Remote Platform for Photovoltaic Panel Characterization

Boyanka Nikolova[1], Georgi Nikolov[2] and Marin Marinov[3]

Abstract – **An important factor for the successful installation and maintenance of solar panels is the good training of staff. Good training involves carrying out appropriate practical activities. The present paper introduces a platform for remote measurement of base photovoltaic parameters, based on a source-measure unit, graphical programming environment and technology for remote access to hardware via a standard web-browser.**

Keywords – **Active teaching methodologies, LabVIEW programming, Photovoltaic characterization, Remote panels, Source-measure units.**

I. INTRODUCTION

Solar energy systems have become an appropriate source of renewable energy, and are now widely used for a variety of domestic and industrial applications. In particular, photovoltaic (PV) power is an established technology and has grown rapidly over the last ten years. Photovoltaics offer many advantages such as: negligible environmental pollution, high reliability, absence of noise, low maintenance cost, etc. The characteristics and parameters of photovoltaic systems are variable because the amount of sunlight energy received by any surface depends on many factors including season, geographical location, time of the day, local weather, and local landscape. For this reason, installing and maintaining such systems requires highly trained staff. The training of this staff requires implementation of new pedagogical methodologies, which integrate information and communication technologies. Those modern learning methods allow students to train at anytime and anywhere. The new teaching methodologies are called “active methodologies”, and can be divided into blended learning, flipped learning, ubiquitous learning, work-based learning, problem-based learning and challenge-based learning. All above listed methodologies require practical work. On the other hand, contemporary practical exercises require appropriate measuring equipment and remote access to it.

In order to analyse the important PV parameters, specialized measurement devices are needed. There are a number of commercial measurement systems developed for the semiconductor industry by Keysight Technologies, Tektronix, Inc., and others. These units generate and measure voltage or current and can be controlled by a computer with a wide range of features and capabilities including four-quadrant operation. Of course, these so-called Source-Measure Units (SMU) require software to download the data, save it, and calculate relevant photovoltaic parameters [2]. A very popular and appropriate software platform for control of measuring instruments is the graphical programming environment LabVIEW. This environment also has built-in capabilities to create remote experiments. A key feature of LabVIEW for distance learning is the support of technology called Remote Panels. With this feature, it is possible to create an intuitive user interface for instrumentation and publish it on the World Wide Web. This internet-based LabVIEW technology comes with a web server that automatically deploys the application, and on the client side the user is able to see and manage the user interface by standard web-browser.

The present study proposes a virtual platform for remote characterisation of low power photovoltaic panel. This platform is designed for educational purposes and consists of source-measure unit U2722A, graphical programming environments LabVIEW and technology Remote Panels.

II. BASE PARAMETERS OF PHOTOVOLTAIC MODULE

Characterization of photovoltaic panel includes different measurements at the solar cell level. Although measurement accuracies, speeds, and parameters may differ in importance across different levels of the industry and across space and terrestrial use, there are a number of key parameters that are typically measured in any testing environment [1, 2]:

Open-circuit voltage (V_{OC}) – the cell voltage at which there is zero current.

Short-circuit current (I_{SC}) – the current flowing out of the cell when the load resistance is zero.

Maximum power output of the cell ($P_{\max}$) – the voltage and current point where the cell is generating its maximum power. The $P_{\max}$ point on an I-V curve is often referred to as the maximum power point (MPP).

$$P_{\max} = I_{\max} V_{\max} . \qquad (1)$$

Voltage at $P_{\max}$ ($V_{\max}$) – the cell’s voltage level at $P_{\max}$.

Current at $P_{\max}$ ($I_{\max}$) – the cell’s current level at $P_{\max}$.

