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Real-time virtual instrumentation of Arduino and LabVIEW based PV panel characteristics

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Abstract. This paper describes a virtual instrument based on a low-cost embedded board to monitor and plot the PV panel characteristics under real operation condition. The system design is based on a low-cost Arduino acquisition board in which the ATmega328 microcontroller is integrated. The acquisition is made through a low-cost current and voltage sensors and the data are transmitted in LabVIEW by using LIFA Interface for Arduino. Hence, the I-V (current-voltage) and P-V (power-voltage) characteristics for PV panel, which processed under actual conditions, can be obtained and plotted directly on a monitoring platform in LabVIEW. The proposed instrument can be used for educational or research purposes using a low-cost and easily hardware without having extensive knowledge about electronic engineering. The present instrumentation technique provides easy access to the collected data for further analysis.

1. Introduction

The increasing demand for energy in line with the world's challenge to reduce the use of fossil fuels, which pollute the environment, has greatly increased interest in renewable energy sources (RES) [1], [2]. PV solar power is one of the RES for electricity generation and it is the most popular in the world because of the continuous evolution of PV technology and lower prices [3]. As a result of the popularity of PV solar power, many researchers around the world are working in this field of science to contribute to the current knowledge about this technology and improve its cost-effectiveness. Therefore, they must have scientific instruments to conduct the required experiments. Tracing of PV characteristics (current-voltage (I-V) and power-voltage (P-V) curves) of a PV device is the most important and basic experiment test, that should be performed by any researcher or anyone interested in PV technology, to obtain information about its behavior and performance [4]. Different traditional instruments are used in order to acquire the PV panel characteristics such as Multimeters. Nevertheless, by using this kind of instrument, there is a high probability that the characteristics obtained and traced manually do not give enough information about the PV device state because it can not be taken directly in real-time [5]. In addition, the experiments test are tiring and require a lot of time.

On the other hand, different commercial data loggers are available for purchase on the internet for virtual instrumentation of PV panel characteristics [6], [7], such as the DAQPro 5300 [8] and the CAMPBELL Scientific CR800 [9]. Generally, the most data loggers are too expensive and demand to be coupled with special software, which increased cost and requiring additional specific skills. In addition, they have many disadvantages that make them customized for specific applications, limited in terms of the input voltage and the number of input/ output channels, inadequate input channels for the connection of some sensors. For these reasons, we must design and developed new data instruments that



can monitor PV systems at low-cost and with flexible design. For that, many virtual instrument systems for the PV panel have been proposed in the literature, such as virtual instrumentation in LabVIEW for real-time PV system monitoring [10]-[12] and virtual instrumentation by the standard simulation software Matlab [13]. In this paper, we present a real-time virtual instrument system based on low-cost hardware to monitor and trace the P-V and I-V characteristics of the PV panel in real operating conditions. The system design of the proposed instrumentation is based on LabVIEW and Arduino. A current and voltage sensors sense the output current and voltage from PV panel. The measured data of the current, voltage and power are plotted directly on a monitoring platform developed in LabVIEW. The main advantages of the present technique are its simplicity and utilization of the low-cost components such as Arduino UNO board, low-cost current and voltage sensors. Moreover, the current, voltage, power and the characteristics I-V and P-V of the PV panel are plotted directly in LabVIEW. That is done by building a simple block program compared to other LabVIEW instruments in the literature that using multiple and complex blocks in the LabVIEW program. This work allows the user to acquire, supervise and trace the solar panel characteristics in real time with a simpler, cheaper and faster way.

The paper is arranged as follows: The design and description of the proposed instrument system are presented in Section 2. The performed experiment and the results are done in Section 3. Finally, Section 3 summarizes this paper.

