Solar Cell Curves Measurement Based on LabVIEW Microcontroller Interfacing

YOUSRY ATIA[1], AND MOHAMED ZAHRAN[1,2] ABDULLAH AL-HOSSAIN[4]

1. Electronics Research Institute, PV Dept., El-tahrir St., Dokki, 12311-Giza, EGYPT, yousry_atia@yahoo.com
2. Jizan University, Faculty of Engineering, Electrical Engineering Department, KING SAUDI ARABIA, Tel./Fax. +9667-3230003/+9667-3230004. mbazahran_2007@yahoo.com
3. The Dean, Faculty of Science, Acting Dean of Academic Development Deanship, Jazan University: abo_hossam@hotmail.com

Abstract: -This paper describes a novel data acquisition system designed and implemented with facilities for measuring and monitoring the characteristics of a PV solar cell , module and/or system. The functioning of the equipment is based on the so-called virtual instrumentation. This is a non-conventional concept, however it does not have the many limitations in other systems. Additionally, the whole equipment can be implemented at significantly lower cost than the commercial one. The dark characteristics test facility, based on LabVIEW software to design an easy handling Graphical User Interface (GUI) and use a single chip microcontroller with a serial interface. The system is used to acquire the measured data from the cell under test and transfer it to a supervisory computer for monitoring and other signal processing. The preliminary test we have made indicates that the equipment we propose here is highly reliable, which allows measuring and monitoring variety of solar cell characteristics with a good accuracy.

Key Words**:** LabVIEW, AVR Microcontroller, Solar Cells, Solar Array, I-V Curve Measurements, I-V Curve Tracking.

1. Introduction

In the photovoltaic field, manufacturers provide ratings for PV modules for conditions referred to as standard test conditions (STC). However, these conditions rarely occur outdoors, so the usefulness and applicability of the indoors' characterization in standard test conditions of PV modules are a controversial issue. Therefore, to carry out photovoltaic engineering well, a suitable characterization of PV module electrical behavior (V–I curves) is necessary [1].

Since solar cells convert light to electricity it might seem odd to measure the photovoltaic cells in the dark. However, dark I-V measurements are in valuable in examining the cell properties. Under illumination, small fluctuations in the light intensity add considerable amounts of noise to the system making it difficult to measure. Dark I-V measurements use injects carriers into the circuit with electrical means rather than with light generated carriers. In most cases the two are equivalent and the Dark I-V measurements give extra information about the cell for diagnostic purposes. Even in the absence of noise there is a wealth of information in comparing the illuminated and dark I-V curves [2].

The solar cell characteristics are handled in many references [3-13]. Alternatively, the static parameters and characteristics of solar cells are normally determined from their illuminated current-voltage characteristics under standard solar simulators, based on flash lamps or distributed light sources, or outdoor conditions. They are used in assessing solar cell efficiency and fill factors. On the other hand, dynamic parameters are required in designing circuits containing solar cells and switching devices as well as providing important diagnostic tools.

2. Survey of Previous Work

Daniel KOSTER et. al, have reported in [7] that, as commonly known the most significant method to describe the performance characteristic of PV modules is the measurement of I-V curves under real operating conditions. Although there is no need to reinvent the wheel since all recognized PV test-facilities and a number of manufacturers of PV modules are using their specific equipment.

Yan-Fang Li, et. al, have reported in [9] that, Basic Stamp 2 (BS2) is a popular microcontroller used both in hobby and industrial projects. Similar to other microcontrollers, BS2 programming environment lacks graphical user interface (GUI) capability. In there paper, they present an approach to endow the BS2 microcontroller with GUI capabilities by interfacing it with Matlab and by exploiting Matlab's abundant GUI tools. The proposed Matlab-based GUI environment for BS2 relies on the use of serial communication between the BS2 and a personal computer.

Also, in space application, the spacecraft photovoltaic arrays (PVA's) must be carefully handled during ground integration processing and transportation to the launch site. Care is exercised to avoid damage that could degrade on-orbit electrical performance. Because of this damage risk, however, PVA's are typically deployed and illuminated with a light source so performance characteristics can be measured prior to launch. *Another alternative is dark forward electrical testing. This testing is performed while the array stowed, obviating the need for deployment and illumination test support equipment. Dark test support equipment is inexpensive, it is easily portable to launch site facilities, and testing can be accomplished with only one or two test engineers [13].*

So the dark measurements of a single solar cell or a complete photovoltaic module or system are a trustworthy in the photovoltaic world as well as the outdoor measurements.

