https://doi.org/10.1051/e3sconf/20186701020

Simple method for I-V characterization curve for low power solar cell using arduino nano

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Abstract. In general, solar cells properties were measured under standardized environment. Recent method uses a Solar Simulator or Sun Simulator to measure a solar cell characteristic by the condition of 1000 W/m^2 irradiance and 25^{o}C temperature. However, solar simulator is expensive, therefore in this paper we propose a simple I-V characterization method with microcontroller, potentiometer, and sensors to measure I-V characterization of solar cell. Our method used a microcontroller to record any detected current and voltage from sensors generated by the solar cell driven by halogen light on low power poly-Si solar cell. This method is limited by the sensor rated voltage and current, thus a higher power solar cell is possible to be measured with a higher rated voltage and a current sensor for the future development. The measured Voc and Isc of 3 Wp poly-Si solar cell have 1.94% difference in Voc and 49.1% difference in Isc against the standardized environment. This method is able to characterize a low power solar cell with slight difference on Voc and about half value of Isc compared to standardized I-V curve characterization due to the limitation of halogen lamp spectral irradiance.

1 Introduction

Indonesia has a potential of 4.8 kWh/m^2 solar energy [1] and electrical energy has become an irreplaceable part of mankind life. Solar cells provide a way to transform solar energy into electrical energy. Solar cell is a device that converts light into electric energy. The conversion is accomplished by absorbing photonic energy and ionizing crystal atoms creating free electrons and hole [2]. Solar cells generally have a series and parallel resistance, both are parasitic as indicated in Figure 1. The series resistance consists of semiconductor material resistance, contact resistance between metallic contact and semiconductor, wires and terminal connections. The parallel resistance is caused by the presence of crystal defects.

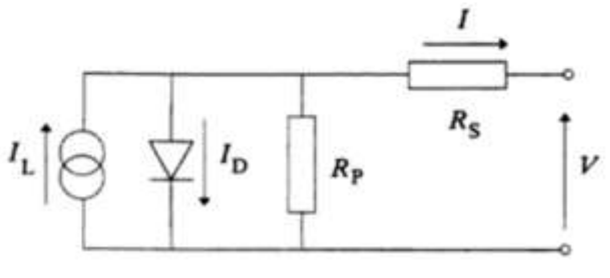

Fig. 1. Equivalent Circuits of a solar cell [3].

Solar cell has several parameters such as I-V Curve, short-circuit current, open-circuit voltage, fill factor and efficiency. The short-circuit, Isc, is the maximum current generated by a solar cell. The open-circuit voltage, Voc, is the maximum voltage available from a solar cell. Fill factor, FF, is a ratio of the maximum power to the product of Voc and Isc. Each of this parameter should be obtained through practical simulation.

Solar simulator or sun simulator is the equipment used to simulate the solar irradiance and spectrum with purpose to provide controllable test conditions in laboratory and must fall into at least class C of the standard. The common standard for solar cell testing is ASTM E927 – 10 [4]. Solar simulation can be done in a continuous or a pulsed illumination system [5]. Continuous illumination system characterization will suffer a drop in open-circuit voltage caused by heating and losses. While pulsed illumination system has low-temperature rise, the short flash duration means fewer data for the I-V curve characterization. For a simple method, continuous illumination system offers convenient design and inexpensive component while pulsed illumination system needs a high response time measurement system and it means more expensive component. Practically, solar simulation produced standardized I-V curve used to compare a solar cell to another one.

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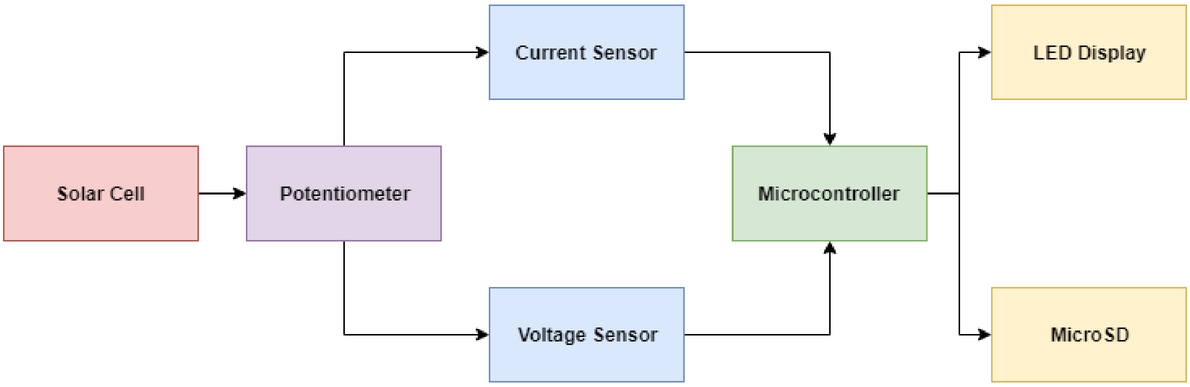