2. The PV panel instrumentation system

Figure 1 shows the schematic diagram of the PV panel instrumentation system. The current and voltage sensors sense the output current and voltage from PV panel. Then, the readings of the two sensors are transmitted to the microcontroller of the Arduino UNO board. While the LabVIEW Interface for Arduino (LIFA) serves as an interface between the Arduino microcontroller and computer to make communication between the microcontroller and LabVIEW through a serial connection. During the acquisition process, the measured data of the current, voltage and power are plotted directly in LabVIEW. As shown in figure 1, the Arduino board is the heart component of the real-time acquisition system. The design of the proposed instrument is divided into two parts: hardware system and software system.

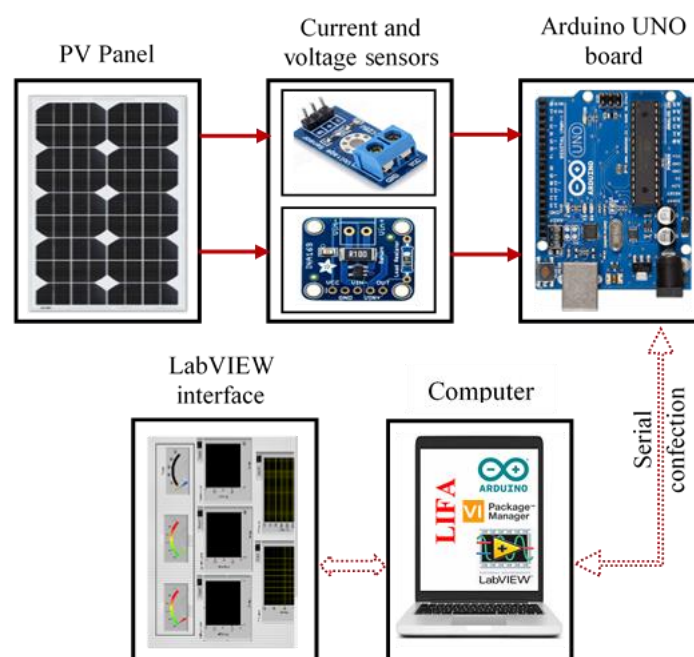


Figure 1. Schematic diagram of the PV panel instrumentation system.

2.1. Hardware

The proposed PV panel instrument system consists of a PV panel, Arduino UNO board, current sensor, and voltage sensor.

A. PV Panel

PV panels are intended to recover the energy of solar radiation to transform it into continuous electrical energy [14]. A monocrystalline PV panel M20-36 is used in this work, and its features at STC (Standard Test Conditions) are presented as follow [15]:

- Maximum power, P_{max} : 20 W;
- Voltage at P_{max} , V_{mp} : 18.76 V;
- Current at P_{max} , I_{mp} : 1.07 A;
- Short-circuit current, I_{sc} : 1.17 A;
- Open- circuit voltage, V_{oc} : 22.70 V;
- Temperature coefficient of V_{oc} , K_v : 0.35%/°C;
- Temperature coefficient of I_{sc} , K_i : -0.043%/°C;
- Number of cells: 36;
- Light-generated current, I_{ph} : 1.173 A;
- Diode saturation current, I_s : 2.6797e-11 A;
- Ideality factor: 1.0036;
- Shunt Resistance R_{sh} : 405.962 Ω ;
- Series Resistance R_s : 1.0547 Ω .

B. Arduino UNO

The data acquisition board used in this work is Arduino UNO, it is a low-cost board [5]. Figure 2 shows the Arduino UNO board, and table 1 presents its technical specifications [16].

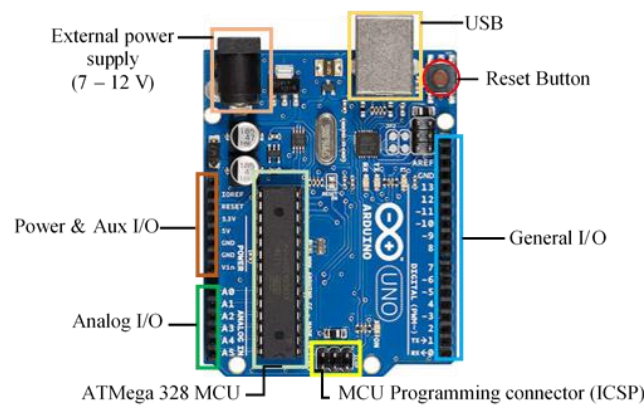


Figure 2. Arduino UNO board.

