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ORIGINAL ARTICLES

Design and Practical Implementation of a Simple Data Acquisition System for Photovoltaic Applications

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ABSTRACT

There are several commercial systems for testing PV modules under field conditions but they are expensive. This paper presents a design and implementation of a simple, low cost and high efficient data acquisition system for testing the photovoltaic modules under different operating conditions (different solar radiation levels and surface temperatures). It has been designed to be the laboratory basic element for the photovoltaic generators characterization. This data acquisition system is designed to acquire and then records the signals from the different sensors that are used for measuring the different parameters of the PV system. These measurements of the different parameter include the incident solar radiation on the PV module, PV module surface temperature, load voltage, and load current. These parameters are measured via physical sensors and transducers and recorded using Analog-Digital (AD) card driven by a PC.

Key words: Data acquisition system, Solar radiation measurements, temperature measurements, Load voltage and current measures.

Introduction

Nowadays, people are much concerned with the fossil fuel consumed at the present high rate as well as the environmental damage caused by the conventional power generation (Tsai, 2010). Renewable energy is being increasingly utilized in electric power systems due to environmental concerns and energy cost escalation associated with the use of conventional energy sources (Chang, 2010). Renewable energy resources will play a significant role in the world energy supply in the upcoming future. Among the renewable energy resources, solar energy is the most essential and prerequisite resource of sustainable energy because of its ubiquity, abundance, and sustainability. Regardless of the intermittency of sunlight, solar energy is widely available and completely free of cost (Tsai, 2010). The photovoltaic (PV) system is a generating system using the photoelectric effect which changes the light energy into electric energy. And the performance of PV system is depended on radiation and temperature (Ko and Chung, 2012).

Since the output energy from any PV system depends mainly on the operating point, i.e the PV system can operate at various electric parameters current – voltage (I-V) according to the operating conditions and the nature of the electric load, knowing the actual I-V and power –voltage (P-V) performance of any PV system accurately is a very important feature in designing such systems.

Several Papers have appeared in literature for measurement the current-voltage (I-V) characteristics and the power-voltage (P-V) characteristics (Mahmoud, 2006; Bonanno *et al*., 2012; Kuai and Yuvarajan, 2006; Benghanem, 2009; van Dyk *et al*., 2005; Forero *et al*., 2006). So, the accurate measurement for electrical (I,V,P) and environmental parameters (solar radiation and module temperature), is very important for accurate system design and operation.

Fig. 1 shows I-V and P-V characteristics of PV module (Vengatesh and Rajan, 2011). PV modules have two main relations mainly specifying its performance. These characteristics are the current-voltage (I-V) characteristics and the power-voltage (P-V) characteristics. The (I-V) characteristic of the photovoltaic system is a nonlinear relation as shown in Fig. 1 the voltage drops considerably as the current increases and is approaching zero as the current approaches short circuit current. So, the curve has three main points describing its performance. These points are; short circuit current, open circuit voltage, and maximum power point. These points change with the change in the environmental conditions. The second important relation is the P-V characteristics, which indicate directly the relation between the extracted power from the PV module and the operating voltage, as shown in Fig. 1 this curve indicates clearly that there is one unique maximum power point for a certain solar radiation level.

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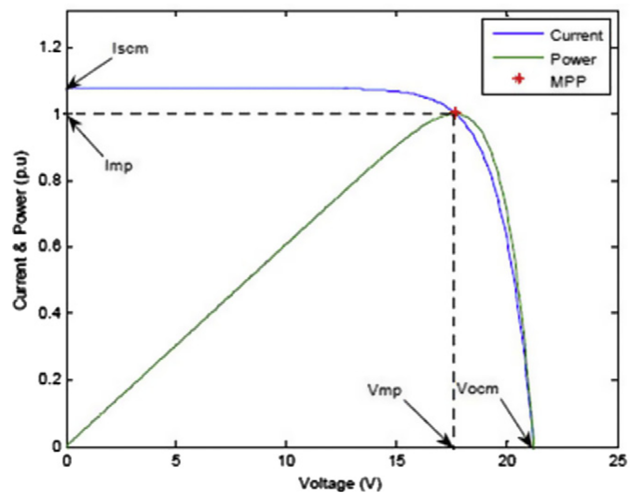

Fig. 1: I-V and P-V curves of PV module.

As shown above, determining an accurate I-V characteristics is essential for designing any PV system, especially in calculation the required PV panels for a certain electric load.