Fill factor (FF) – the ratio of the maximum power point, $P_{\max}$, divided by the V_{OC} and the I_{SC}:

$$FF = \frac{P_{\max}}{V_{OC} . I_{SC}} . \qquad (2)$$

Conversion efficiency of the device (η) is the percentage of power converted (from absorbed light to electrical energy)

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and collected when a solar cell is connected to an electrical circuit. This value is calculated using the ratio of the maximum power point, $P_{\max}$, divided by the input light irradiance (G, in W/m²) under standard test conditions (STC $G_0 = 1000$ W/m^2 with an air mass of 1.5 and cell temperature of 25°C) and the surface area of the solar cell (A_C in m²):

$$\eta = \frac{P_{\max}}{G.A_C} = \frac{V_{OC}.I_{SC}.FF}{G.A_C}\,. \tag{3}$$

Generally, a photovoltaic panel, as an elementary PV electrical energy source, is described by equivalent electrical circuit - a five-parameter model. Parameters of the equivalent circuits of PV cell are cell diode properties (like ideality factor N and diode saturation current or dark current I_0), cell series resistance (R_S) and cell shunt resistance (R_{SH}).

Most of the parameters given in data sheets of the solar cell can be taken from the I-V characteristics. Figure 1 shows the I-V characteristics of a typical PV cell. Note that the amounts of current and voltage available from the cell depend upon the cell illumination level. In the ideal case, the I-V characteristic equation is

$$I = I_{PH} - I_0\left(e^{\frac{V}{V_T}} - 1\right), \tag{4}$$

where I_{PH} is photo-current and V_T is the diode thermal voltage.

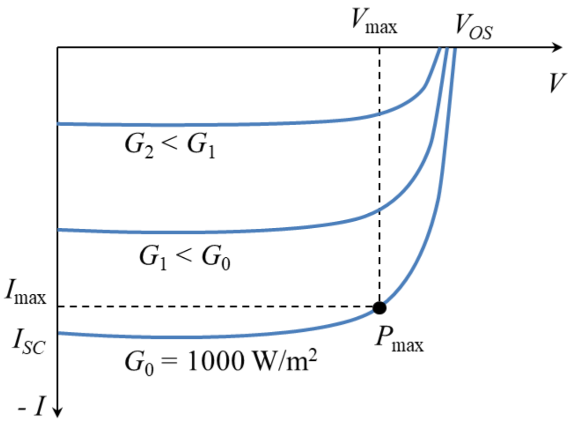


Fig. 1. I-V characteristics of a typical PV cell

Because the measured I-V characteristics of actual PV cells differ from this ideal version, including the parameters of the equivalent circuit, the equation (4) can be expressed as:

$$I = I_{PH} - I_0\left[exp\left(\frac{V + I.R_S}{N.V_T}\right) - 1\right] - \frac{V + I.R_S}{R_{SH}}\,. \tag{5}$$

As it can be seen from Fig. 1, parameters V_{OC}, I_{SC}, $I_{\max}$ and $V_{\max}$ can be defined directly from I-V characteristic, measured under STC. For example, to determine the short circuit current of a PV cell, simply set $V = 0$. Then parameters $P_{\max}$, FF and η can be easily calculated using the equations from (1) to (3). The parameters of the equivalent circuits of PV cell can be estimated from forwarded and reversed biased I-V characteristics at different solar irradiances as described in reference [3].

One of the primary problems with PV cell characterization is the measurement of solar irradiances G. The simplest approach is to allow for a very good approximation, that the cell current is directly proportional to the cell irradiance. Thus, if the photo current under STC I_{PH0} is known, then the cell current at any other irradiance, G, is given by

$$I_{PH} = \frac{I_{PH0}}{G_0}G = k_G G\,. \tag{6}$$

Regarding temperature, when all parameters are constant, the higher the temperature the lower the voltage. This is considered a power loss. The drop in V_{OC} with temperature is mainly related to the increase in the leakage current of the PV cell I_0. The magnitude of voltage reduction varies inversely with V_{OC}. This means that cells with higher V_{OC} are less affected by the temperature than cells with lower V_{OC}.

