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Educational set up for measurement of photovoltaic modul electrical parameters

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Abstract: *This paper presents educational set up for practical teaching about photovoltaic systems. The paper gives theoretical aspects of photovoltaic panels with description of the current-voltage characteristic. Measuring of electrical parameters using conventional measurement instruments and data acquisition system are shown. Usage of the measuring data acquisition systems speeds up obtaining important characteristics of photovoltaic panel. The main focus is on the processing and analysing of results, not on reading the data from conventional measurement instruments. The LabVIEW software automatically generates a report after completing the measurement. Ideas for further development of set up and enhance the teaching of photovoltaic modules are also given.*

Keywords: *photovoltaic cells; photovoltaic module, I-V characteristics, LabVIEW*

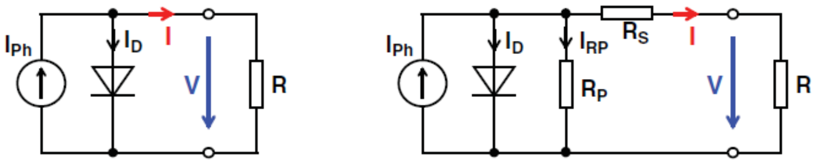
1. INTRODUCTION

Besides other technologies of renewable sources, photovoltaic (PV) systems have a significant part in the electricity production. Total global installed capacity of photovoltaic systems at the end of 2014 was 177 GW [1]. The increasing usage of PV sources require a greater number of teaching units at secondary schools and faculties for teaching this technical field. Students on courses about renewable energy sources should equally have theoretical classes and practical exercises. In this way, students better understand working principles of generate electricity using renewable energy sources. Secondary schools and faculties should improve their teaching with practical work as much as possible. This primarily refers to work in the laboratory and practical work in industry, if possible. Because the use of real system in the laboratory improves the quality of teaching.

2. ELECTRICAL CHARACTERISTICS OF PHOTOVOLTAIC CELL

The most important characteristic of photovoltaic cells and panels is current-voltage (*I*-*V*) characteristic. This characteristic give information of some important PV cell/panel parameters. PV panel is modelled by electric equivalent circuit, and *I-V* characteristic is described by a mathematical function. The dependence of certain values can be confirmed by measuring witch also gives the mathematical model of the system [2]. Electrical values measured using data acquisition equipment can be easily processed. So, these example can be further developed through the concept of distance learning [3].

Photovoltaic cell can be modelled with a current source, anti-parallel diode, a shunt resistance and a series resistance (Fig. 1b). Current source I_{Ph} represents photo current and it is proportional to irradiance and PV cell area.



(a) (b)

Figure 1. *Equivalent circuit for loaded ideal (a) and real (b) PV cell [4]*

PV cell without a shunt and series resistance becomes ideal PV cell (Fig.1a). Load current of ideal and real PV cell are:

$$I = I_{Ph} - I_D = I_{Ph} - I_s\,(e^{eV/nkT} - 1) \tag{1}$$

$$I = I_{Ph} - I_s\,(e^{eV/nkT} - 1) - (V + I \cdot R_S)/R_P \tag{2}$$

where I_s is the saturation current of the diode, e is the charge of electron ($1.6 \cdot 10^{-19}$ C), n–is diode quality factor, (usually n=1), k is the Boltzmann constant ($1.38 \cdot 10^{-23}$ J/K), T is the absolute temperature in K.

Output voltage of PV cell is obtained from the equation (1):

$$V = (nkT/e)\ \ln\{1+[(I_{Ph} - I)/I_s]\} \tag{3}$$

Fig. 2 presents current-voltage characteristic and power-voltage characteristic with a PV cell area of 102 cm^2, irradiance amounting to 1 kW/m^2 and 25 °C cell temperature [1]. These characteristics represents some values which are the most important parameters of the PV cells/panels: I_{SC} is the short circuit current, V_{OC} is the open circuit voltage, P_{MPP} is maximum power point, I_{MPP} is the current at this maximum power point, V_{MPP} is the voltage at this maximum power point. These parameters are commonly given on nameplate of each PV panel. MPP point at the $I=f(V)$ function is the point of maximum power at known irradiance and temperature value.