This paper presented a simple and accurate measuring data acquisitions system for collection the required parameters for getting an accurate I-V characteristic for any PV system based on a computer - instrumentation system.

The Data acquisition system:

The data acquisition system (DAS) is used to record the signals from the different sensors that are used for measuring the different physical parameters of the PV system. These measurements include the incident solar radiation on the surface PV module, PV module surface temperature, load voltage, and load current. These parameters can be measured and recorded via a PC driven by AD card. In the following section, the components of the measuring system will be introduced. Fig. 2 shows the schematic diagram for the proposed data acquisition system. The electronic circuit diagram for the proposed data acquisition system is shown in Fig. 3 the details of the hardware parts of the proposed data acquisition system are discussed in the subsequent sections.

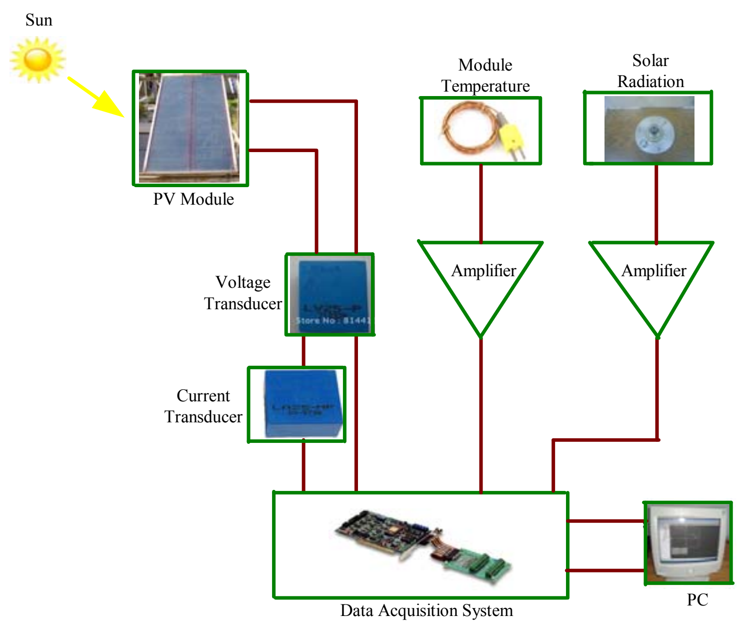

Fig. 2: Schematic diagram for proposed data acquisition system.

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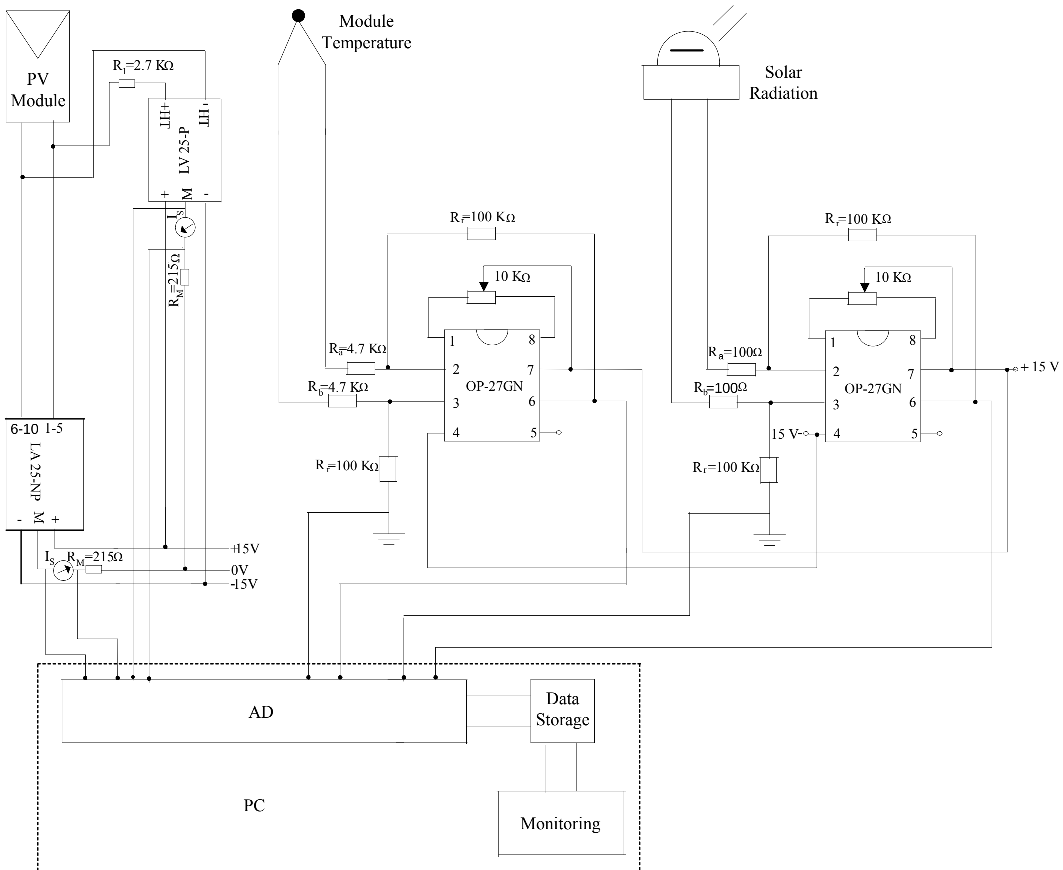