3. Solar Cell Characteristics

In the characterization of PV modules several types of methods can be differentiated. Those are able to obtain the PV module behavior in STC. The methods obtain the characterization of the PV module in STC from outdoor measures. In these cases, a process in two stages is necessary:

1st, the experimental measurement of I-V characteristic along with the predominant conditions of operation, and

2nd, the extrapolation of the measures to STC.

In this work, the I-V characteristics of the solar cell is provided in the dark mode as a diode characteristics, then data extrapolation is made to normalize the test result curves to STC.

3.1. I-V Curve Measurements of SC

3.1.1. Cells model

A solar cell is usually represented by an equivalent one-diode model. The model contains a current source I_{ph} and series resistance R_s, which represents the resistance inside each cell and in the connection between the cells as shown in Figure 1. The net current is the difference between the photocurrent I_{ph} and the normal diode current I_D:

$$I = I_{ph} - I_D = I_{ph} - I_0\left(\exp\frac{e(V + IR_S)}{mKT_{ab}} - 1\right) \quad \text{Eq. 1}$$

Where:

m is the idealizing factor,
K is the Boltzmann's constant,
T_{ab} the absolute temperature of the cell,
e electronic charge and
V is the cell voltage.
I_0 is the saturation current, which depends strongly on the cell temperature.

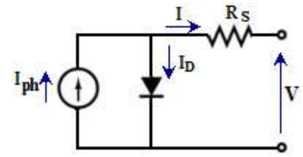

Figure 1, Solar cell model.

3.1.2. System objective

The system was developed for measuring and monitoring a PV solar cell, module and/or system. It provides facilities to get the test through three kinds of measurements:

Environmental and system variables (ambient temperature, solar radiation, current, voltage, energy, power, etc.).

The dark I-V characteristics for the cell, module and/or system. (open circuit voltage, V_{oc}; short circuit current, I_{sc}; fill factor, FF; efficiency, η and maximum power, P_{max})..

Forecast the I-V and P-V curves of the PV cell, , module and/or system in STC or any condition as well as determination of its electric cell parameters.

The user can display in a computer screen the instantaneous values of any of the above parameters and graphs of the I-Vs. V and P vs. V curves

3.1.3. System Setup Circuit

The proposed mentioned data acquisition system is using the microcontrollers as a data logger for measuring and acquiring the signals and transmitting it to a PC through serial port RS-232.

The experimental setup circuit for cell dark characteristics is shown in Figure 2.

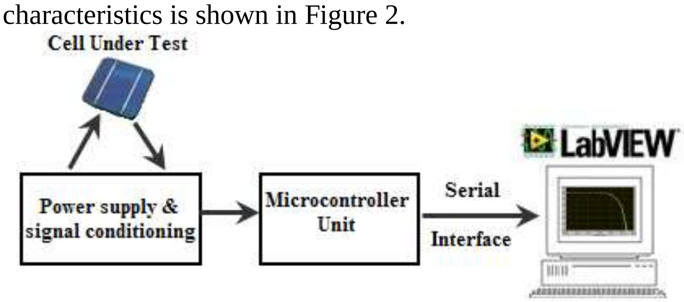

Figure 2, Dark cell measurements setup circuit.

Usually, the data transmission through the serial port is limited when data acquisition at high sampling rates is required [14]. In our work we acquiring the data and saving it in the microcontroller S-RAM, after test is completed the data are transmitted to the PC via the serial port. Also this limitation does not occur when the data acquisition is performed using I/O modular devices. Another limitation we have identified in conventional data acquisition systems is the difficulty of making any modification to the test programs. This limitation is absent where the programs are developed using LabVIEW, where the user can modify and process the collected data to minister his own objectives. Additionally,

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the high cost of commercial automatic data acquisition systems that are capable of monitoring and operational control of PV solar plants is the main limiting factor for the development of PV system projects in developing countries.

4. Measurement System Description

The dark test equipment consists of AC power supply with DC offset adjustment facility (function generator FG) , signal conditioning circuit, AVR microcontroller and a personal computer (PC), as shown in the schematic diagram.

