The Measurement of Electrical Parameters for a Solar Cell I-V Characteristic Curve by Using Simple Resistive Load Based on LabVIEW

Napat Watjanatepin*, Paiboon Kiatsookkanatorn

Faculty of Engineering and Architecture, Rajamangala University of Technology Suvarnabhumi, 7/1 Nonthaburi.1 Nonthaburi, Thailand.

* Corresponding author. Email: Napat.w@rmutsb.ac.th

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Abstract: There are two methods to measurement of the characteristic of a solar cell which include: dark and light I-V characteristic measurement. The light I-V measurement method can be used for either natural Sun or a Sun simulator as the light source. This article presents the development method of electrical parameters measurement of the solar cell by using a simple resistive load with light I-V measurement. The solar cell was tested under standard testing condition with a solar simulator. This was done in order to plot the current and voltage characteristic of the solar cell. The author developed the measurement and monitoring program by using LabVIEW environment. The voltage-divider technique was used for the solar cell voltage measurement, and the hall-effect current sensor was applied for the current measurement. A variable resistive load was applied by a manual control. The solar cell specimen is a mono-crystalline 1 W 7.5 V. The results found that this method is simple and beneficial for the study of the current-voltage characteristic and exhibited positive performance of the solar cell with a good accuracy. The measurement system is not complicated and is compatible for interfacing devices. The graphical user interface software could display all of electrical parameters. Moreover, it can plot the I-V curve and P-V curves of solar cell under testing conditions. As for future work, the author has to develop an electronics load to replace a resistive load in order to complete the current-voltage characteristic curves with a computer control.

Key words: Graphical user interface, I-V characteristic, solar cell, LabVIEW.

1. Introduction

The characterization of the solar cell (or photovoltaic cell/module) is represented by the I-V and P-V characteristic curve. Normally, two measurement methods are applied which includes the dark I-V measurements and the light I-V measurement. The light I-V measurement is used for testing conditions under the natural Sun or a Sun simulator [1]-[3]. The measurement of the current-voltage characteristic of the solar cell follows the standard IEC 60904-1 [4]. This standard will give a general indications about the basic measurement parameters of the solar-cell such as the short circuit current (I_{SC}), Open circuit voltage (V_{OC}), Maximum power (P_{MPP}), Maximum power point voltage (V_{MPP}), Maximum power point current (I_{MPP}) and a fill-factor (FF) [4]. The measurement method is conducted by connecting the load of the two terminals of a solar-cell for the test. The resistive load and electronics load both can be applied. The measurement test has to be done under the natural sun light or by the solar-simulator. It is also necessary to test under standard testing conditions (STC) [4].

In 2017, the authors develop the LED-based solar simulator (Fig. 1) for the use in the laboratory of Solar Energy Research Technology Transfer Center, Rajamangala University of Technology Suvarnabhumi, THAILAND [4], [5]. This solar simulator was evaluated to possess the quality of light in accordance to IEC 60904-9 of class BAA. However, the solar simulator system that the author developed was not completed yet. The part of the solar cell current and voltage characterization system still needs to be improved. This study provides the measurement system for solar cell voltage-current characteristic curve, by using a manual variable resistive load based on LabVIEW. This study will be applied to the prototype of the solar simulator that the author already developed in the laboratory. The main concept of the study will involve obtaining the electrical parameter results, calculating the performance of the solar cell and comparing the calculated values with ones obtained from the performance test by the manufacturer.

2. Material and Method

2.1. Solar Cell Characterization and Measurement

The characterization of the solar cell will show the relationship between voltage and current on a curve called the V-I characteristic curve of solar-cell (Fig. 1A). This curve is used for determining other parameters that can be used to describe the performance of the solar cell such as I_{SC}, V_{OC}, P_{MPP}, V_{MPP}, I_{MPP}, FF and also, the efficiency of solar cell. [4] IEC 60904-1 [1] standard defined a method to measure the voltage and current of the single solar cell under a solar simulator or the real sunlight. However, it is of importance that the measurement conditions follow the STC condition. This means that (1) The solar cell have to be tested under the irradiance of 1000 W/m2. (2) The light spectrum reference is AMI.5G. (IEC 60904-3) [6]. (3) The temperature of solar-cell during test is about 25°C (Fig. 2). (4) The light source must be measure by the linear Pyranometer.