Table 1. Technical specifications of Arduino Uno board

Microcontroller	ATMega328
Operating Voltage	5 V
Input Voltage (recommended)	7 – 12 V
Input Voltage (limits)	6 – 20 V
Digital Input / Output Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA

Flash Memory	32 KB
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

C. Voltage sensor

For measuring the PV panel's output voltage, a voltage sensor F031-06 is used. Figure 3 shows the F031-06 voltage sensor module, figure 4 presents its connectors with the Arduino UNO board and the specifications of this sensor are shown in table 2.



Figure 3. F031-06 voltage sensor module.

Table 2. Features of the F031-06 voltage sensor module

Features	F031-06 voltage sensor module
Input Voltage Range	DC 0-25 V
Voltage Detection Range	DC 0.02445 V - 25 V
Analog Voltage Resolution	0.00489 V

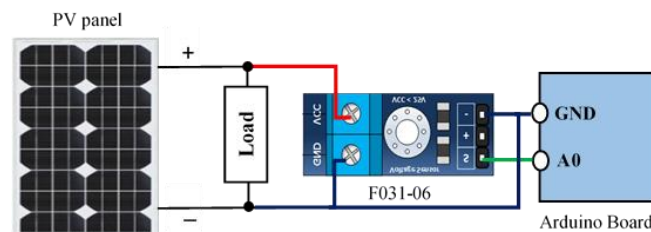
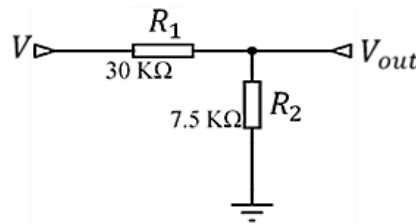


Figure 4. Schematic view of the F031-06 sensor connected to the Arduino board.

The F031-06 voltage sensor uses the principle of the voltage divider, it is essentially a voltage divider using a resistance of 30 k Ω and a resistance of 7.5 k Ω as shown in figure 5 [17]. It is used to reduce the input voltage up to 5 times compared to the original voltage because the maximum analog input voltage of the Arduino microcontroller is 5 V. The voltage sensor module will be installed in parallel with the PV panel load as shown in figure 4. The sensor reading is a digital value (V_{out}) which varies between 0 and 1023. Since the ADC of the microcontroller is coded in 10 bits, the resolution of the PV panel module voltage is 0.00489 V (5/1023) and the input voltage of this module must be more than 0.02445 V (0.00489 V \times 5). Hence, the output voltage of the PV panel can be formulated as the following equation:

$$V = 5 \times V_{out} \times \frac{5}{1023} \quad (1)$$

**Figure 5.** Voltage divider circuit.

D. Current sensor

The current sensor used to sense the PV panel output current is the INA169 module (figure 6), it can measure a continuous current up to 5 A [18]. In table 3, the specifications of the selected current sensor are presented.

**Figure 6.** INA169 current sensor module.**Table 3.** Features of the INA169 current sensor module

Features	INA169 current sensor module
Common Mode Voltage Range	DC 2.7 V - 60 V
Full-Scale Sense Input Voltage	500 mV
Input Offset Voltage (Max)	$\pm 1000 \mu\text{V/V}$
Input Offset Drift (Max)	$\pm 1 \mu\text{V}/^\circ\text{C}$
Nonlinearity Error (Max)	$\pm 0.1\%$
Total output Error (Max)	$\pm 2\%$
Common Mode Rejection Ratio (Typ)	120 dB
Bandwidth	440 kHz
Supply Voltage Range	DC 2.7 V - 60 V
Operating Temperature Range	$-40^\circ\text{C} - 85^\circ\text{C}$
Quiescent Current	60 μA

Figure 7 shows the INA169 current sensor circuit [18]. The INA169 is a high-side current monitor that measures the voltage drop across a sense resistor (R_s). Then, a voltage level (V_o) is generated at the output resistor (R_L) [18]. Therefore, as shown in figure 7, the output current of sensor module can be obtained by the following equation:

$$I_s = \frac{V_o \times 1K}{R_s \times R_L} \quad (2)$$

Where:

V_o : is the voltage we measured at the output of the INA169.