Under dark condition, an AC signal from FG is imposed on the cell under test, and then the resulting current and voltage signals are collected. Several current-voltage data points are obtained to generate the dark cell characteristic curve. The data are stored in the microcontroller S-RAM. The PC then collects the data from the microcontroller via the RS-232 serial port. The data can be stored in a data file for documentation purpose, in a table and in X-Y graph for mentoring on the PC screen. Those data can be manipulated to obtain the illuminated electrical performance for the solar cell, module and/or system.

4.1. Solar Cell I-V Test Program

Unlike [7], [9], LabVIEW based GUI program (vi) is developed to configure the computer as supervisory monitoring system and interfaced with AVR microcontroller via RS232 serial communication. The program controls the microcontroller by ordering it to start solar cell testing, and to collect the measured data. The PC LabVIEW receives the data from the microcontroller, save it in a file, then viewing the measured points in a table, processing the received data and controlling the result graphs. The graph preview area shows the collected data points after a sweep. The voltage, current and power data are recorded in a table specified by the user. The program allows the user to configure and modify the method of data processing.

4.2. LabVIEW Program Block Diagram

The solar cell I-V & P-V test setup block diagram is shown in Figure 3. The block diagram can be divided into two main sections; the first section is the initialization of serial VISA interface while the second section is responsible for measured data processing.

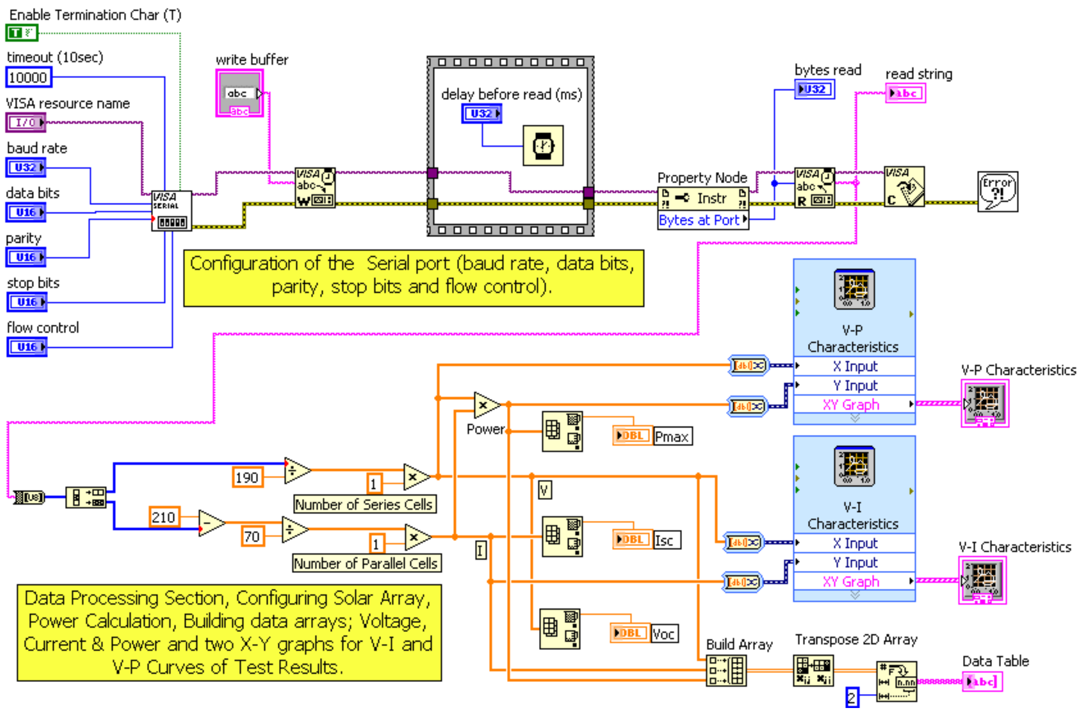

Figure 3, LabVIEW Serial Interface and I-V Curve Measurement Block Diagram

4.3. LabVIEW Program Front Panel 'GUI'

The front panel of the developed LabVIEW Program is shown in Figure 4. The measured data is presented in the front panel of LabVIEW program in two forms, table with four columns; numbers of measured points, voltage, current and power. The other form is the X-Y graph for I-V and P-V. Also the other important points as I_{SC} , V_{OC}, and P_{max} are presented. The initialization parameters of the serial VISA are presented also in the front panel allowing the user to input the relevant data for his application. The output buffer (write) orders the microcontroller to start testing process then transferring data to PC. The measured data are back to input buffer (read) that is included also in the front panel. The solar cell I-V & P-V diagrams are shown in Figure 4.