Fig. 3: Electronic circuit diagram for proposed data acquisition system.

Analog to Digital Conversion (ADC):

The main part in the data acquisition system is the AD574 analog to digital module, which receives the voltage analog signals from the measuring devices and converts theses signals into digital signals to be processed by the PC. The AD card has 8 input analog channels each with 12-bit resolution.

The Voltage Measurement:

The load voltage can be measured accurately by using an appropriate voltage transducer. The used voltage transducer is a bipolar LV 25-P voltage transducer, with galvanic isolation between the primary circuit (high voltage) and the secondary circuit (low voltage).

For the voltage measurements, a current proportional to the measured voltage must be passed through an external resistor R_1, which is installed in series with the primary circuit of the transducer. The connection circuit diagram for voltage measurement is shown in Fig. 4.

An excellent accuracy, very good linearity, low thermal drift, low response time, and high immunity to external interface voltage transducer is used to get a voltage signal (from 0 to 5 V) corresponding to the measured value. The measured voltage signal is passed to the AD card. The calibration curve that is used to get the actual measured voltage from the transducer output voltage signal is shown in Fig. 5.

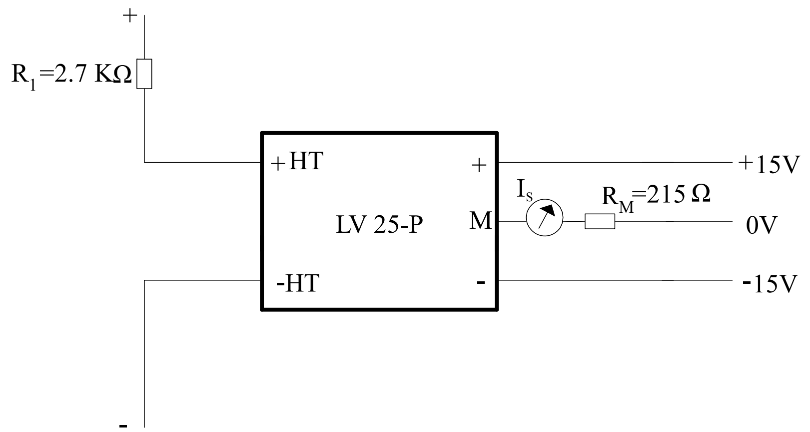

Fig. 4: Voltage transducer connection circuit.

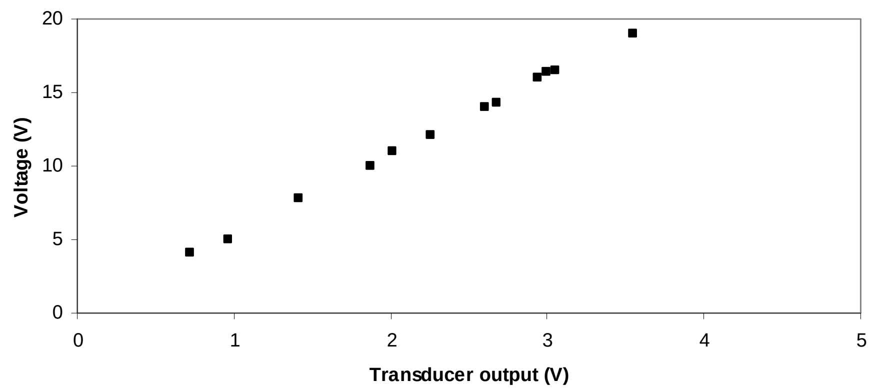

Fig. 5: The relation between the actual measured voltage and the transducer output voltage signal.

