Testing the Efficiency of a Solar Cell at Varying Wavelengths

An Application Note

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http://www.pv-tech.org/assets/images/pse_Degratest_Labtool_550.jpg
Introduction:

Over the years there has been an enormous increase in the media coverage and awareness of the “energy crisis” and the fear of “global warming” resulting in a movement that calls man to be more energy efficient. Today there are current or pending legislatures all over the United States that call for more and more energy to be from a renewable energy sources to wean us of our dependence on coal and fossil fuels. A major player in the renewable energy market is solar power since once you have the means to harness the power you can do it anywhere anytime the sun is shining and there is low cloud cover. The means to harness the suns energy is a solar cell.

There are multiple reasons why a solar cell would need to be tested before it can be used to harness the suns energy. The most important reason is to verify it is an efficient piece of equipment that works properly after it is produced. At this level of testing it is essential to understand what a solar cell is and how it works in order to develop an appropriate testing system. The information that follows explores all the required elements to fully test a solar cell and ensure it is working at its peak efficiency.

Theory:

A solar cell is a diode and therefore under dark conditions its current vs. voltage will be nearly identical to that of a standard diode. Once the solar cell is illuminated the photons of light are absorbed by the material and interact with it in a way that generates electron hole pairs which are then driven in opposite directions by a built in potential. Graph 1 shows the current vs. voltage behavior of a solar cell under both dark and illuminated conditions.
How the exact structure of the solar cell is formed and what is going on in the solar cell that causes it to behave as it does is not required knowledge for testing, however figure 1 provides the basic structure as a reference.
What is important to know is a basic photovoltaic model of the solar cell. The model consists of a series resistance, shunt resistance, a built-in voltage, and a current that is induced when the cell is illuminated; it can be seen in figure 2.

![Figure 2](image)

The open circuit voltage occurs when the current passing through the cell is zero. It can be read from a solar cell’s I vs. V curve as the point on the voltage axis where the current is zero; it is labeled on graph 1. At this point in figure 2:

\[ V(\text{at } I = 0) = V_{oc} \]

The short circuit current occurs when the voltage out of the cell is zero. It can be read from a solar cell’s I vs. V curve as the point on the current axis where the voltage is zero; it is labeled on graph 1. At this point in figure 2:

\[ I(\text{at } V = 0) = I_{sc} \]

The point where the load line crosses the I vs. V curve is the maximum power point of the solar cell when a load is given. For this testing apparatus we will not use a given load but rather read the V output of the solar cell and use this as \( V_{\text{max}} \) then use that to find \( P_{\text{max}} \) on the I vs. V curve.

The conversion efficiency of the solar cell is the percentage of power converted (from absorbed light into electrical energy) when the solar cell is connected to an electrical circuit. This can be calculated by:
\[ \eta = \frac{P_{\text{max}}}{E \times A_c} \] (1)

Where;

- \( P_{\text{max}} \) is the maximum power determined using the I vs. V curve in W

\[ P_{\text{max}} = V_{\text{max}} \times I_{\text{max}} \] (2)

- \( A_c \) is the surface area of the solar cell being tested in m\(^2\)
- \( E \) is the irradiance in W/m\(^2\) found by:

\[ E = \frac{2\pi hc^2}{\lambda^2(e^{\frac{hc}{\lambda T}}-1)} \] (3)

Where;

- \( \lambda \): Wavelength of the light source in m
- \( T \): Temperature of the testing environment in K
- \( h \): Planck’s constant = \(6.62606957 \times 10^{-34}\) joule·s
- \( c \): Speed of light in a vacuum = \(2.99792458 \times 10^8\) m/s
- \( k \): Boltzmann’s constant = \(1.3806488 \times 10^{-23}\) joule/K

**Procedure:**

In order to test the solar cell you will require:

- A solar cell to be tested with a known or obtainable surface area
- Tunable wavelength LED light source
  - USB cord
  - Computer for control
- Multimeter
- Thermometer

You first must determine the solar cells I vs. V curve. We will do this by measuring \(V_{\text{oc}}\) and \(I_{\text{sc}}\) then drawing a curve connecting them that is similar to the one shown in graph 1.
To measure $V_{oc}$ and $I_{sc}$ of the solar cell take the solar cell and the multimeter to a place with exposed sunlight angling the solar cell towards the light. Connect the positive terminal of the multimeter to the positive terminal of the solar cell and the negative terminal of the multimeter to the negative terminal of the solar cell.

For $V_{oc}$ set the multimeter to measure voltage with the setup above, the multimeter is now displaying the open circuit voltage of the solar cell and it should be around 17-18 volts.

For $I_{sc}$ set the multimeter to read in the 10A range with the setup above, the multimeter is now displaying the short circuit current of the solar cell and it should be around 4 – 5 Amps.

Once the I vs. V curve for the solar cell under testing (SCUD) is found the solar cell can be placed underneath the LED light source. Ideally the procedure should be performed in an environment with little to no other light sources so that outside light sources do not contaminate the results; you can either use a dark room or isolate the solar cell and light source from the rest of the room using blockers.

Set the multimeter to measure voltage and connect the positive terminal of the multimeter to the positive terminal of the SCUD and the negative terminal of the multimeter to the negative terminal of the SCUD. Select the wavelength you want to determine the efficiency for and set the LED light source to output this wavelength at the lowest intensity using the computer user interface; the multimeter is now reading the minimum $V_{max}$. On the same grid of the I vs. V curve plot the line $x = V_{max}$; where this line intersects the I vs. V curve is the minimum $P_{max}$ at the chosen wavelength.

To determine the nominal value of $P_{max}$ find $I_{max}$ by drawing a horizontal line through the point that’s equivalent to $P_{max}$; where this line crosses the current axis (y-axis) is the value of $I_{max}$. Once you have the nominal value of $I_{max}$ use equation 2 to determine $P_{max}$.

Determine the irradiance at your chosen wavelength using equation 3. Once the irradiance is found calculate the efficiency using equation 1; this is the minimum efficiency.
Alter the LED light source on the user interface to output maximum intensity; the multimeter is now reading the maximum $V_{\text{max}}$. Use the same method described above to determine $P_{\text{max}}$ then use the same irradiance (independent of intensity) as before to calculate efficiency using equation 1; this is the maximum efficiency.

**Conclusion:**

This procedure can be repeated over and over with as many different wavelengths as desired. The purpose of testing over variable wavelengths is to ensure that a solar cell maintains efficiency over many wavelengths since sunlight covers a wide spectrum of wavelengths. This procedure simply tests the efficiency of the solar cell, this set-up can easily be adjusted and added to in order to determine the fill factor or diode ideality factor of solar cells.

**Resources:**