5. AVR ATmega16 Microcontroller

The AVR ATmega16 microcontroller that is used in the proposed work is a low-power CMOS 8-bit microcontroller. It has powerful instructions in a single clock cycle, the ATmega16A approaching 1 MIPS (million instruction per second) per MHz allowing the system designer to optimize power consumption versus processing speed. It has the following important features:

0 - 16 MHz
32 Programmable I/O Lines
Byte-oriented Two-wire Serial Interface
8-channel, 10-bit ADC
16KB of Self-programmable Flash program memory
512 Bytes EEPROM
1K Byte Internal SRAM

The following two sections illustrate the control circuit hardware and the microcontroller control program flow chart.

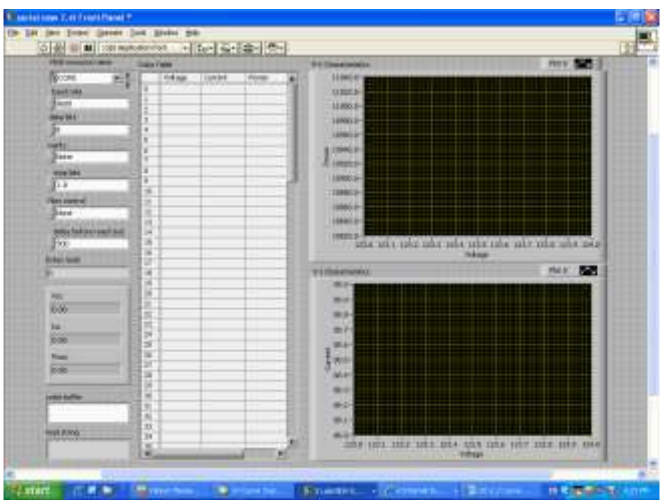

Figure 4, LabVIEW Graphical User Interface Menu.

5.1. Microcontroller Control Circuit with Serial Interface

The microcontroller control circuit is shown in Figure 5. Serial interface is used to communicate with PC where the Graphical User Interface software is developed using the LabVIEW Software package. The converter and conditioner device MAX232 chip is used to interface the microcontroller serial terminals and the PC RS232 via standard serial cable. The required power supplies, reset and crystal circuits for microcontroller operation are developed also.

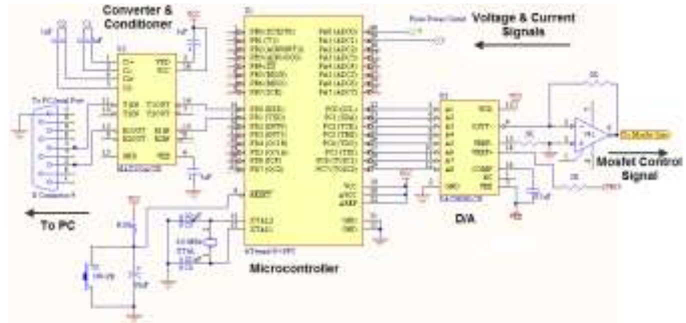

Figure 5, The Microcontroller Interfacing and Measurement Control Circuit.

The microcontroller is configured where one port (port C) is interfaced with D/A device to generate the analog control signal that controls the power switch of solar array testing in illuminated mode. Port A is used as A/D converter; channel 0 and channel 1 are used to measure the solar array current and voltage. Serial Interface is used to communicate with PC where the Graphical User Interface Software is developed using the LabVIEW Software package.

5.2. Program Flow Chart

The microcontroller program flow chart is shown in Figure 6.