The Current Measurement:

A multi-range current transducer LA 25-NP is used to measure the load current. The current transducer has an excellent accuracy, very good linearity, low temperature drift, optimum response time, wide frequency bandwidth, no insertion loses, high immunity to external interface, and current overload capability.

The current transducer is used to convert the module current into a voltage signal (from 0 to 5 V) to be suitable for reading by the AD card. Fig. 6 shows the connection diagram for the current measurement, while the calibration curve for converting the transducer voltage signal to the corresponding actual current is shown in Fig. 7.

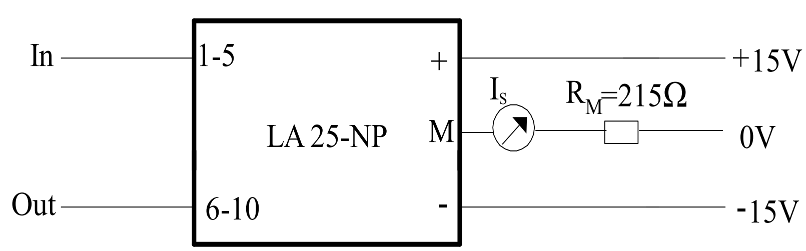

Fig. 6: Current transducer connection circuit.

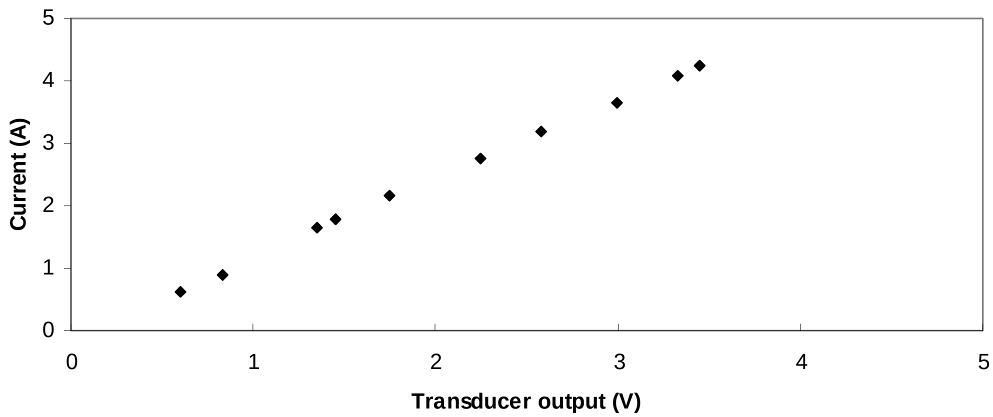

Fig. 7: The relation between the actual measured current and the transducer output voltage signal.

The Solar Radiation Measurement:

For any efficient use of solar energy, it is necessary to have a good knowledge of the amount of incident solar radiation on the surface of the solar system. The solar radiation incident on any arbitrary surface is composed of three components; the direct (normal) radiation, the sky diffuse radiation, and the ground reflected radiation. Each of these radiation components has its own characteristics that different from the others. The normal radiation is the solar radiation received directly from the sun without having been scattered by the atmosphere. This component is affected only by the incidence angle of the sun rays on the surface. The sky diffuse radiation is the solar radiation received by the system from the sun after its direction has been changed by scattering by the atmosphere. The ground reflected radiation is the solar radiation reflected from the ground and received by the system. This component is greatly affected by the nature of the ground. The total solar radiation received by the system is the sum of all these components.

A thermopile pyranometer of type Kipp & Zonen (model CM5-774035) as shown in Fig. 8 is used to measure the solar radiation intensity. The pyranometer is mounted at the PV module structure and parallel to the module.

Fig. 8: Athermopile pyranometer of type Kipp & Zonen model.

Since the pyranometer output voltage is in the range of millivolts corresponding to the measured radiation, the output voltage signal must be amplified to be suitable for the AD card. Fig. 9 shows the amplification circuit for the solar radiation measurements. Since, the output from the amplification circuit is sensed by the AD (0 to 5 V), it must then be converted into its actual radiation value. Fig. 10 shows the relation between the AD input signal to the correct radiation value.