Fig. 2. Diagram Schematic

In general, solar cell parameters are measured by Solar Simulator or Sun Simulator at air mass 1.5 solar spectrum (AM1.5) with total irradiance of 1000 W/m^2 and 25^{O}C temperature for terrestrial usage [6]. Solar cells used for space application are generally characterized using air mass 0 solar spectrum (AM0) with a spectral irradiance of 1366.1 W/m^2 [7]. Compared to sunlight, solar simulators have limitations. The light that solar simulator produce is an inadequate spectral match to the standard, spatially non-uniform, and is temporally unstable [8].

By using a voltage sensor and current sensor in the output through potentiometer, we could easily obtain Voc and Isc to estimate the solar cell properties. However, practically, a solar cell would act differently in a different environment. Re-measurements are needed to obtain the characteristics of any available solar cells before its usage, as that would help other calculations be more realistic with respect to the different environment. Therefore, in this study, we suggest a simple characterization method using a microcontroller, linear potentiometer, and sensors to make the I-V characterization process of poly-Si solar cell inexpensive. The result of measurement test using halogen light will be compared to the standardized measurement condition.

2 Design

The simple I-V characterization method for low power solar cell proposed to find approximately how the solar cell will behave in the tested location atmosphere. Re-measurement of the solar cell characteristic directly in the practical usage makes it more convenient to aid theoretical calculation. The problem of direct sunlight measurement is how the stability of sunlight illumination always vary over time. Choosing a perfect time and weather condition could provide the most reliable result version of this method and it is possible for the next development.

The measurement system in this study was used to measure the voltage, current output and record it at a different resistance in potentiometer to characterize a solar cell. Figure 3 shows simplified measurement system without microcontroller and other component.

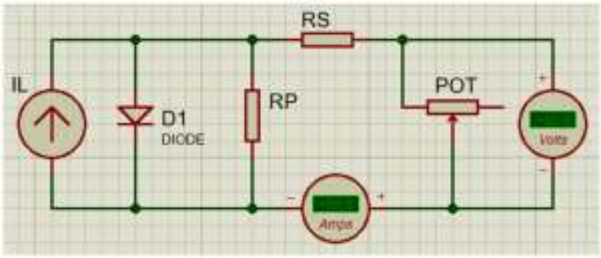

Fig. 3. Sensor Circuit Schematic

Figure 2 shows the full diagram schematic of the measurement system using an Arduino nano as a microcontroller. The potentiometer act as the resistive load. Voltage and current sensor measure the potentiometer voltage as the total solar cell resistance. Theoretically, when the potentiometer resistance is zero, there is no voltage difference between it and the current can flow without losses and the Isc parameter can be obtained. When the potentiometer resistance changes to close to infinity the resistance blocks the current and the voltage difference across the potentiometer can be obtained as Voc parameter. The sensors measure the current and voltage value in real-time and potentiometer resistance is set to change slowly to allow the microcontroller to process and record the measured voltage and current data from the sensors.

2.1 Microcontroller

A Microcontroller was used to record the output of sensors in the system. Some algorithm was added for LED Display compatibility and to calculate the electrical power generated by the solar cell by multiplying the voltage and current read by sensors in real-time. The microcontroller is supplied by 5 V battery while the sensor, LED Display and MicroSD Adapter draw the power from the microcontroller.

Arduino Nano with Atmel Mega 328P was used as the microcontroller. Atmel Mega 328P used 16Mhz crystal oscillator, about 62.5 ns clock cycle. This microcontroller provides digital communication for the sensor with USB connection, therefore serial monitor to PC for real-time monitoring can be more convenient.

