Conference Proceedings
Solar World Congress 2015
Daegu, Korea, 08 – 12 November 2015

A simple low cost Solar Panel/Cell Characterization Experiment for Senior Undergraduate Students

Sebastian Waita*, Justus Simiyu, Alexander N. Kiragu, Vivian Imali and Bernard Aduda
University of Nairobi, Department of Physics, P.O BOX 30197-00100, Nairobi, Kenya

Abstract
A simple low cost solar cell characterization experiment has been developed for senior undergraduate students in the Department of Physics, University of Nairobi. Experiments were conducted with solar panels (also called solar modules/photovoltaic modules) rated 20 W and 40 W peak power on different sunny days on the roof top of Physics Department, University of Nairobi. It was observed that the current- voltage (I-V) curves obtained for all the measurements for each panel were comparable. The fill factor (FF), short circuit current (I_{sc}), open circuit voltage (V_{oc}), current at maximum power point (I_m) and voltage at maximum power point (V_m) were within acceptable margins when compared with the manufacturer's rated values, an indication of the reliability and accuracy of the method. The method eliminates the need for expensive characterization equipment like solar simulators, unaffordable by many developing country institutions. The experiment is recommended for senior undergraduate students with an interest in renewable energy as one way of introducing them to renewable energy. The experiment may also help in arousing the learner's interest in solar energy.
.

Key words: cost, solar cell, characterization, experiment, panel, solar panel, undergraduate, solar energy

1.0 Introduction

In 2004, the Government of Kenya through the Ministry of Energy developed the sessional paper No. 4 on energy which created the background for the energy act of 2006. The energy act in turn provided the legal framework for the enactment of the national energy policy on renewable energy in 2012 which was revised last year, 2014[1]. The action by the government was interpreted by stake holders in the renewable energy sector as an act of seriousness and commitment in promoting renewable energy, prompting them into action. As a result, there has been a lot of renewed effort and activity in the renewable energy sector in Kenya. Workshops and seminars to develop training curriculum and build Human technical capacity in renewable energy especially photovoltaic have been on the increase. Similarly, photovoltaic training centers have sprung up in large numbers in various institutions in the last two years.

The high demand in the photovoltaic training has been necessitated by the government's requirement that solar photovoltaic design and installations be done by only those licensed by the Energy Regulatory Commission (ERC), a government agency created to regulate the energy sector. Further, the government also made it compulsory for vendors, importers and contractors to employ technical people who have undergone formal training and have been licensed by ERC[2]. Currently, most training is being carried out in government institutions and by staff who work in the same intuitions after going through training. It has been observed that most of the participants (trainees) in the trainings are mainly fresh school leavers, entrepreneurs and even people working in

doi:10.18086/swc.2015.09.07 Available at http://proceedings.ises.org

other sectors of the economy[3]. It is interesting to note that the same institutions have done little if any, to develop such training or relevant laboratory experiments for their students in the institutions, especially at the University undergraduate level. There is therefore need to introduce students to these technologies at early stages. Besides, developing theoretical courses, there is need to design and develop related experiments to run parallel to the theory work. In the Department of Physics, University of Nairobi, a simple and low cost experiment for analyzing the performance of a solar panel has been developed. The experiment has been found to be useful to senior undergraduate students in creating interest as well as introducing them into solar energy. The experimental details of the set up are outlined below.

2.0 Experiment Title: Photovoltaic solar panel characterization

2.1 Objectives

The objectives of the experiment were:

1. To understand how electricity is generated from a solar cell

2. To establish the difference between a solar cell and solar panel

3. To determine the total number of solar cells in a solar panel

4. To determine the variation of current and voltage for the solar panel

5. To understand the meaning of characterization parameters: Fill Factor (FF), Short circuit current (I_{sc}), Open circuit voltage (V_{oc}), Maximum current (I_m), Maximum voltage (V_m and Maximum power (P_m).

6. To determine the: Fill Factor (FF), Short circuit current (I_{sc}), Open circuit voltage (V_{oc}), Maximum power point (P_m), Current at maximum power point (I_m), Voltage at maximum power point (V_m and compare with the rated values.