The temperature coefficient is defined as the rate of change of a parameter with respect to the change in temperature. It can be current, voltage, or power temperature coefficient. For example, the temperature coefficient of voltage is the rate of change of the voltage with temperature change. A typical datasheet of a commercial PV module specifies temperature coefficients for the power, V_{OC} and I_{SC} under STC. Therefore, the values of these parameters under current cell temperature T_{Cell} can be calculated as:

$$\begin{aligned} P_{\max} &= P_{STC} + TCP_{\max}\left(T_{Cell} - 25°C\right), \\ V_{OC} &= V_{STC} + TCV_{OC}\left(T_{Cell} - 25°C\right), \\ I_{SC} &= I_{STC} + TCI_{SC}\left(T_{Cell} - 25°C\right), \end{aligned} \tag{7}$$

where P_{STC}, V_{STC} and I_{STC} are the values of the parameters under STC, and $TCP_{\max}$, TCV_{OC} and TCI_{SC} are the corresponding temperature coefficients.

III. REMOTE PLATFORM DESIGN

A. Hardware Design

The block diagram of the remote virtual platform for photovoltaic panel characterization is shown in Fig. 2. The hardware part of the system consists of SMU U2722A and Test Fixture U2941A for I-V measurement of solar cell, PV reference device for irradiance measurement and temperature sensor for measuring current cell temperature T_{Cell}.

Modular SMU U2722A from Keysight Technologies has three channels and can operate in four-quadrants of I-V characteristic. Each SMU can force voltage or current and simultaneously measure voltage or current, as shown on the equivalent circuit in the Fig. 3. The figure shows the three basic modes of operation of every SMU – voltage source, current source and common. In addition, SMUs have the ability to specify a compliance setting. The setting is current compliance when the SMU is in voltage source mode and voltage compliance when it is in current source mode. When the SMU reaches compliance, it acts appropriately as a constant current source or voltage source.

The modular device U2722A can operate entirely with the Keysight U2941A parametric test fixture which is designed for the end connection between SMU and electronic components and semiconductors, including solar cells.

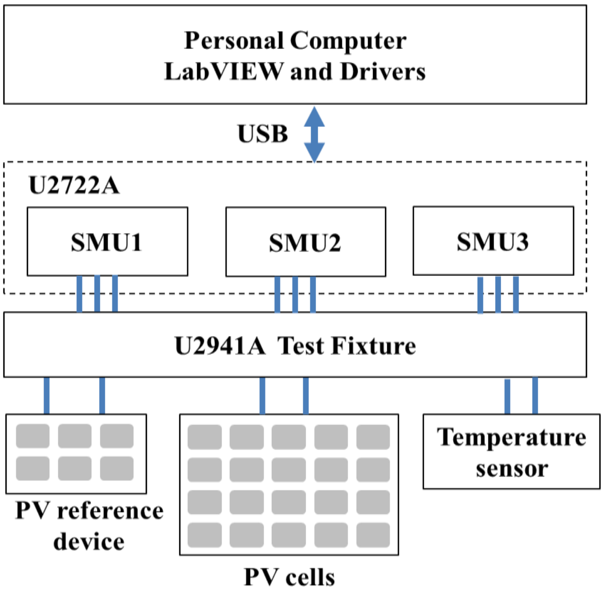


Fig. 2. The block diagram of the remote virtual platform for photovoltaic panel characterization

For PV reference device in this platform is used low-power, low cost photovoltaic panel SilverCrest SLS 2200 calibrated for irradiance as described in reference [3]. As can be seen in Fig.2. the PV reference device is connected to SMU1. The SMU1 is programmed in zero voltage source and current measure mode. Thus, a short-circuit current of reference photovoltaic is measured and irradiance is obtained according to the calibration equation. Since the SMU has capabilities of current/voltage source and measure, the temperature can easily be measured with voltage output temperature sensor (like integrated temperature sensor AD22100 by Analog Devices), resistance temperature detector (Pt100, Pt1000) or thermistor. In the present project the temperature is measured with Pt100 by SMU3, programmed in current source/voltage measuring mode of operation. The base electrical parameters of SMU U2722A are summarized in Table 1 [4].

