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# A device for the analysis of photovoltaic panels

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In this paper we present the elaboration and functioning of an electronic unit for examining the Volt-Ampere (V-I) and the output (P-V) characteristics of a PV panel. The unit was designed by us to record the PV panel voltage at different current loads. A digitally controlled electronic load was developed to set the current values by a chosen increment. Then, the unit measures the corresponding voltage value for each current value by an analog-digital converter (ADC). All pairs of values are used as input to a microcontroller and then transferred to a PC, where they can be graphically visualized by a specialized software. Different PV panels with varying output (P-V) characteristics were used to test the performance of the elaborated electronic unit. These experiments revealed that the unit is appropriate for PV panel analysis both under laboratory and field conditions.

**Keywords:** photovoltaic panel, current vs. voltage characteristic, power output vs. voltage characteristic

## INTRODUCTION

The rapid development of technologies for energy production from renewable sources, such as the Sun, makes it necessary to introduce new algorithms and methods for increasing the efficiency of the devices for energy output, conversion and storage. To meet market needs, manufacturers are using new technologies for the production of photovoltaic cells and modules. One of the main photovoltaic modules parameters is their efficiency and tests and studies are constantly being performed to improve the modules efficiency. Basic parameters and characteristics of the photovoltaic cell are the voltage vs. current characteristic, the short-circuit current, the open circuit voltage, the maximum power output and the Fill-Factor.

The study of these parameters and characteristics is applied for the comparison of the power, produced by the cells in laboratory and in actual field conditions. Typically, devices for testing the characteristics and parameters of a photovoltaic cell are using DC loads, whose resistance changes across the operating range of the cell. These equipment solutions are expensive and complex. In recent years a number of devices for testing of photovoltaic cells and modules has been developed [1, 2, 4].

This publication presents an electronic circuit and a device, developed to study the voltage vs. current and the power output (I-V and P-V) characteristics of photovoltaic panels. Relatively inexpensive and up-to-date components and integrated circuits were used in the development of this appliance, making it suitable for conducting both laboratory tests and field studies.

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## DESCRIPTION

When examining the characteristics of the photovoltaic panels the following basic values are usually considered; ($I_{sc}$) - short circuit current; ($V_{oc}$) - open circuit voltage; ($I_{mp}$) - rated current; ($V_{mp}$) - rated voltage; (MPP) - the point of maximum power; (FF - Fill-Factor) – a coefficient of filling; η - solar element efficiency. A voltage vs. current characteristic can be calculated to give an idea of the photocurrent generation, the panel surface being irradiated with light for this purpose [2].

Typical voltage vs. current relation, known as an I/V curve (red line) and power output vs. voltage characteristic (blue line) are revealed on Fig.1 [3]. The ratio of the dark violet rectangle area, to the area of the bright violet rectangle is defined as the FF-factor (factor of filling).

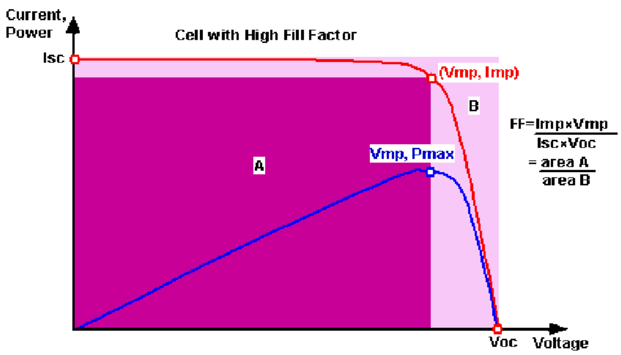


**Fig.1.** A voltage vs. current and power output characteristics of a PV cell and definition of the duty cycle (FF- Fill Factor)

The FF-factor is used to assess the quality of photovoltaic panels and it is also known as the efficiency coefficient of a panel and should be as close to 1 as possible [4]. It may be determined by formula (1):

$$FF = \frac{I_{mp}.V_{mp}}{I_{sc}.V_{oc}} \quad (1)$$

Another key parameter of a photovoltaic panel is its efficiency, which is the ratio of the electrical power output to the input radiant power (formula (2)).