R_s : is the value of the shunt resistor, this is set at 0.1Ω .

R_L : is the value of the output resistor, this is set at $10 \text{ K}\Omega$.

Hence, the output current of the PV panel can be formulated as the following equation:

$$I = \frac{V_o \times 5}{1023} \quad (3)$$

The output voltage of the INA169 module is the input voltage at an Arduino analog pin (A1), which varies between 0 and 1023. The current sensor module must be connected in series to the positive side of the PV panel and that of the load as shown in figure 8.

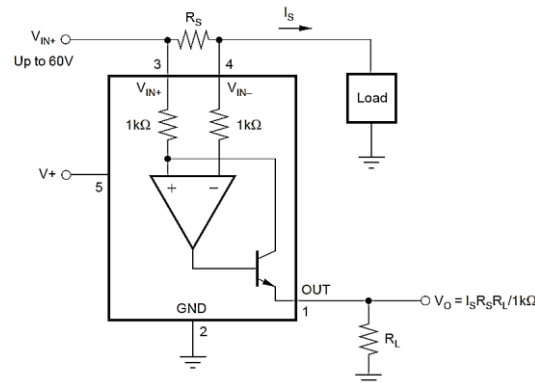


Figure 7. INA169 current sensor circuit [18].

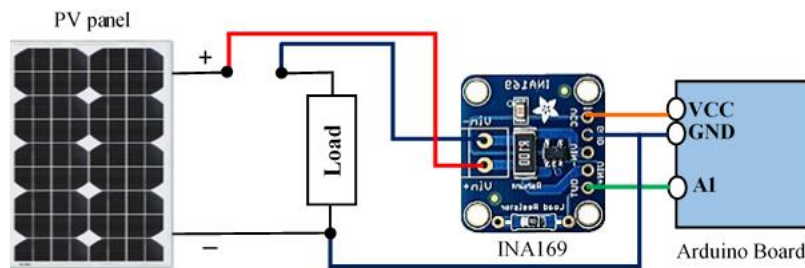


Figure 8. Schematic view of the INA169 sensor connected to the Arduino board.

2.2. Software

The real-time virtual instrumentation system of PV panel characteristics was designed using a LabVIEW and Arduino based controller. For that, in the software part, we present all tools requested for sending data from Arduino board to LabVIEW, hence, the steps for obtained the I-V and P-V curves of PV panel in real-time.

A. LabVIEW Interface For Arduino (LIFA)

To send data from Arduino to LabVIEW, the LIFA is necessary to make the connection between the Arduino microcontroller and computer. For this, to make the interface as shown in figure 9, you will need to follow the following steps:

- Install the LabVIEW software (LabVIEW 2011 or later);
- Download the NI-VISA drivers and install it. Since the Arduino appears as a serial instrument device for LabVIEW, the NI-VISA drivers must be downloaded and installed to communicate with Arduino board in LabVIEW;
- Download the JKI VI Package Manager (VIPM) and install it, it allows to install and update LabVIEW libraries;
- Install the LIFA by following the next steps:

Lunch LabVIEW → click on tool → go to VIPM → browse to LIFA in the list of packages → click on the Install Upgrade Packages button;

- Download the open source Arduino IDE software and install it;
- The LIFA provides a sketch program that must be uploaded to the Arduino before you can use the virtual instruments to communicate with it. For this, Open the Arduino IDE application and following the next steps to uploading LIFA firmware to the Arduino board:
 - ✓ Go to File → Click on Open → go to the sketch which is located at:
C:\ProgramFiles(x86)\National Instruments\LabVIEW 2015\vi.lib\LabVIEW Interface for Arduino\Firmware\LIFA_Bas;
 - ✓ Select the type of used Board (Arduino UNO);
 - ✓ Connect the board to computer via USB cable and select the used serial port;
 - ✓ Verify and Upload the sketch program LIFA to the Arduino microcontroller;
- After that, you can start building your code in Arduino with LIFA Block Diagram.