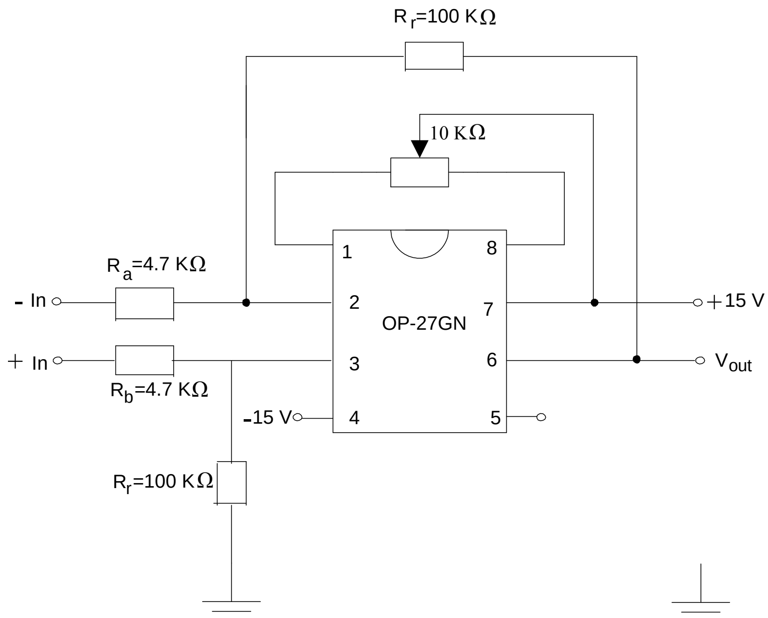

Fig. 9: The electrical circuit diagram used to amplify the pyranometer output voltage.

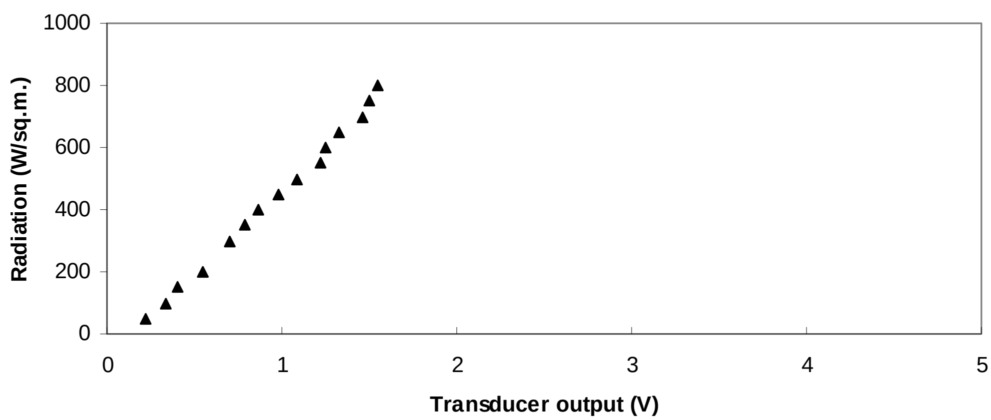

Fig. 10: The relation between the actual measured solar radiation and the AD input voltage signal.

The PV Module Surface Temperature Measurement:

Since the temperature is important parameter on the PV module performance, it must be measured continuously to get the correct response from the PV system. A type K thermocouple as shown in Fig. 11 is used to measure the PV module surface temperature. The thermocouple converts the module temperature to a very small voltage signal (≈ 1 mV for each 25 ^{o}C). A suitable amplification circuit as shown in Fig. 12 is used to amplify this signal to be suitable for the AD card. The actual measured temperature is obtained using Fig. 13 that introduces the calibration curve of the temperature measuring circuit.

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Fig. 11: A type K thermocouple

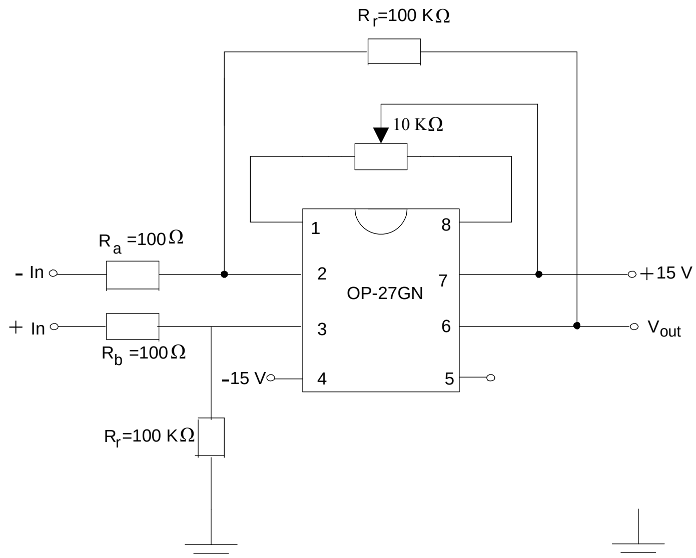

Fig. 12: The electrical circuit diagram used to amplify the thermocouple output voltage signal.