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

where η is the efficiency, $P_{out}$ – the electrical power output ($I_{mp}.V_{mp}$), H – the radiant energy falling on the photoelectric cell in mW/ $cm^2$, and S - the active area of the photoelectric cell in $cm^2$ [1, 5]. The purpose of our paper was to develop an electronic device, which by performing voltage and current measurements on a PV panel, to calculate and provide its main parameters.

The full scheme of the device for testing PV panel parameters and characteristics is presented on Fig.2. The elaborated appliance allows to determine the I/V curve of photovoltaic panels with voltage up to 22V and maximum output current up to 1 A. The I/V curve and the power output curve of a PV panel can be displayed graphically on a PC monitor.

The development of the unit for testing PV panel parameters and characteristics is based on the PIC16F876A microcontroller When using a microcontroller in a device, its principle of operation can largely be changed only by introducing the necessary adjustments in the controller program [6].

The main functions, which the microcontroller performs, are to communicate with a personal computer, manage the digital to analog converter MCP4821 [7] and to convert analog data into digital form by using the integrated module in it for analog-digital conversion (ADC) [8]. The operational amplifier LM324, which is powered by stabilized unipolar constant voltage 24V, was used to measure the voltage, produced by the photovoltaic panel. For this purpose the integral stabilizer uA7824 was applied. The operational amplifier U2 acts as a voltage follower. His non-inverting input is connected directly to the positive output terminal of the panel. This solution provides the highest possible entrance impedance of the amplifier. Thus, the current consumption in the input circuit will be minimal, which is essential for the accuracy of these measurements.