Figure 9. Process of installing LIFA and its firmware to Arduino board.

B. LabVIEW program

In figure 10 and figure 11, the overview of the block diagram and the software interface of the real-time virtual instrumentation system of PV panel characteristics are shown. For enriching understanding, the block diagram is separated into four part. The first one illustrates the blocks of initialization and configuration of the serial connection between the hardware (Arduino UNO) and software (LabVIEW), that by defining the type of used Arduino (Arduino UNO), type of serial communication (USB) and the Baud Rate (9600 bits per second). In the second part, the voltage and current readings will be obtained from the microcontroller by using the analog read function in LIFA's palette in which the initialization of the selected Arduino pins as inputs was made, A0 pin for voltage reading and A1 pin for current reading. The third part shows that the current, voltage and output power readings are carried out and will be plotted directly according to time by using scrolling graphs in LabVIEW palette. Note that the reading of the voltage is multiplied by 5 because as it is demonstrated in the hardware part that the voltage reading by the microcontroller varies between 0 and 5 V, it is necessary to multiply it by 5 to obtain the PV panel's output voltage. The PV panel's output power reading is done out by the product of the current and voltage reading. Finally, in the last part, the I-V and P-V curves of PV panel characteristics will be plotted in software interface of the system by using x/y graphs in LabVIEW palette.

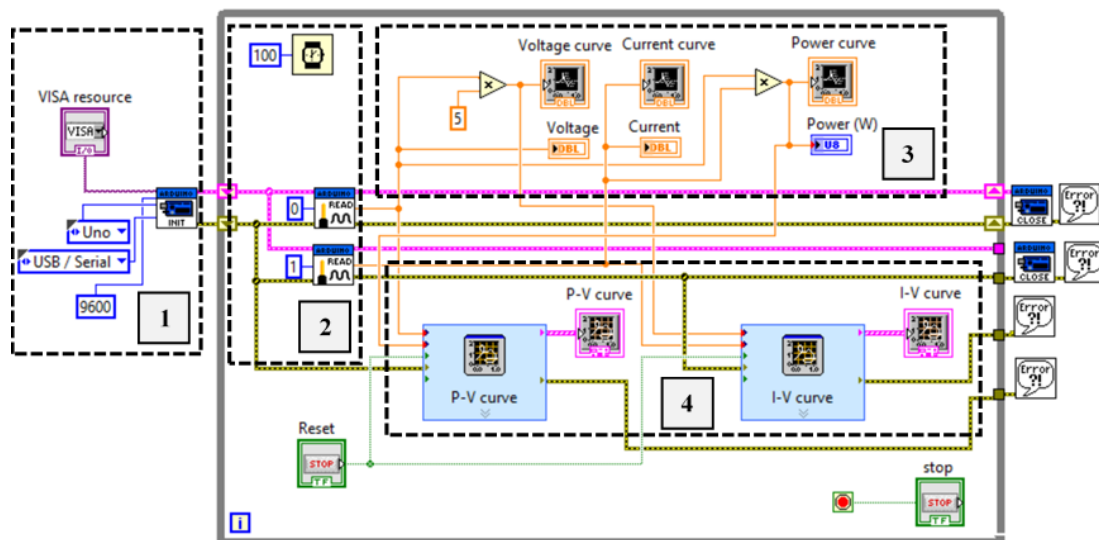


Figure 10. Block diagram of the real-time virtual instrumentation system under LabVIEW.