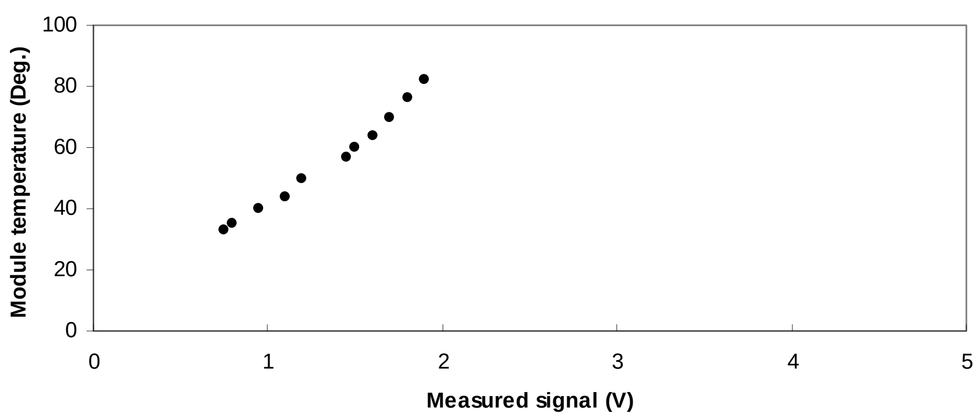

Fig. 13: The calibration curve that relates the measured module surface temperature to the input voltage signal of the AD card.

Case Study:

The proposed DAS was verified by actual measurement for different I-V curves for different I-V modules this measurement was carried out in the test field of solar energy department (SED) of National Research Center (NRC) in a sample day in spring season for the different PV modules.

Photovoltaic Module (1):

This module has maximum power of 64 W and it is amorphous module. Table (1) shows PV module characteristics. The measured current-voltage characteristics of the PV module at different operating conditions are shown in Fig.14, Fig. 15, and Fig. 16. Also, the photograph of the PV module 1 is shown in Fig. 17.

Table 1: Photovoltaic modules characteristics (at 25 ^{o}C ambient temperature and 1000 W/m^2 global radiation)

Module	Dimension In cm^3	Weight	Operating Temperature	Maximum power	Short-circuit current	Open circuit voltage
1	137×74.1× 3.2	9.17 Kg	47^{o}c	64W	4.8 A	27.1 V

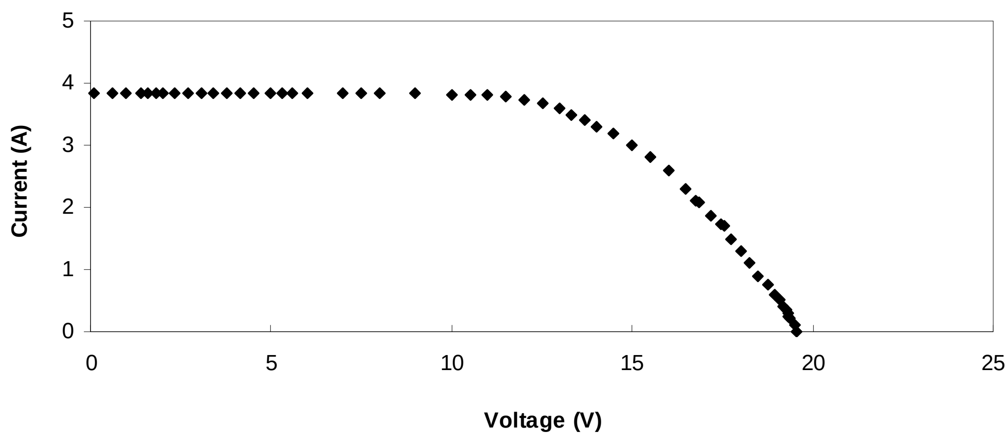

Fig. 14: Current-voltage characteristic of PV module (64W) at 10:00 AM.