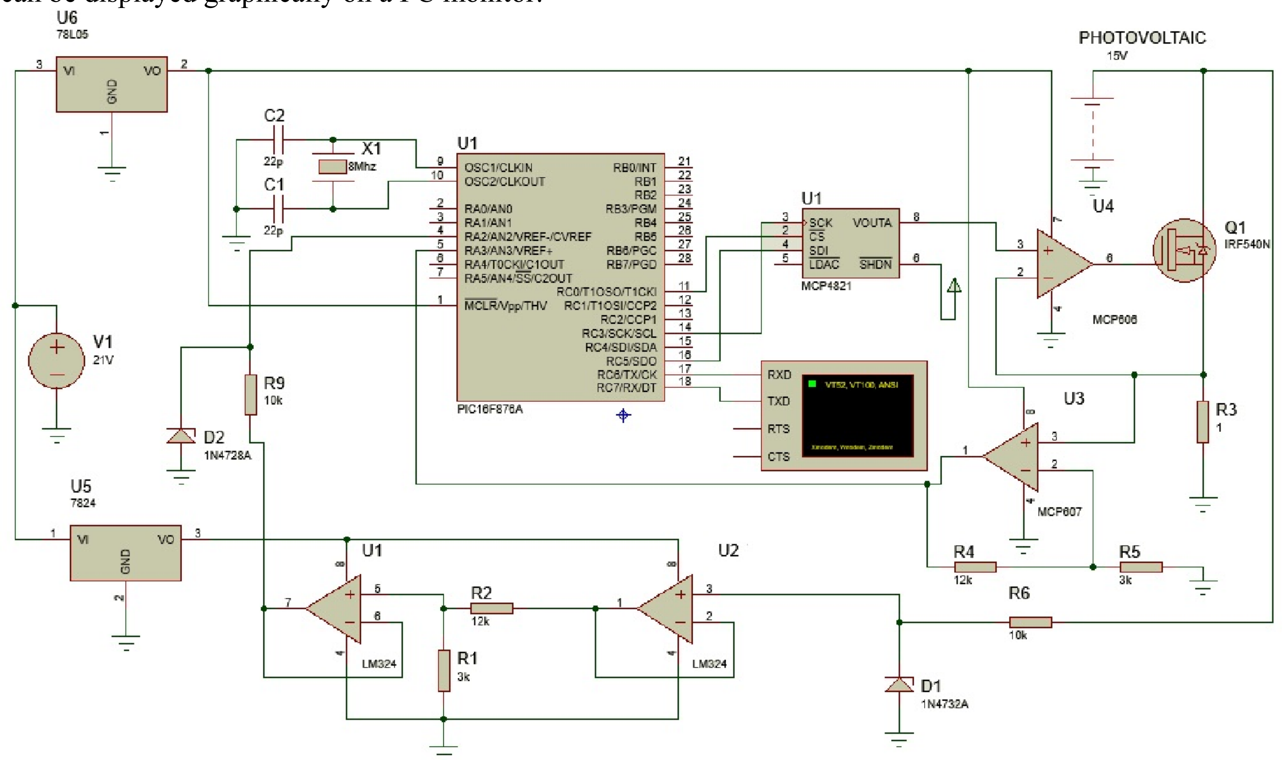


**Fig.2.** General circuit of the device for analyzing of the PV panels

At the same time the voltage follower provides a low output impedance, which in this case is a necessary condition as to the output of U2 is connected to a voltage divider, constructed of resistors R1 / R2. The divisor transmission coefficient is 1/5. Since the ADC works with the reference voltage 5V, the maximum value of the analog input voltage, that can be converted into digital code, can not exceed 5V. By using this divider we enable the possibility to submit voltages to the ADC up to 25V. The ADC resolution, which is (4.88mV), can be determined by formula (3).

$$\Delta V = \frac{V_{REF}}{2^{10}}, \quad (3)$$

where $V_{REF}$ is the reference voltage of the ADC (5V), $2^{10}$ is the ADC sparsity (10bit).
The output of the second operational amplifier U1 is connected directly to the ADC module analog input (AN2) of the PIC16F876A microcontroller.

To determine the current flowing through the photovoltaic panel, a circuit has been developed, consisting of a DAC and a current generator, and thereby we achieved a controllable electronic load. The circuit is powered by a stabilized DC voltage 5V, which is obtained from the integral stabilizer 78L05. It can be divided into two main parts. The front part is developed by DAC (MCP4821) and an operational amplifier, in which the DAC converts the digital code and turns it into analog voltage that is fed to the operational amplifier [9]. The voltage which is obtained at the output of MC4821 can be calculated by formula (4).

$$V_{out} = \frac{(2048.D_n)}{2^n}.G \quad (4)$$

The minimum step, by which the voltage can be altered at the output of the DAC, can be 1mV at G = 2 and 0,5mV at G = 1, where G is the gain of the integrated amplifier in the DAC. This voltage serves to control the transistor. The amplifier, used in this case, is MCP607. It is characterized by a very small asymmetry voltage (offset of 250 μV) and is designed to operate with unipolar power [10]. The small amplifier offset is essential for the proper operation of the scheme, as this voltage would lead to an error in the electric current control. The N-channel MOSFET transistor (IRF540) plays the role of a controllable load and serves to ensure high output current. Through negative feedback, connecting the source of transistor with the inverting input of the operational amplifier, the electric current value through the reference resistor R3 is being adjusted. The electric current in the load circuit can be determined by formula (5).

$$I_{load} = \frac{V_{in}}{R3} \quad (5)$$

where $V_{in}$ is the input voltage of the operational amplifier, which is set by the DAC. It is obvious that the value of the current in the load circuit depends on the input voltage $V_{in}$ and the value of the resistor R3. It is known that the current flow through a resistor dissipates heat. This will lead to an increase in temperature, and accordingly to a change of its resistance value. This may cause deviation between the digital set point current through the DAC and the actual value of the flowing current in the circuit. To reduce this effect, it is necessary to use a resistor with a low temperature coefficient and to shorten the measurement time. Since this temperature dependence cannot be completely avoided, the amplifier U3 is applied for monitoring and measuring of the exact current value in the load circuit. It helps to monitor the voltage drop across the reference resistor R3, which is proportional to the current, flowing into the load circuit. In this circuit U3 is connected as non-inverting amplifier with a gain of 3.