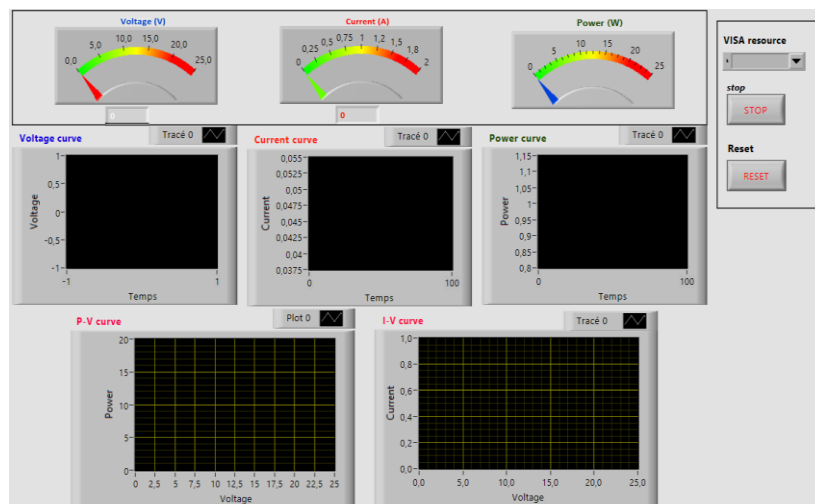


Figure 11. The software interface of the real-time virtual instrumentation system under LabVIEW.

3. Experimental results

In figure 12, the experimental setup of the real-time virtual instrumentation system is shown. Apart PV panel, Arduino UNO board, voltage and current sensor, different components are used in the experimental setup such as lamps of 100 W that acts as a solar simulator, a variable resistance between 0 and 300 Ω as a load and acting as a light intensity driving. The microcontroller's operation is programmed in the block diagram to measure the values relative to the current and the voltage captured by the sensors successively every 100 ms. Once the Arduino board is connected to the computer through USB cable, we launch the software interface of our system under LabVIEW. Then, we defined in the visa block the serial port where the Arduino board is connected to the computer. Thereafter, after the execution of the program, the output data will be plotted in real-time on the software interface under LabVIEW. The results of direct monitoring and the I-V/ P-V curves of the PV panel are shown in figure 13.

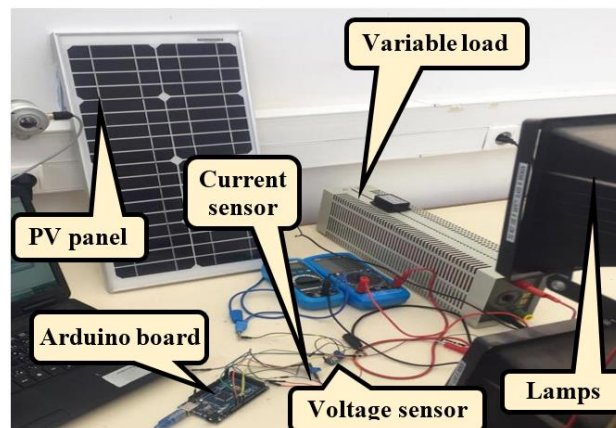


Figure 12. Experimental setup of the measurement system

In figure 14, a comparison between the P-V characteristic of the PV panel which is obtained by the proposed solution and that obtained by an experimental test through calibrated Millimeters is shown. The results presented in figure 14 indicate that the developed real-time virtual instrument in this work is valid. The price of the hardware components used for data acquisition in the proposed instrumentation is presented in table 4.