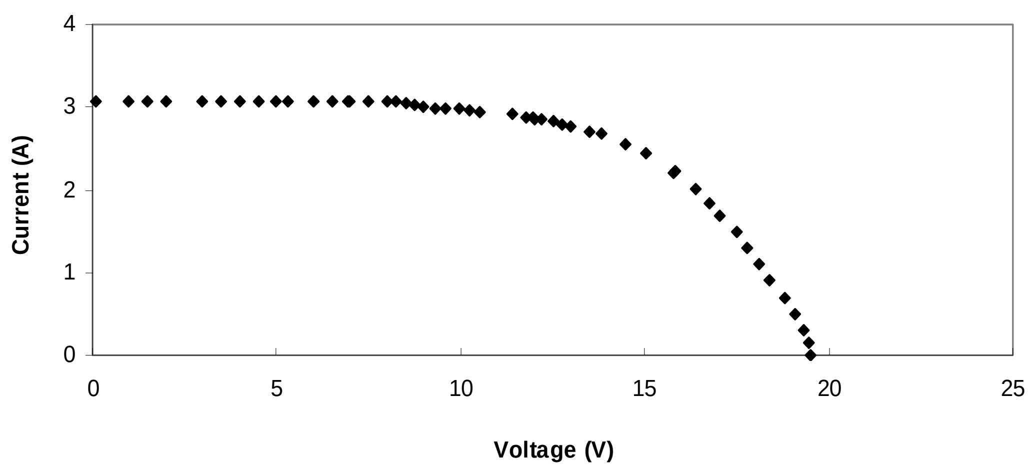

Fig. 15: Current-voltage characteristic of PV module (64W) at 01:00 PM.

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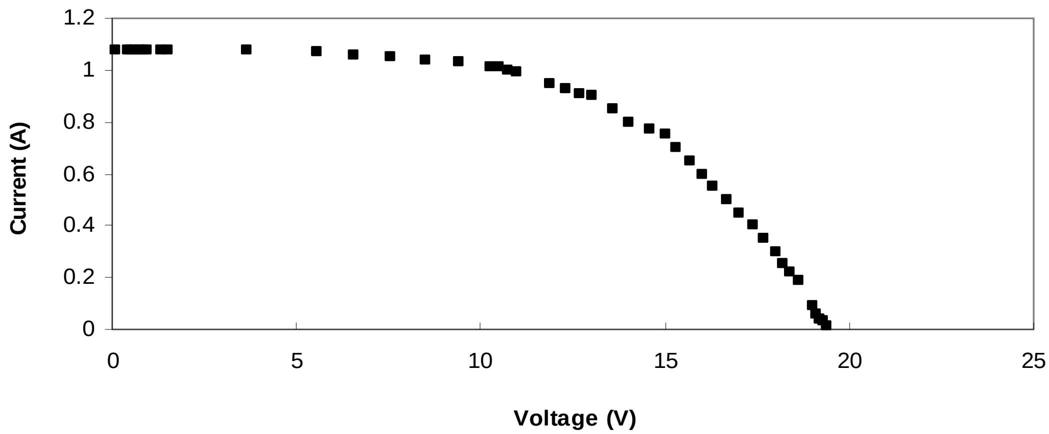

Fig. 16: Current-voltage characteristic of PV module (64W) at 04:00 PM.

Fig. 17: Photograph of PV module 1.

Photovoltaic Module (2):

This module has maximum power of 50 W and it is single (mono) crystal module. Table (2) shows the characteristics of the PV module. The measured current-voltage characteristics of PV module is shown in Fig.18, Fig. 19, and Fig. 20. At different operating conditions. Also, the Photograph of the PV module (2) is shown in Fig. 21.

Table 2: Photovoltaic modules characteristics (at 25 °C ambient temperature and 1000 W/m^2 global radiation)

Module	Dimension In cm^3	Weight	Operating Temperature	Maximum power	Short-circuit current	Open circuit voltage
2	120x53x 3.95	7 kg	47°c	50W	5 A	22 V