The advantage of such a circuit topology is the high input impedance of the amplifier, which is important in order to avoid its influence on the current generator. The voltage at the output of U3 is fed directly to the analog input (AN3) of the ADC module, where it is converted into digital form. Thus, information is constantly submitted to the microcontroller about the actual value of the current flowing through the photovoltaic panel.

The conversion of analog current and voltage values of the photovoltaic panel in digital form and the communication with the PC is carried out by the microcontroller. The setting of a series of values for the load current in the circuit of the photovoltaic panel, which vary by the chosen step, is performed by a PC, which communicates with the microcontroller via a serial interface (UART). The microcontroller measures the current and the voltage values after each change of the load current. The measured values are converted into digital form and transmitted to the PC where they are displayed graphically on the computer monitor by specially developed software.

## RESULTS

Fig.3 and Fig.4 expose the I-V curve and the PV characteristic, which were obtained, using the device, we developed. Analysis of two different PV panels was performed with power output of 5W and 0.7W. From the voltage vs. current characteristic, shown on Fig.3 (blue curve), it can be seen that when the voltage of the photovoltaic panel has a minimum value, the current in the load circuit is maximum. One can also get that at a minimum load current the voltage between the terminals of the panel has a maximum value, which is characterized as an open circuit voltage.

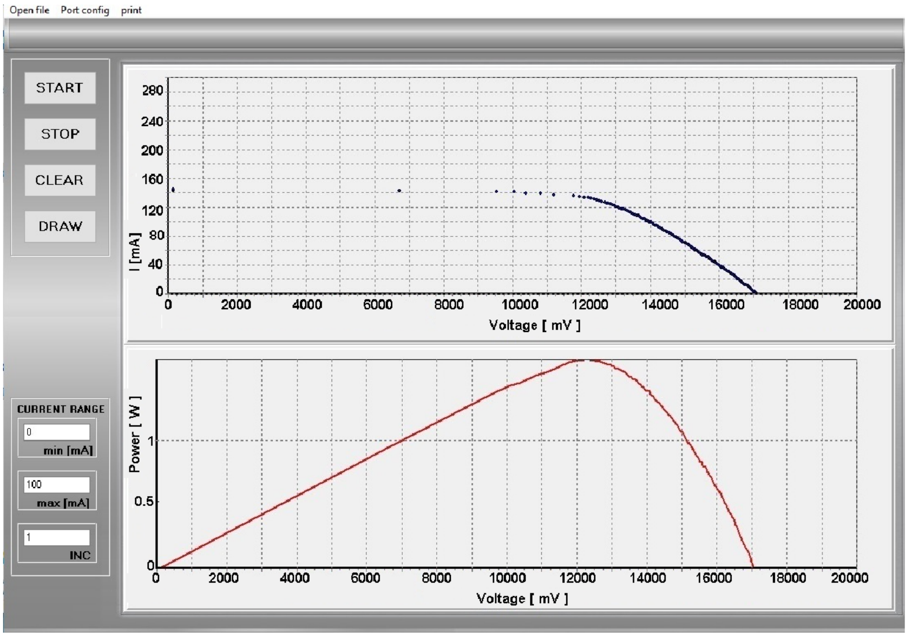


**Fig.3.** I-V curve and P-V characteristic for the PV panel of maximum 5W power output. The experiment was done at an illuminance level of 78 000 lx and surface temperature of the studied photovoltaic module of 28° C

The point of maximum curvature of the I-V graph identifies the I-V combination, for which the panel generates maximum power output. At voltages well below Vmp, the electric current, generated by the photovoltaic panel is relatively independent of the output voltage. Near the area where the curvature increases, one can see that the nature of the correlation sharply changes. As the voltage in this region increases, a greater percentage of the generated charge carriers recombine within the volume of the photovoltaic panel and a smaller portion flows through the load (low current). At the point where the voltage is maximum and hence the current through the photovoltaic panel is minimal all carriers recombine within volume.The red curve on Fig.3 exposes the power output vs. the voltage (P-V) curve. Since the photovoltaic panel is a DC source, its power output is calculated by the relationship R = U.I. If we calculate the power output of the photovoltaic panel for each point of the I-V curve, we obtain the P-V curve, its maximum identifying the maximum power output of the respective panel.