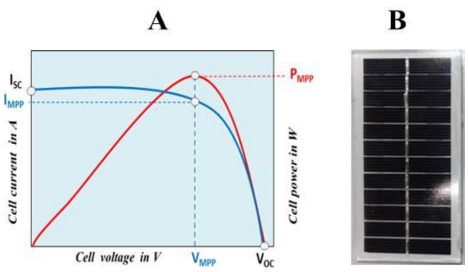

Fig. 1. V-I characteristic curve of solar-cell measurement of voltage and current characteristic (A) and solar cell specimen (B).

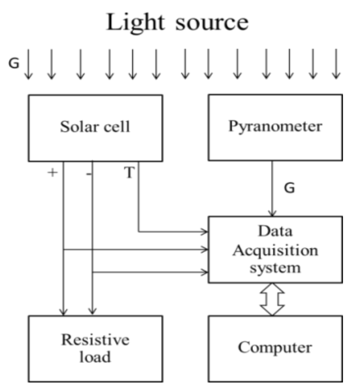

Fig. 2. Solar cell I-V characteristic measurement diagrams.

2.2. Solar Cell Specimen and Resistive Load

For the characterization of the solar cell under Class BAA simulator according to IEC 60904-9 Standards [6], natural sunlight and seven solar simulators were used in this study. The solar cell was obtained from a local module manufacturer. It is a mono-crystalline silicon solar cell with a dimension of 6.5 cm × 12.5 cm. The power output is 1 Watt and open circuit voltage is 7.5 Volts. The solar cell is encapsulated with EVA (Fig. 1B). During the measurement of the electrical parameters, the solar cell was installed at the test plane at the top of a solar simulator (Fig. 3).

A simple resistive load is 100 Ω 2 watts linear (carbon) type potentiometer (NTE Electronics, USA) as used for a manual adjustable load of a solar cell (Fig. 3).

2.3. Solar Simulator

The solar simulator that was applied for this study was developed by using six different spectra of light emitting diode (LED). It has an illuminating area of 900 cm^2 under variable irradiance. The spectrum range covers from 400 nm to 1100 nm, which offers the possibility to characterize silicon solar cell technologies. The evaluation of the light quality is in reference with IEC 60904-9. The testing result confirmed the spectral match of class B, the non-uniformity of light classification of class A, and the temporal instability of irradiance of class A (Fig. 3 and Table 1) [5]. The IEC 60904-1 described the procedure for the measurement of voltage-current characteristics of photovoltaic devices in natural or simulated sunlight. ICE 60904-1 is applicable for a single PV, either a Solar cell, a sub-assembly of PV solar cell, or a PV module. The electrical instruments that were used to measure the current and voltage of the solar cell must have an accuracy of within ±0.2% of VOC and ISC. The impedance lead type was applied for the measurement at the terminal of a solar cell. The impedance leads require the shortest possible length. In case of the measurement test under solar simulator, it will have a certification for class BBB or higher according to the IEC 60904-9 standard [7]. Lastly, the test plane of the solar simulator must be larger than the solar cell size. The Pyranometer linear type could be applied for the irradiance measurement, and it will be placed on the same test plane.

