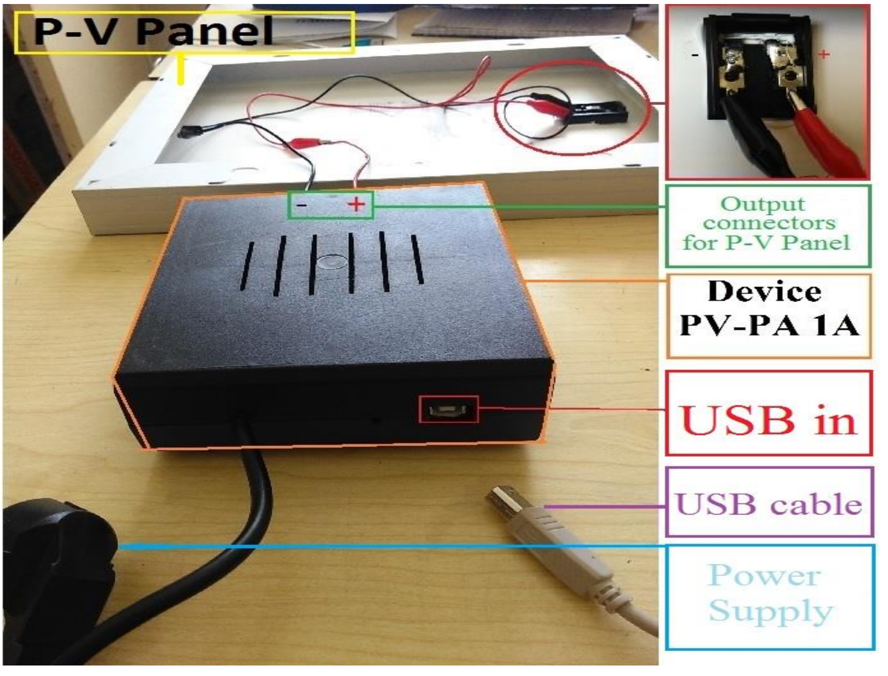


Figure 6. A picture of the *PV-PA 1A* module with its basic elements, connected to a PV panel

Once the device is connected to the photovoltaic panel, you can switch to measurement. We start the measurement by clicking on the 'START' button. Then the system determines the volt-ampere characteristics of photovoltaic panels with a voltage up to 22V and a maximum output current of up to 1A. The obtained values of the photovoltaic panel characteristics are visualized in a graphical form on the screen of a personal computer. One can find more details about the applied software in (Sotirov et al., 2016b).

Task 4: Calculation and layout of the lab exercise results

The results should be presented as shown in Table 1. First, the student should measure and write down the values of the illuminance L_x (in our case we use MASTECH MS8209), short circuit current I_{sc} and open circuit voltage V_{oc} through a proper multimeter. Then the fill factor FF should be calculated and written down, and the PV panel power, as calculated by the software, should be recorded. ***Task 4*** should be repeated for different sources of light and the students should orally make conclusions about the causes of the obtained results variation.

Table 1. Measured parameters and basic characteristics values for the examined PV panel

PV panel 5w	Illuminance [option]	Short circuit current I_{sc}	Open circuit voltage V_{oc}	Rated current I_{mp}	Nominal voltage V_{mp}	PV panel power W	$FF = \frac{I_{mp}.V_{mp}}{I_{sc}.V_{oc}}$
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Conclusions

We developed a lab exercise to analyze the functioning characteristics of a PV panel through the *PV-PA 1A* module, elaborated previously by the authors. The exercise describes the execution of subsequent steps and the application of a certain software to measure how electrical voltage changes when applying different electrical loads to a PV panel and thus to determine the maximum power point (MPP) for the examined panel.

The lab exercise also allows verifying how close real PV panel characteristics are to the factory ones

Acknowledgements. This research was supported by the University of Plovdiv "Paisii Hilendarski", under contract FP17–FF–010/16.05.17.

NOTES

1. https://books.google.bg/books?id=sEINA3tyLUAC&printsec=frontcover&hl=bg#v=onepage&q&f=false
2. http://www.icrepq.com/icrepq'12/565-leite.pdf
3. https://www.researchgate.net/publication/269390463_Analysis_of_the_Effect_of_Fill_Factor_on_the_Efficiency_of_Solar_PV_System_for_Improved_Design_of_MPPT

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