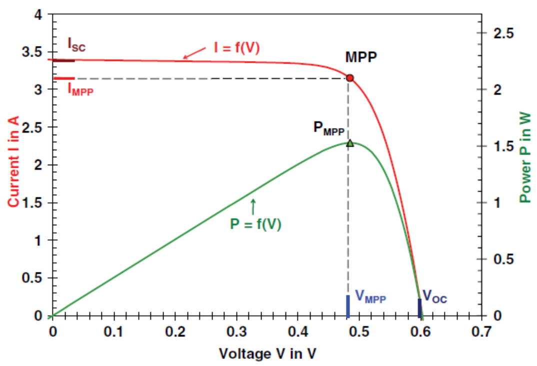


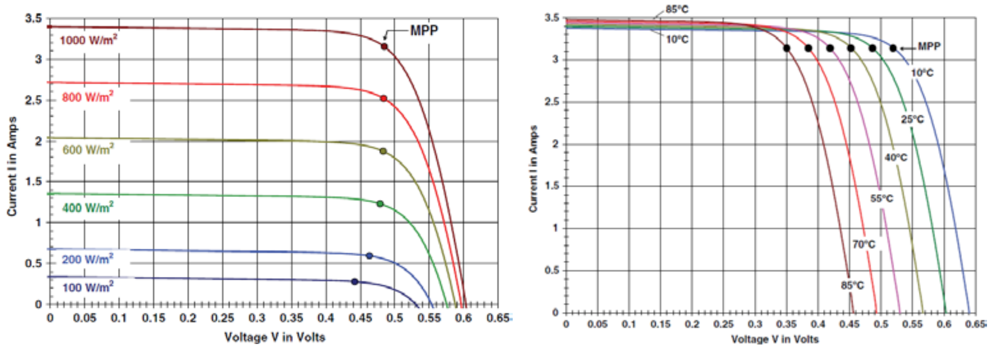
Figure 2. *Characteristic curves I=f(V) and P=f(V) of photovoltaic cell [4]*

Fig. 3 shows the current-voltage characteristics of PV cells for different values of irradiance and cell temperature. The value of short circuit current largely depends on irradiance, while the open-circuit voltage depends on the cell temperature. The V_{OC} and I_{SC} values as a function of temperature in %/°C are often given on the nameplate of PV panels.

Beside efficiency, fill factor (FF) shows the quality of PV cell [4,5]. Power P_{MPP}, or the product of voltage and current at MPP is always less than the product of open circuit voltage V_{OC} and the short-circuit current I_{SC}. Fill factor is given as ratio of these two powers:

$$FF = P_{MPP}/V_{OC}\cdot I_{SC} = V_{MPP}\cdot I_{MPP}/V_{OC}\cdot I_{SC} \quad (4)$$

Fill factor is mainly in the range of 60 to 80%.



(a) (b)

Figure 3. *Characteristic I=f(V) for photovoltaic cells at different irradiance (a) and temperature (b) [1]*

3. MEASUREMENT OF PV MODUL ELECTRICAL PARAMETERS

3.1. Measuring with classic measurement instruments

The simplest methods of measuring the electrical parameters of the PV panels can be realized using conventional measuring instruments. Besides PV panels ammeter, voltmeter and variable load resistance *R* are needed. Power of applied resistors mast be less or equal to the maximum power of the panel. Measuring the temperature of the panel can be made by any sensor for temperature measurement (thermocouple, Pt100 sensor). Input power (irradiance) is provided by direct sunlight exposure, or more practically, using artificial light sources. Usage of the artificial light sources allows much easier control of input power irradiance. The measurement can be realized at any time of day. Panels can be connected in series, parallel or mixed. In this case, the *I-V* characteristic is defined with: the short circuit current $m\cdot I_{SC}$, where *m* is the number of parallel connected panels; and the open circuit voltage $n\cdot V_{OC}$, where n is the number of series connected panels.