Table 1. Classification of LED-Based Solar Simulator that Provide in this Study

Quantity	Measurement	Classification (IEC 60904-9)
Spectral match	1.39 in 500-600 nm 0.62 in 900-1100nm	B
Non-uniformity	1.91	A
Temporal instability	1.09	A

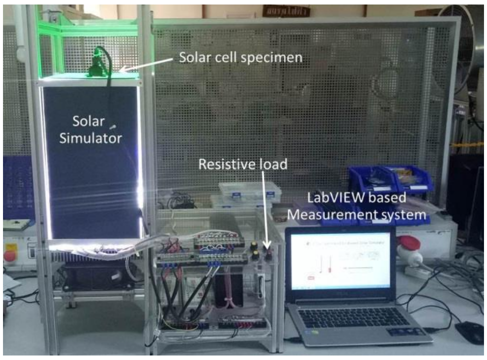

Fig. 3. Simulator class A prototype of LED-based solar BAA [3].

2.4. Data Acquisition Device (DAQ)

DAQ is an instrument that can process of measured electrical (or physical) data such as voltage current, temperature and other parameters with the computer. This study focus on low-cost DAQ model NI-6008 (National instruments, Texas, USA), and used the LabVIEW software to communicate the hardware via USB port. The NI-6008 is sufficient for this study.

2.5. V-I Measurement Circuit

This study focuses on measuring the current and voltage of the solar cell when connected to the resistive load. The solar cell voltage measurement was conducted by using the voltage divider method, and the current was measured by the Hall-effect current sensor model CS25-NPA (5A, accuracy ±0.8%, AMPLOC: USA) (Fig. 4A) Load resistance was determined by the characteristic resistance method [4]. The appropriate load resistor is about 50 Ω. The decade resistor (0-200 Ω) was applied to be a load of solar cell. The output of voltage sensor was connected to the analog input (CH AI1-AI5), and the output of current sensor was connected to analog input channel Ai2-Ai6 of DAQ NI-6008 (Fig. 4A). A solar cell specimen is a mono-crystalline 1W 7.5V (Model-M12514y, Bangkok solar company (BSC), Thailand). The connection diagram of the current-voltage sensors and DAQ device is showed in Fig. 4B.

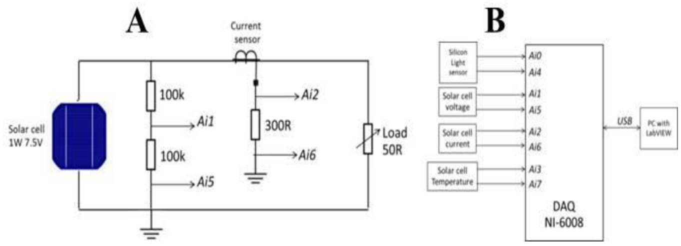

Fig. 4. (A) Current- Voltage measurement circuit (B) Connection diagram diagrams.

2.6. LabVIEW I-V Measuring Program

The LabVIEW program developed by the author is as shown in Fig. 5. The code of the program is shown in the virtual block (VIs) format. DAQ assistant is the command that connects the hardware to acquire the electrical measurement data such as voltage, current, temperature and the irradiance from the solar cell under testing conditions. The data will be displayed in numerical mode and in the graph x-y. Moreover, all of the acquired data will be written in the data files in a computer. The command to send the signal to control the irradiance of a solar simulator is situated at the bottom right corner.

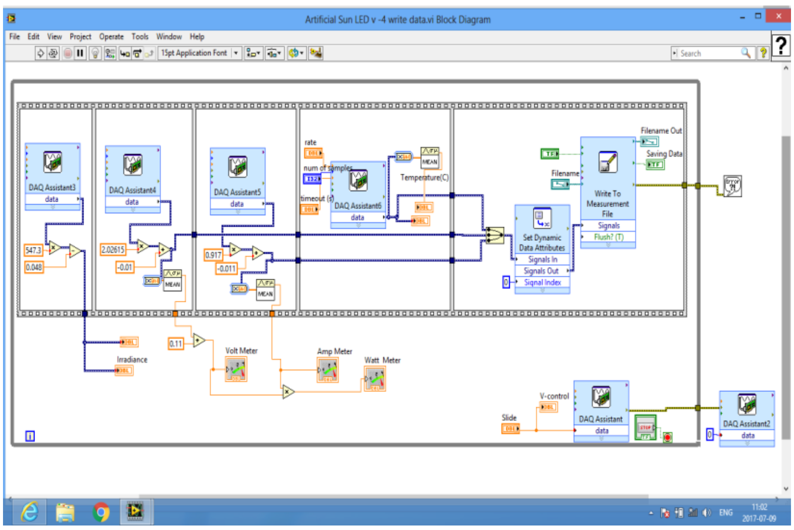

Fig. 5. VI block diagram of a solar cell I-V measurement.