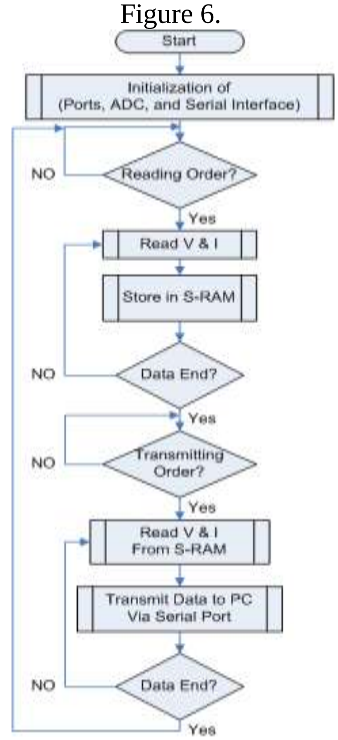

Figure 6, The microcontroller control program flow chart.

The microcontroller measurements control program starts with initialization of all microcontroller peripherals as parallel and serial ports, ADC channels, ..etc. The program is divided into two main phases; data measuring phase, and data transmitting phase. This technique is used to override the serial port speed limitations.

6. The Dark Test Circuit

The dark test circuit of the single solar cell is illustrated in Figure 7.

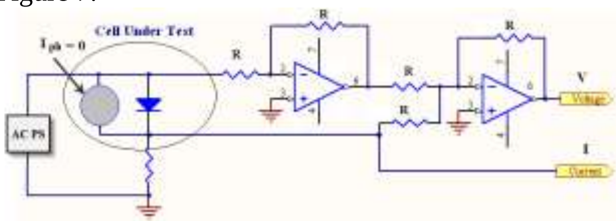

Figure 7, Single solar cell dark test, and signal conditioning circuit.

As the microcontroller A/D device is a unipolar, so it can't measure negative signal. A DC offset signal is added to the AC signal of power supply (AC PS). A signal conditioning circuit is built to read two signals (V&I) with one common ground.

7. Illuminated Solar Array Test Circuit

The power circuit of the solar array module or subsystem testing in illumination mode is illustrated in Figure **8**.

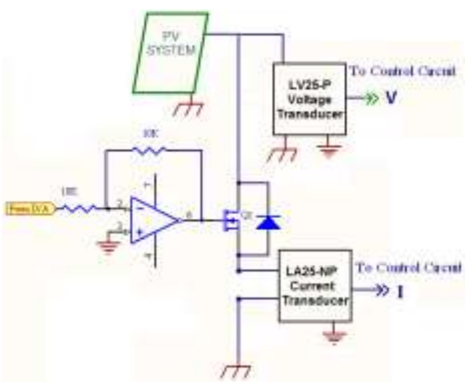

Figure 8, I-V Measurements Power Circuit.

It consists of the following components:

- The solar module or solar array under test, A voltage transducer LV25-P type to measure the solar array terminal voltage, A power MOSFET that represents an electronic load to change the solar array output current from zero to short circuit value, or to the change the solar array terminal voltage from open circuit to zero value,
- A signal conditioning circuit used to isolate the control signal from microcontroller and to control the operation of the power electronic switch (MOSFET) which operated in the linear (active) region,
- A current transducer LA25-NP type to measure the solar array output current,
- The two output analog signal; voltage and current (V & I) are wired to the input two analog channels in the AVR microcontroller.

8. Experimental Results

The implemented proposed system is shown in Figure 9. The system composes the following components; solar cell under test, conditioning circuit, power supply, microcontroller board and the measuring tools oscilloscope and supervisory control (Laptop Computer) with the developed LabVIEW software program. The solar cell tests are executed in two stages. In the first stage, the system is used to measure the diode characteristics of the solar cell under test. The solar cell is a Si mono-crystalline cell with 10x10 Cm^2. The I-V curves are measured and the results are shown on an Oscilloscope monitor as well as on the front panel of implemented LabVIEW GUI software.

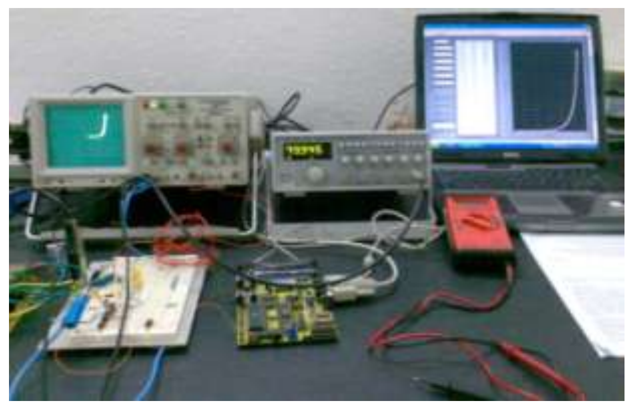

Figure 9, Hardware setup showing I-V on Oscilloscope and Laptop monitor using LabVIEW GUI Software.