3.2. Measurements using the virtual instrumentation and data acquisition equipment

Traditional work in the laboratory is based on the use of classical instruments in the form of analog or digital ammeters, voltmeters and thermometers. Today, when everything runs on computers and mobile devices, still further laboratory work starts on the traditional setups with basics devices. With such assumptions the basic principles can be learned. Also, all those basic knowledges that were moved in the background with electronic devices can be seen. After the use of traditional instruments for measurement, data acquisition systems can be introduced. In modern measuring stations traditional devices are replaced with a data acquisition device (DAQ). For that reason, identical setting is formed, by using acquisition card and PC. Block diagram of such setup is shown in Fig. 4.

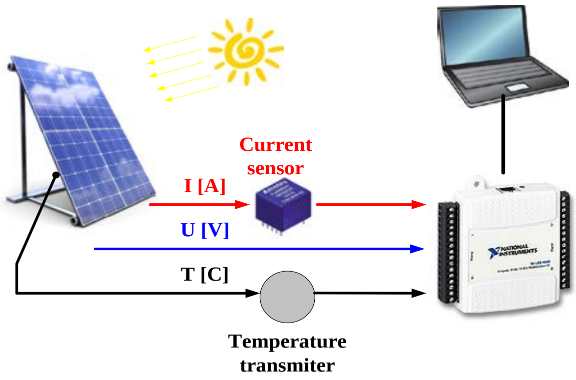


Figure 4. *Block diagram for measurement of PV panels parameters by using DAQ system*

In Fig. 5 can be seen PV panels and measurement acquisition card USB type NI6009 [6]. As this type of acquisition card has only voltage inputs with measuring range of ± 10 V, it is necessary to adjust all input voltage levels. Therefore, voltage divider is used to scale down the voltage, while the current sensor is used to measure current [7]. Current sensor works on the Hall effect principle and current value of 0 - 2.5 A is converted into a voltage signal of 0-5 V. To measure the temperature Pt100 sensor is used. Pt100 is connected to the acquisition card by using transmitter. The transmitter ensures that signals in mV from Pt100 is converted into a voltage signal up to 10 V [8].

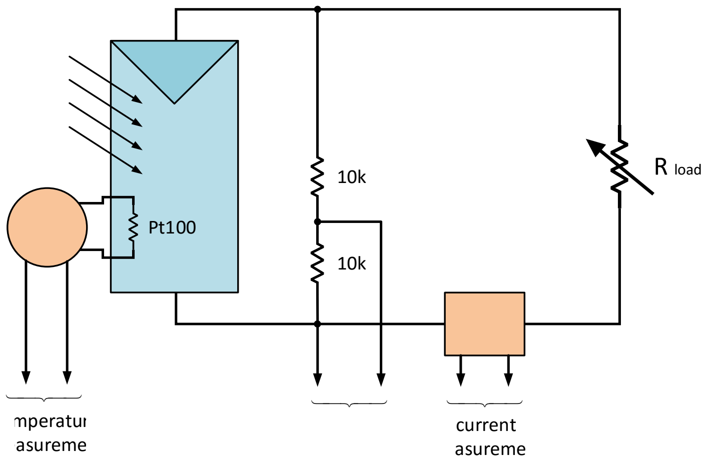
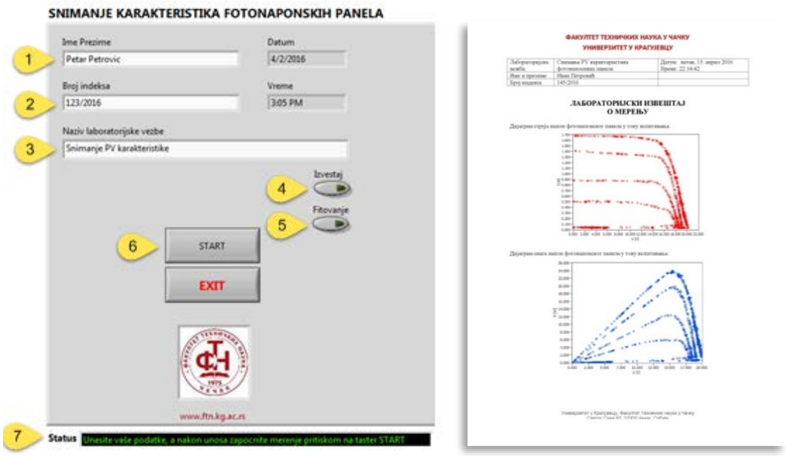