2.2 Sensor and Potentiometer

INA219 is used as a current and voltage sensor. With maximum rated voltage input of 26 V and maximum rated current of 3.2 A, this method is limited to only be usable for solar cell under 83.2 Wp. The I2C made it easier to use with serial communication bus. Linear potentiometer with sufficient power rated was used to vary the solar cell total resistance. A 10 kOhm potentiometer is sufficient to stop most of the current, createing an almost open circuit for the ammeter that shows 0 mA current as the INA219 has 0.3 Ohm shunt resistance. Figure 4 shows the circuit schematic of the prototype.

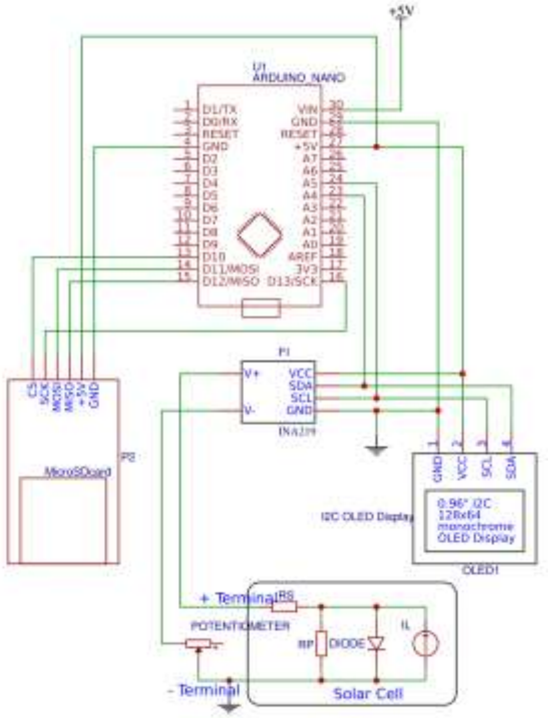

Fig. 4. Electrical Circuit Schematic

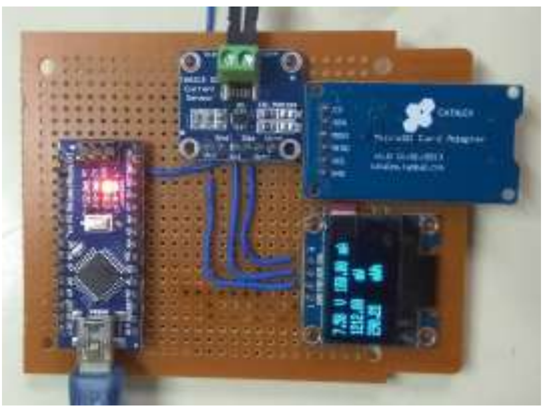

Fig. 5. The Circuit Prototype

Figure 5 shows a prototype of the measurement system. Both microcontroller and sensor can be bought in most country and are both inexpensive. MicroSD card adapter used to store the recorded value from measurement. LED Display is optional as it shows currently detected voltage and current value in real-time.

2.3 Light Source

In industrial and laboratory standard, light source is required to meet many criteria such as spectral quality, illumination uniformity, collimation, flux stability and a range of obtainable flux [9]. The light source is often a high-power xenon arc lamp [10]. Generally, arc lamps produce visible wavelength radiation with additional power in infrared and ultraviolet regions of the spectrum.

In this study, halogen lamp was used to illuminate and power the solar cell. This lamp has a maximum color temperature of 3400 K [11]. It means the lamp radiates weaker ultraviolet and stronger the infrared regions. Despite this disadvantage, halogen lamps are relatively more inexpensive than xenon arc lamp.

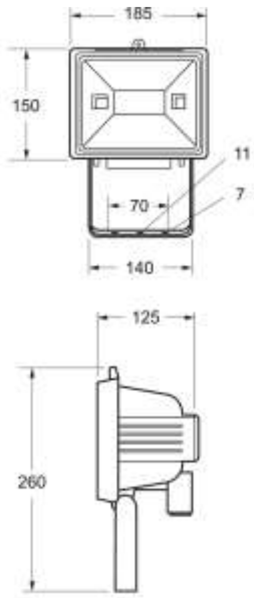

Fig. 6. The halogen reflector [12]

Philips QVF135 HAL-TDS halogen lamp was used to illuminate the solar cell. This lamp illuminates the solar cell from 65 cm distance. The halogen lamp produces 545.2 W/m^2 measured by a solar power meter (SPM-1116SD) at the center of its direct illumination. Most of the poly-Si solar cell module below 10W has less than 0.11 m^2 area. As this study focuses on low power solar cell and low-cost operation, spatial uniformness is neglected. Halogen lamps produce considerable temperature. Thus, the measurement should be done quickly. Faster measurement process also increases the flux stability. However, changing the linear potentiometer resistance too fast will cause the measurement process to fail.