3. Experimental Setup

1) Place a solar cell (Fig. 1B) at the test plan at the top of a solar simulator (Fig. 3).
2) Turn-on and set the solar simulator at 1000W/m^2.
3) Run the LabVIEW I-V measuring program (Fig. 6).
4) Manually adjusting the resistive load slowly (20 seconds per turn) from minimum to maximum. This is done so that the program could acquire the measurement data (current, voltage, temperature and irradiance) from the solar cell.
5) The measurement data will be saved in the excel format on the computer automatically.
6) Open the data file and make an I-V and P-V characteristic curve of the solar cell (Fig. 7).

4. Results and Discussion

4.1. The Measurement and Monitor Results

The measurement and the monitoring of the electrical parameters for the Solar Cell I-V characteristic was done by using a simple resistive load. The results of the current, voltage, temperature and irradiance are shown in Fig. 6. The solar cell current is 182 mA, voltage as 6.097V, power is 1.1 W, cell temperature is 24.33 °C and solar irradiance from a solar simulator is about 1002 W/m2. This is under the standard test condition [6]. The program can measure and monitor all of electrical parameters. The method is appropriate for the user since it is not complicated to understand. The measurement results can be stored in the excel files and easily used to make a characteristic graph. This shows that the goal of this study has been met.

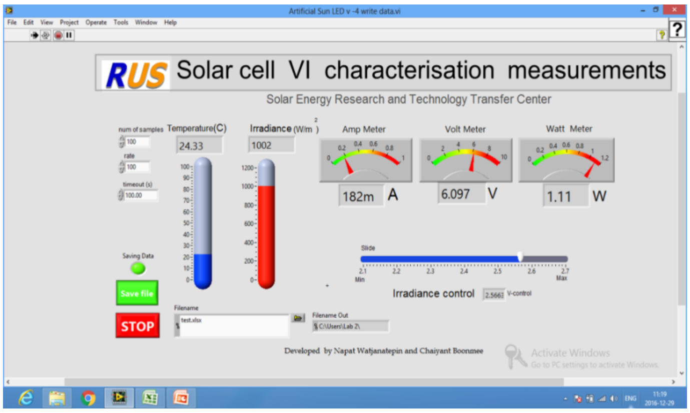

Fig. 6. VI block diagram of a solar cell I-V measurement.

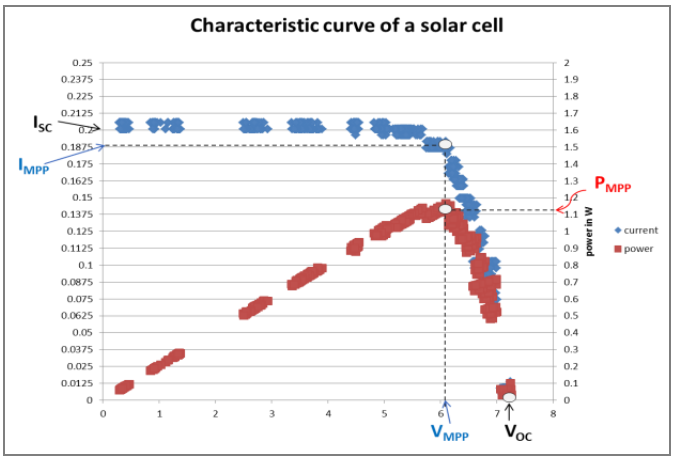

Fig. 7. I-V and P-V characteristic of a solar cell specimen.