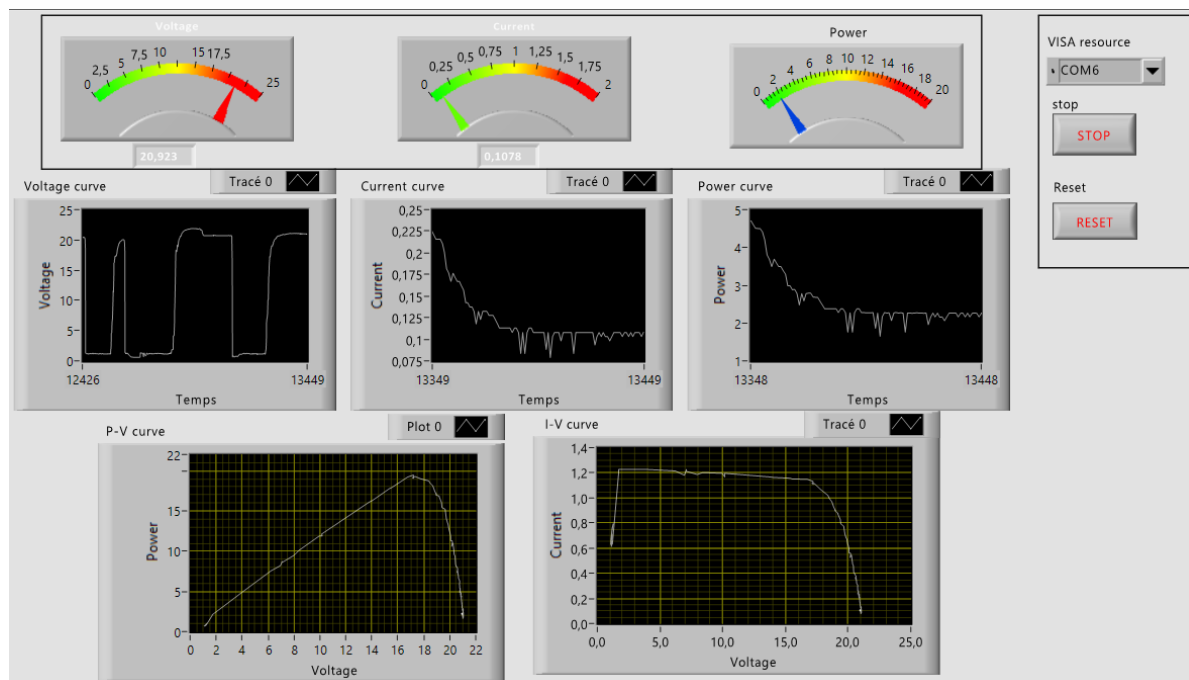


Figure 13. Obtained results in the software interface of the real-time virtual instrumentation system.

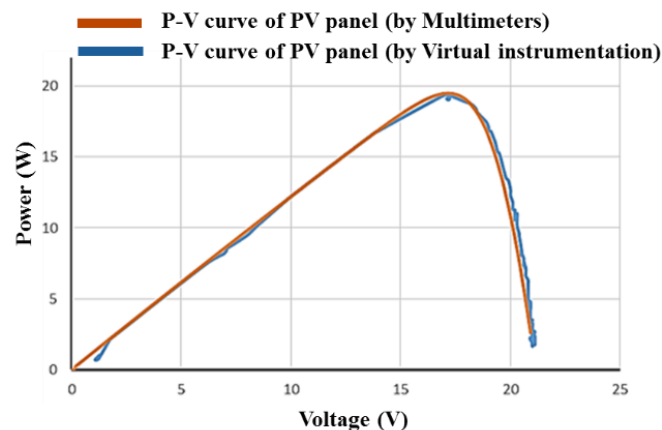


Figure 14. P-V curve of PV panel.

Table 4. Price of hardware components used for data acquisition

Components		Price (\$)
Arduino UNO board	4.75	(www.aliexpress.com)
F031-06 voltage sensor module	0.74	(www.aliexpress.com)
INA169 current sensor	3.30	(www.aliexpress.com)
Total price		8.79

4. Conclusion

This article describes a real-time virtual instrument system of PV panel characteristics based on a low-cost embedded board, which used to monitor and trace the characteristics I-V and P-V of a PV panel under the real condition. For that, PV panel, Arduino UNO board, voltage and current sensors have been used as hardware components coupled to the open-source Arduino IDE, LabVIEW and LIFA as the software for the system design. The present system is validated by comparing the obtained data in LabVIEW interface with that obtained with the experimental test using a calibrated Multimeters. Results show that the data of our instrument are in accordance with experimental data.

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