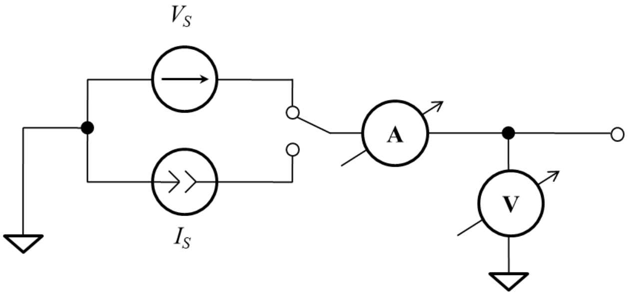


Fig. 3. The simplified equivalent circuit of SMU

TABLE I
THE BASE ELECTRICAL PARAMETERS OF SMU U2722A

Parameter	Range	Accuracy	Resolution
Voltage programming or measure	±2 V	0.075% + 1.5 mV	0.1 mV
	±20 V	0.05% + 10 mV	1 mV
Current programming or measure	±1 µA	0.085% + 0.85 nA	100 pA
	±10 µA	0.085% + 8.5 nA	1 nA
	±100 µA	0.075% + 75 nA	10 nA
	±1 mA	0.075% + 750 nA	100 nA
	±10 mA	0.075% + 7.5 µA	1 µA
	±120 mA	0.1% + 100 µA	20 µA

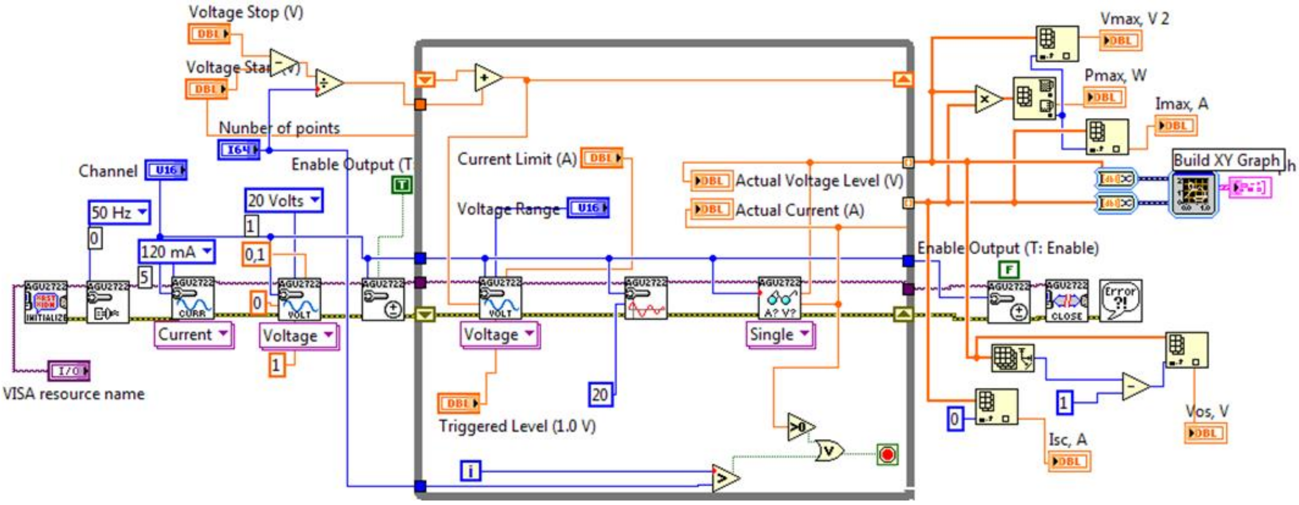
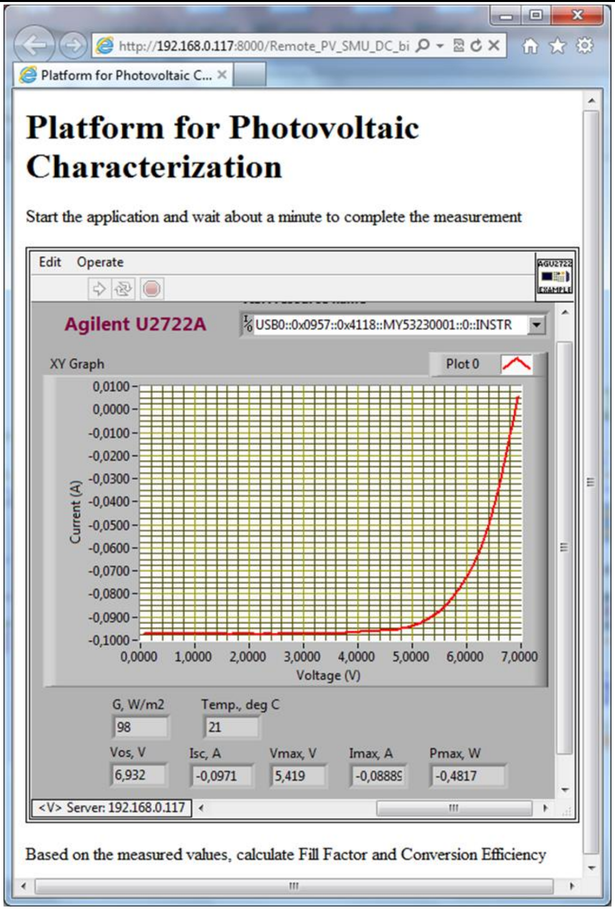