3 Results and Discussion

The experiment was conducted to characterize the GH5P 3 W Grade A poly-silicon solar cell. This solar cell has 0.0312 m^2 total area. The first experiment was a simulation of the solar cell illuminated by a 500 W halogen lamp at 65 cm distance. From the measurement a set of raw data was obtained, as shown in Figure 7.

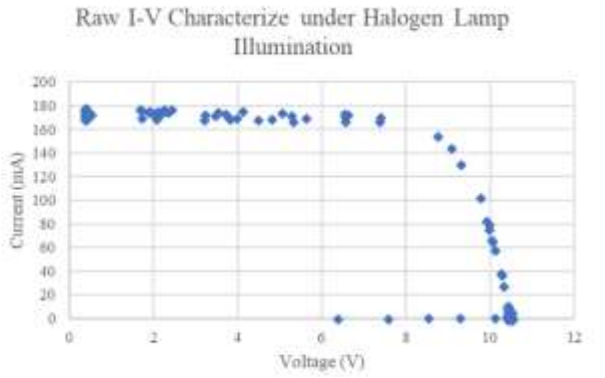

Fig. 7. The Raw Data of I-V

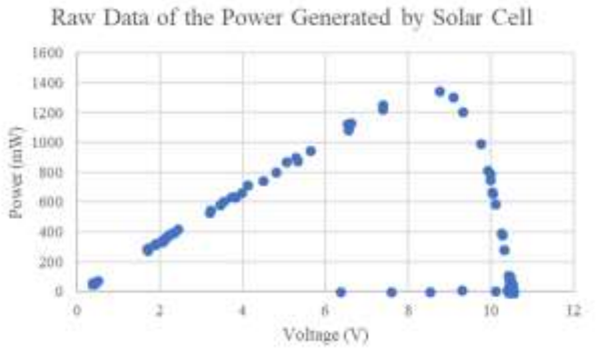

Fig. 8. The Raw Data of Generated Power

There were some errors that made the current reading become 0A. Possible error is current changes caused by potentiometer resistance changes were faster than the sensor reading speed. There is a possibility that the solar cell received current from the sensor and that can be solved by adding a diode in the circuit. Any losses and wiring problem can also cause this error but it is assumed to be negligible for now.

To achieve clear, I-V curve graph, the raw data outside the trend line are considered as errors were removed. The duplicated raw data were also removed. Fitting was done using Microsoft Excel. The filtered data are shown in figure 9 and 10.

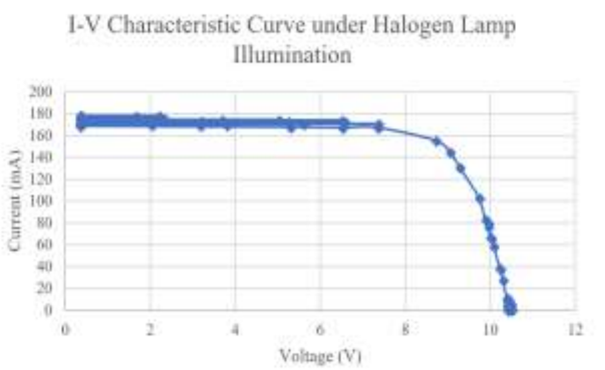

Fig. 9. The I-V Graph of Filtered Data

GH5P datasheet shows, 10.3 V Voc and 0.36 A Isc measured on standard test condition. The obtained data shows a 10.5 V of Voc and 0.183 A of Isc. Lead to Voc difference is about 1.94% while Isc difference is 49.16%. This result is expected since halogen lamp has high intensity at 650 nm to 950 nm wavelength, it mostly has 653 nm wavelength [13] and lower intensity in lower wavelength. From the technical specification, the GH5P solar cell has a generated maximum power of 3 W under 1000 W/m^2 illumination, resulting in 9.61 % efficiency.