4.2. I-V Characteristic of a Solar Cell

After the measurement by the LabVIEW measuring program is finished (Fig. 6), the measurement file was created. The author could make a characteristic curve of a solar cell (Fig. 7). The red line shows the P-V characteristic curve and the blue line is the I-V characteristic. From Fig. 7, the author can determine the major parameters from the characteristic curve (as I-V and P-V) for example, I_{SC}=0.201A, V_{OC}=7.35V, P_{MPP}=1.141W, V_{MPP}=6.10V and I_{MPP}=0.18A. These parameters are used to calculate the fill factor of a solar cell in the next step.

4.3. Determine the Errors from This Method

Table 2 indicated the solar cell performance parameters. The table compares the specification data between the measurement results and the manufacturer specification data. The author found that the errors from current measurements are around 8% but the errors of voltage measurement are about 1-2%. Furthermore, the fill factor that was determined from the measurement data was very close to the manufacturer, with an error of 0.823%. This means that this method could be applied for the silicon solar cell characterization.

Table 2. The Comparative of the Electrical Parameter and Relative Error [8]

Solar cell test	I_{SC} (A)	V_{OC} (V)	P_{MPP} (W)	I_{MPP} (A)	V_{MPP} (V)	FF (%)	Temperature (C)
Manufacturer	0.186	7.530	1.070	0.173	6.200	76.583	26.6
Experiment	0.201	7.350	1.141	0.187	6.100	77.213	24.3-26.8
Relative errors	8.065	-2.390	6.607	8.092	-1.613	0.823	

4.4. Discussion

The LabVIEW measuring program that the author developed is suitable for the data acquisition device (NI 6008). This device has sufficient input and output ports for solar cell characteristic curve applications. Therefore, the current and voltage measurement hardware was used on a simple circuit. It is showed that LabVIEW is very useful for this application. This is because the programme serves the purpose for controlling, measuring and monitoring many parameters. The LabVIEW programme also has a friendly user interface. Thus, the LabVIEW tool is a very appropriate for the application in the science and engineering control and monitoring system [9], [10].

The scattered plot of I-V and P-V characteristic curve that was measured from this study (Fig. 7) show a non-continuous line. Because the author used the simple resistive load, it was not possible to change the load resistance equally in each step stable. This then affected the measurement results of voltage and current from a solar cell specimen, resulting in non-continuous plot for characteristic curves. A possible solution for this problem could be to use the programmable electronics load to replace the manual resistive load. [4] Although, the initial cost of the system will be increased, this method is fitting for this purpose, because the specimen is a low short circuit current (ISC=200mA). It is worth mentioning that this is improper for the application in testing the characteristic of the solar cell in case of higher short circuit current. This is due to the fact that high current will increase the power rating ($P=I^2R$) and size of the resistive load.

The experimental results (I_{SC}, V_{OC}, P_{MPP}, V_{MPP}, I_{MPP} and FF), when compared with the manufacture specification data (Table 2), showed that the solar cell voltage has a lower error (high accuracy) than the current measurements. The current measurement error was about 8% because of the instruments error. When focusing on the current sensor module (CS25-NPA), the typical current is ±5A. But the short circuit current of solar cell specimen is around 0.2A which is lower than the specification of the current sensor module. The other causes are excluded because the solar simulator is in a good Class BAA (IEC 60904-9) and were calibrated. Additionally, the standard test condition [4] was applied in this experiment.

5. Conclusion

The simple resistive load method is appropriate to be the load of the solar cell under testing in the solar simulator (BAA: Class). This method can be used for measuring and plotting the I-V and P-V characteristic curve. Although the characteristic curve is still discontinuous, however, this method is able to determine the electrical parameter of solar cell with good accuracy. The measurement system is not complicated and is compatible for interfacing devices. The graphical user interface software is easy to use due to the unique properties of LabVIEW. This method is suitable for the application with the solar simulator or other indoor test settings.