Figure 5. *Electrical circuit of DAQ system*

To speeds up the process of obtaining measurements and characteristics of PV panel, an application is made in LabVIEW program. Application automatically generate report after the measurement, and can store data over a long period of time. The application enables to monitor parameters of PV panel from a remote location. Monitoring of parameters is usually needed when the solar power plants are on the locations outside the settlements, and there is no need for the physical presence. In this way, students will learn about the concept of remote monitoring of the PV panels parameters, and some possibilities of SCADA systems.

After starting the application student can see the display as shown in Fig. 6 (a). Student need to enter some data like, it's first and last name (1), the index number (2) and the name of the measurement to be performed (3). There is a choice whether they would like to create a report (4) and whether it wants to perform fitting obtained characteristics (5). At any time, information about the current status of the application can be tracked at the status line (7). Generated report is shown in Fig. 6 (b). The appearance of the report can be easily adapted to the needs of practical exercises, and can add other necessary data which are essential when performing exercises.



(a) (b)

Figure 6. *Start window for data entry and options selection (a) and generated report (b)*

After data entry application can be run on the START button. Student can choose between measurements of the current and voltage values in time or *I-V* characteristics and power-voltage (P-V) characteristics. This part of the application is shown in Fig. 7.

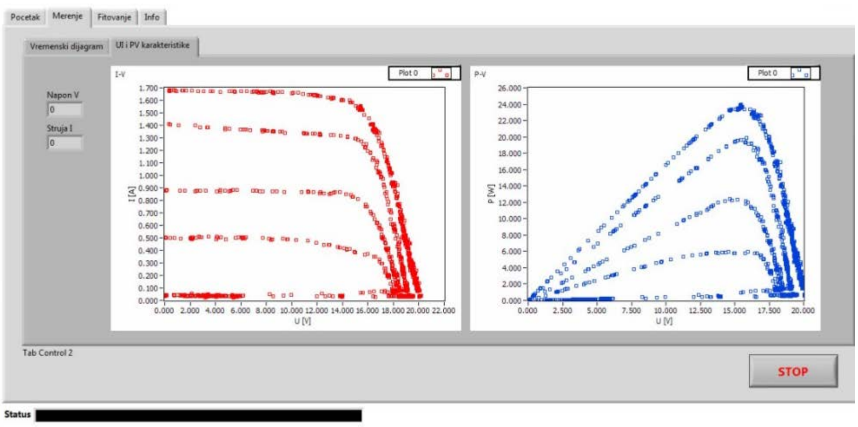


Figure 7. *Application tab for the measurement of I-V characteristics*

4. CONCLLUSION

Practical classes significantly affect the understanding of certain teaching unit witch students study during theoretical teaching. The purpose of this laboratory setup is that students in the subject of renewable energy, get better acquainted with the functioning of these systems. Also wish is to extend theoretical classes with as many as possible practical application examples. Recording *I-V* characteristics of the PV panel is one of the basic exercises in a series of practical exercises of PV systems. Further development of this application will go in the direction of the monitoring and storage parameters remotely. For monitoring of specific parameters like elevation, azimuth, altitude and GPS location sensors will be added. That will allow students to see how characteristics of PV panels changes with these parameters. Sun trucking system also will be implemented so beside measurement students will have possibility to control PV system in order to achieve the highest insolation. The creation of a remote experiment will increase the availability of laboratory setup, which would allow students to comfortably perform lab exercises from another remote location without the presence in the laboratory.

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