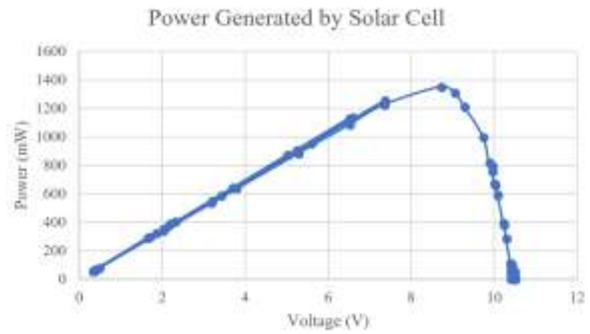

Fig. 10. The Filtered data of Generated power

The maximum power generated from halogen illumination is 1355.08 mW lead to 7.96 % efficiency. This low power output is also expected from 545.2 W/m^2 halogen illumination and temperature losses. However, the shape of the I-V curve in measured condition similar to any other measurement result with different illumination verifies that our measurement system provides reliable information regardless of light source.

The second experiment used direct sunlight. Direct sunlight measurement generates the most reliable set of data since solar simulator was not available in our laboratory. The GH5P 3 Wp poly-Si solar cell characteristic was measured under direct sunlight, and the result is shown in Figure 11. The measured power generated by GH5P under direct sunlight is shown in Figure 12. The result of second experiment is 10.8 V of Voc and 381.4 mA of Isc. Lead to 4.85 % difference in Voc and 5.94 % difference in Isc from standardized measurement verify our measurement system is considerably good.

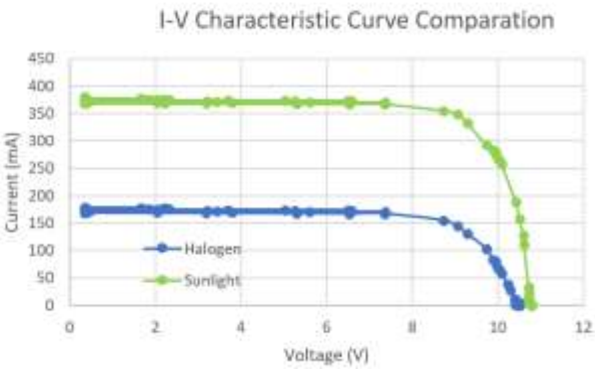

Fig. 11. The I-V Graph of Filtered Data under Direct Sunlight and under Halogen Light

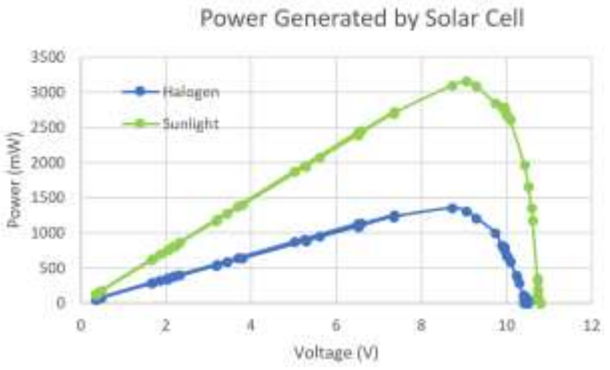

Fig. 12. The Filtered data of Generated power under Direct Sunlight and under Halogen Light

There is similar method to characterize a solar cell using MOSFET as variable load with digital controller and indirect sunlight in [14]. Our study used halogen light that produce about half of standard irradiance resulting in half of Isc from standard measurement. We can use this approach to characterize specific poly-Si solar cell with a ratio of $Isc_{(halogen\ light)}/Isc_{(standard)}$ 0.509 to obtain standardized Isc or simply double the measured Isc while the ratio of $Voc_{(halogen\ light)}/Voc_{(standard)}$ close to 1. Fill Factor and efficiency can be obtained from the Voc and Isc value.

4 Conclusion

The experiment is able to characterize a low power solar cell with slight difference on Voc and about half value of Isc compared to standard I-V curve characterization. This is due to the limitation of halogen lamp spectral irradiance. This result is expected since halogen only has 650 nm to 950 nm spectral wavelength. Therefore this method can be used to characterize I-V Curve of poly-Si solar cell with slight difference in Voc and about half of standard Isc. This method offers inexpensive procedures and interchangeable illuminator to characterize any solar cell. Thus, a better light source will generate more reliable set of data and different ratio of $Isc_{(halogen\ light)}/Isc_{(sunlight)}$. For practical use, direct sunlight illumination is the most preferred.

This work is supported by PITTA (No. 2549/UN2.R3.1/HKP.05.00/2018) Research Grant 2018 from Universitas Indonesia.

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