The test results are shown in the following two graphs; Figure 10 and Figure 11.

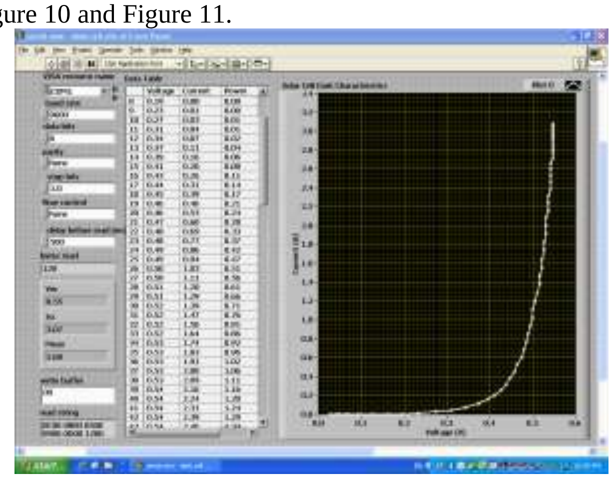

Figure 10, the I-V Curve of diode characteristics of the solar Cell under test.

Figure 11, 10x10 Cm2 Solar Cell I-V Test Results, X-axis: 0.2V/div, Y-axis 1A/div

Comparing the two I-V curves, it seems that they are identical by means that, the data processing in the developed LabVIEW test program is valid. In the second stage, a data processing module were added to developed LabVIEW program block diagram to present the I-V in the first quarter as usual form. Also, the power curve (P-V) is deduced from the measured data. Both I-V and P-V curves are presented in the GUI front panel window. The results are shown in Figure 12.

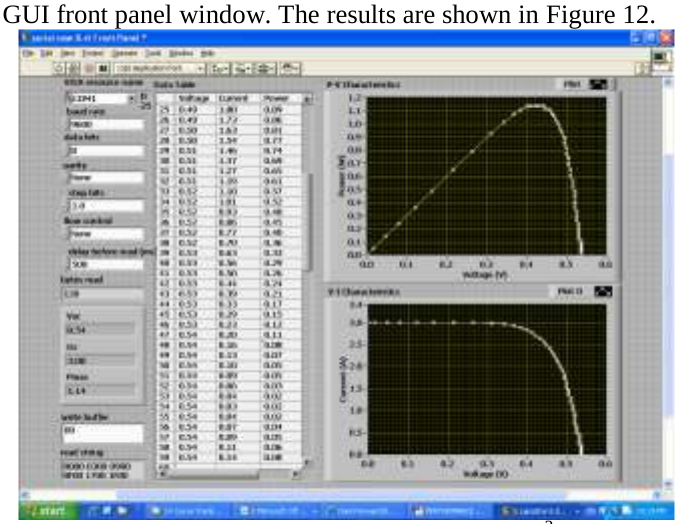

Figure 12, Test Results; I-V & P V -of 10x10 Cm^2 Solar Cell.

9. Conclusions

A developed technique for presenting the methodology of solar cell characteristics is presented in this paper. The hardware setup of the proposed technique is illustrated in details in this paper. The AVR ATmega16 is applied and the wiring diagram of the microcontroller and all the necessary conditioning circuits are given. The flow chart of the developed microcontroller software program is given also. The power circuit of measuring the solar cell (or solar array) characteristics in both dark and illumination modes are implemented and illustrated.

The LabVIEW software is applied in this work to pack and draw the collected data of solar cell characteristics from microcontroller subsystem. The complete block diagram is shown in details in this paper. A graphical user interface (front panel) is designed in the developed LabVIEW solar cell testing program. It is used to present the measured solar cell testing data, the packed data and the plotted I-V and P-V curves. A mono-crystalline solar with $10x10Cm^2$ is used and the test results before and after the normalization process are given.

An intelligent module is added in the block diagram to normalize the measured solar cell characteristics data in dark mode to be presented in the usual form. An examination of the implemented LabVIEW model is applied and the results shows a compatibility between the test results presented directly on Oscilloscope monitor with other presented on the developed LabVIEW model front panel.

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