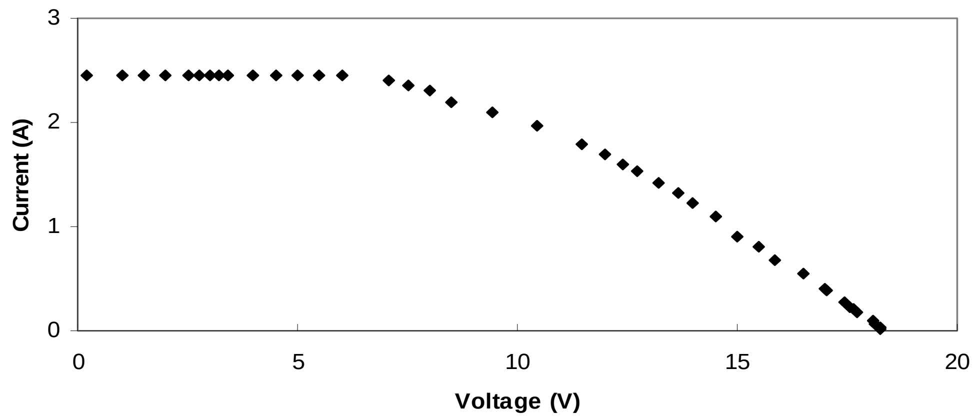

Fig. 18: Current-voltage characteristic of PV module (50W) at 10:00 AM.

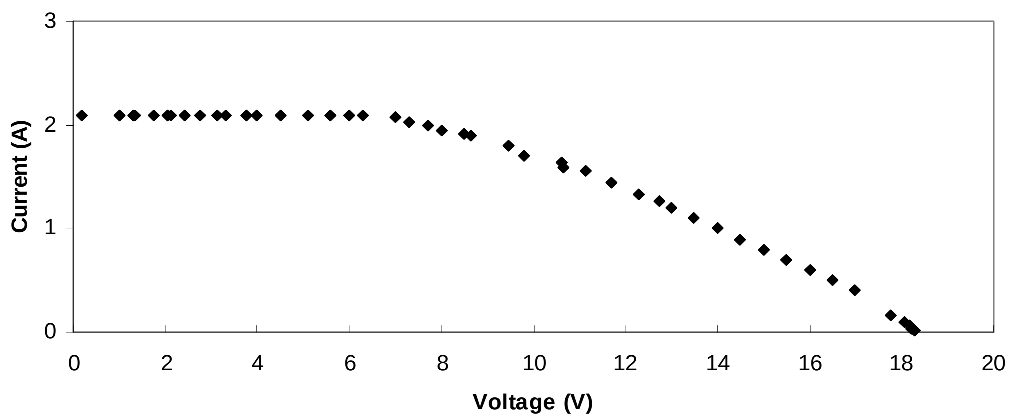

Fig. 19: Current-voltage characteristic of PV module (50W) at 01:00 PM.

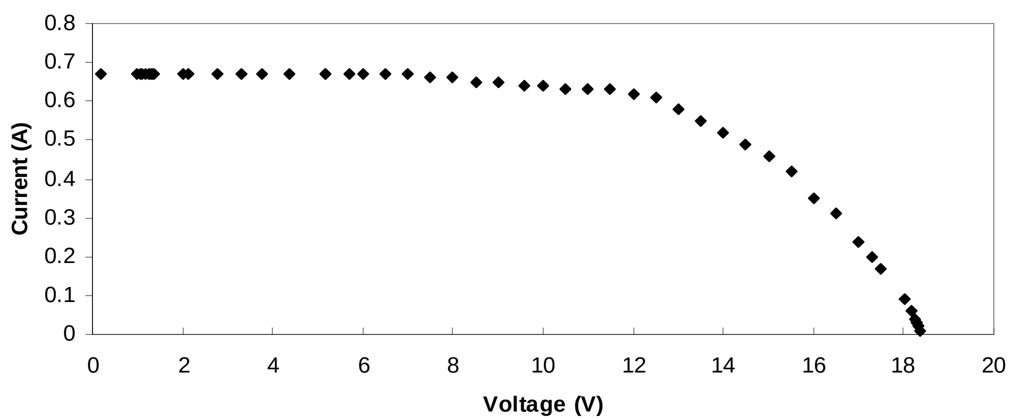

Fig. 20: Current-voltage characteristic of PV module (50W) at 04:00 PM.

Fig. 21: Photograph of PV module 2.

Conclusion:

In this paper, a simple accurate and low cost data acquisition system for measuring and recording the different parameters can be measured in PV systems, such as solar radiation, module surface temperatures, module current and module voltage, at different operating conditions are presented. All hardware circuits and components used in the system are explained and the required calibrating curves are introduced. Finally the paper presented test cases for measuring the different parameters from two PV modules through the day hours.

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