Fig. 4. The LabVIEW block diagram of developed remote virtual platform



http://192.168.0.117:8000/Remote_PV_SMU_DC_bi

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Platform for Photovoltaic Characterization

Start the application and wait about a minute to complete the measurement

Agilent U2722A

USB0::0x0957::0x4118::MY53230001::0::INSTR

G, W/m2: 98

Temp., deg C: 21

Vos, V: 6,932

Isc, A: -0,0971

Vmax, V: 5,419

Imax, A: -0,08889

Pmax, W: -0,4817

<V> Server: 192.168.0.117

Based on the measured values, calculate Fill Factor and Conversion Efficiency

Fig. 5. The front panel of developed remote virtual platform for photovoltaic panel characterization

B. Software Design

The graphical block diagram of the developed virtual platform for photovoltaic characterisation is shown in the Fig. 4. This graphical code consists of LabVIEW Plug and Play instrument driver for U2722A and conventional programming functions and components. On the left are the functions for configuring source-measure units, mode of operation, sweep type, start value, stop value and number of points. The sweep of voltage is accomplished in *While loop*. The loop has two stop conditions - a count reaches a programmed number of steps or the measured current becomes positive. On the right of the block diagram are the functions for manipulation of arrays by which the necessary parameters of the photovoltaic are obtained. It should be noted that the remote user is not given the opportunity to change the operating mode of the measurement experiment, as can be seen from Fig. 5

IV. DISTANCE MEASUREMENT OF BASE PHOTOVOLTAIC PARAMETERS

After the hardware and software parts of the system are completed, it is necessary to provide remote access to the system. With the Remote Panels technology, it is possible to automatically publish the same user interface to a web browser. The process is simple, because LabVIEW comes with its own web server. The developer only selects to publish the desired application and any remote user will see and operate with the front panel as if they were in front of the local computer. The front panel of the developed remote platform for photovoltaic characterisation is shown in Fig. 5. In the figure the measured DC characteristic of low power photovoltaic and determination of base parameters can be seen. The learner can determine the other parameters using the equations (2) to (7).

V. CONCLUSION

In this paper, the design and implementation of a remote platform for photovoltaic panel characterization has been presented. In the project for measuring the electrical properties of solar cells are used modern solutions based on SMU and virtual techniques. Different parameters are extracted automatically using measured I-V curve by developed virtual system and they played an important role for evaluating the PV modules. The technology that provides the implementation and administration of a remote access to the platform is LabVIEW Remote Panels.

Knowing in details the electrical characteristics of a solar cell is critical for determining the device's output performance and efficiency. Therefore, the accomplished remote platform can be used to establish a LabVIEW based distance learning remote laboratory.

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