As for future work, the author has to develop an electronics load to replace a resistive load in order to complete the current- voltage characteristic curves with a computer control.

References

[1] Namin, A., Jivacate, C., Chenvidhya, D., Kirtikara, K., & Thongpron, J. (2012). Construction of tungsten halogen, pulsed LED, and combined tungsten halogen-LED solar simulators for solar cell I-V Characterization and electrical parameters determination. *International Journal of Photoenergy, 2012(3)*, 208-220.

[2] Krishna Chavali, R. V., Wilcox, J. R., Ray, B., Gray, J. L., & Alam, M. A. (2014). Correlated nonideal effects of dark and light I–V characteristics in a-Si/c-Si hetero junction solar cells. *IEEE Journal of Photovoltaics, 4(3)*.

[3] Wohlgemuth, J. H. (2012, September 24-28). Standard for PV modules and components-recent development and Challenges. *Proceedings of the 27th European Photovoltaic Solar Energy Conference and Exhibition*. Frankfurt, Germany.

[4] Namin, A., Jivacate, C., Chenvidhya, D., Kirtikara, K., Thongpron, J. (2013, June). Determination of solar cell electrical parameters and resistances using color and white LED-based solar simulators with high amplitude pulse input voltages. *Renewable Energy, 54*, 131-137.

[5] Watjanatepin, N. (2017, Apr.-May). Design construct and evaluation of six- spectral LEDs-based solar simulator based on IEC 60904-9. *International Journal of Engineering and Technology, 9(2)*, 923-931.

[6] IEC, IEC 60904-3. (2008). *Photovoltaic Devices- Part 3: Measurement Principles for Terrestrial Photovoltaic (PV) Solar Devices with Reference Spectral Irradiance Data*.

[7] IEC, IEC 60904-9. (2007). *Photovoltaic Devices- Part g: Solar Simulator Performance Requirement* (2nd ed.). (pp. 1-30).

[8] Department of Chemistry, Faculty of Science, Chulalongkorn University. Retrieved from the website: www.chemistry.sc.chula.ac.th/course_info/2302241/I.2.pdf

[9] Watjanatepin, N. (2016, May). Fabrication and analysis of the characteristics of the grid-connected photovoltaic system based on LabVIEW. *Australian Journal of Basic and Applied Sciences, 10(11)*, 307-314.

[10] Jamrusnaew, W., Buasri, P., & Tanmitra, K. (2010, June 3-5). Solar cell data recorder by using intranet network. *Proceedings of the 6th National Conference on Computing and Information Technology*. Thailand.

Napat Watjanatepin is an associate professor in electrical engineering, and he was born in Surat Thani, Thailabd in 1962.

He received the B.S. Tech. Ed. in electrical engineering from Institute of Technology Vocational Education, Thailand in 1985 and the M.S. Tech. Ed in electrical technology from King Mongkut's Institute of Technology North Bangkok, Thailand in 1991.

His research interests include photovoltaic energy system, PC based monitor system, power electronics, LED solar simulator and engineering education.

His publications contain 36 books (in Thai), and published in 10 national journals, 21 national conferences, 10 international journals and 33 international conferences.

His is the former dean of Faculty of Engineering and Architecture, RUS-THAILAND, ISFT Thailand chairman. He is the founder of Solar Energy Research and Technology Transfer Center (SERTT), the director of Research Institute of Rajamangala University of Technology Suvarnabhumi (RUS), Thailand.

Paiboon Kiatsookkanatorn was born in Suphanburi, Thailand in 1974. He received the B.S. degree in Tech. Ed. in electrical engineering and the B.Eng. degree in electrical engineering from Rajamangala Institute of Technology, Thailand in 1998 and 2002, respectively, and the Ph.D. degree in electrical engineering from Chulalongkorn University, Bangkok, Thailand in 2012. He is currently an assistant professor in the Department of Electrical Engineering, Rajamangala University of Technology Suvarnabhumi, Thailand. His research interests include PWM techniques, power converters and renewable energy.