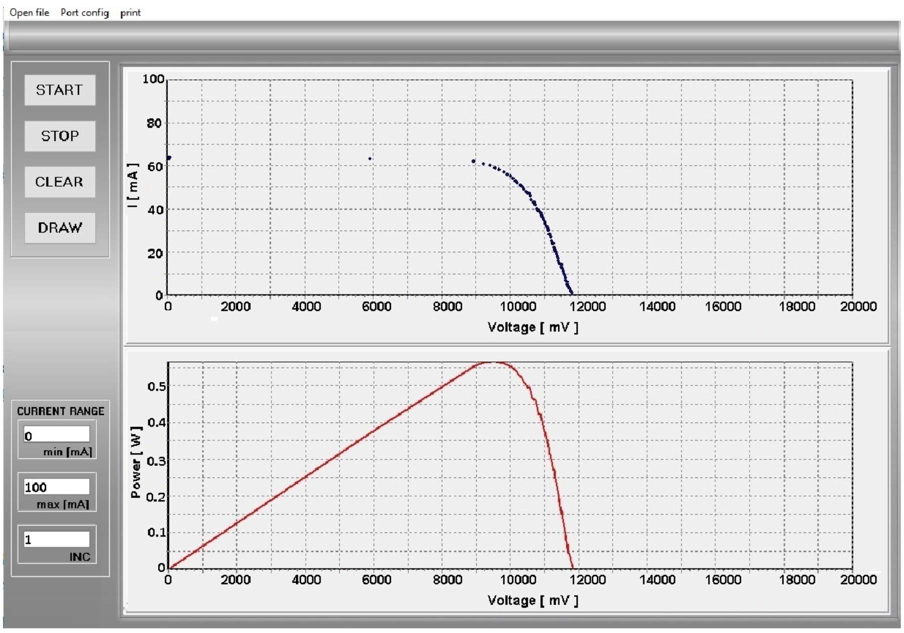


**Fig.4**. I-V curve and P-V characteristic for the PV panel of maximum 0.7W power output. The experiment was done at an illuminance level of 115 000 lx and surface temperature of the studied photovoltaic module of 28° C

The graph on Fig.4 is for a mono-silicon panel with maximum power output of 0.7W. When comparing the P-V curves for both experiments, one can clearly see that the power-voltage curve exibits a typical form, as revealed on Fig.1.

## CONCLUSIONS

In this paper we describe an electronic device, we developed for measuring output current and voltage of a PV panel, by which to study its power output characteristics. We present the appliance scheme and describe in detail how to perform the measurements. Some simulations have been performed before the unit elaboration by the application of the Proteus software. These simulations cover both the hardware and the software parts, allowing the verification in advance of the correct work of the developed schemes and the corresponding PIC microcontroller software. The obtained results demonstrate that the scheme is suitable for the planned device elaboration. The obtained results demonstrate that the scheme is suitable for the planned measurements. After the simulations we designed and developed the hardware circuit itself, based on the PIC16F876A microcontroller, which measures the output voltage and current from the studied module and thus we examined the parameters under concern. The results were visualized on a PC by specialized software.

By measuring the current and the voltage at the panel output, we can calculate the studied characteristics and thus we can test whether the measured characteristics values of a PV panel meet the factory. This was done for both PV panels (5W and 0.7W) and calculated values fit well the factory ones, considering the variation of the experiment conditions.

The device can examine PV panels of voltage up to 22V and maximum output current up to 1A. The implemented experiments demonstrate that the developed device is appropriate for testing and evaluating PV panels efficiency both in laboratory and in field conditions.

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