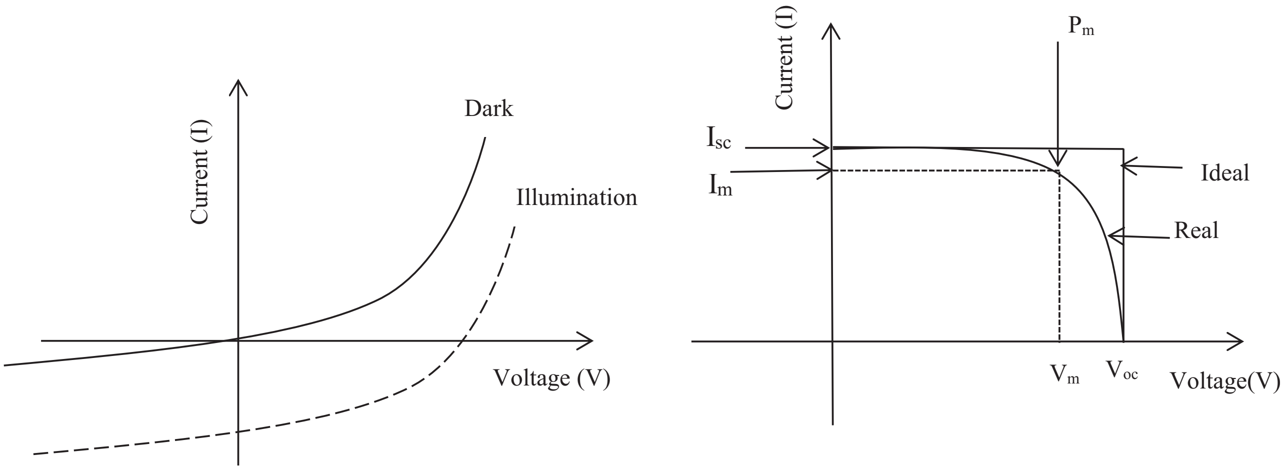
2.2 Theoretical Background

2.2.1 How a Solar Cell generates an electric current

Solar radiation consists of photons of different wavelengths and therefore with various amounts of energy. As these photons fall on a photoelectric surface, they may be reflected, absorbed or transmitted. The absorbed photons transfer their energy to electrons in the atom of the surface material. If the photons have enough energy to break the electron-atom energy bond, then the electron is dislodged from the atom and becomes a free electron, available for electric conduction. The electron leaves its normal position and becomes part of the current in the external circuit. This effect is called “photoelectric effect". The vacant site is a positive charge called a “hole”. In the process, there is separation of charges, electrons and holes and an electric field is build up providing the voltage needed to drive the current through an external load.

2.2.2 Solar Cell Characterization

A solar cell can be considered as a current generator with a diode and in cooperating series and parallel (shunt) resistances within the cell. The performance of a solar cell or solar panel (many solar cells make a solar panel) is done through characterization. Characterization mainly involves determination of the Fill Factor (FF)-a measure of how ideal the solar cell is. The variation of current (I) and voltage (V) of a solar cell in dark resembles the diode characteristics as show in Figure 1 (a) below (solid curve). On illumination, the photo voltage and photocurrent increases resulting in the broken curve[4]. However, in normal analysis and plotting, we usually translate the I-V curve to the first quadrant (Figure 1 (b)). An ideal solar cell I-V curve is also shown in Figure 1(b).



(a) (b)

Fig. 1: The current (I)-Voltage (V) characteristics of a solar cell: in dark-solid curve and on illumination-dotted curve (a), under illumination after reflection into the first quadrant (b).

The power, P, of a solar cell is given by the product of the current and the voltage [4, 5]:

$$P = IV \quad (1)$$

Where I is the current (A) and V is the voltage (V).

The maximum power, Pm (W) is normally represented by the area of the largest rectangle that can be fitted under the curve and is defined by:

$$P_m = I_m V_m \quad (2)$$

Where I_m is the current at the maximum power point and the V_m is the voltage at the maximum power point.

The ability of a solar cell to convert incident radiation into electrical power is commonly referred to as the conversion efficiency of the solar cell. The conversion efficiency (η) of a solar cell is the maximum output power (P_m) expressed as a percentage of the input (incident) power P_{in}:

$$\eta = \frac{P_m}{P_{in}} \quad (3)$$

Thus for a practical (real) solar cell, the closer the I-V curve to the ideal case, the higher the maximum power and so is the conversion efficiency. The fitting of a solar cell I-V curve to the ideal rectangular shape is measured by the fill factor (FF) defined as:

$$FF = \frac{P_m}{I_{sc}V_{oc}} \quad (4)$$

Where I_{sc} is the short circuit current (current at zero voltage) and V_{oc} is the open circuit current (voltage when the circuit is open (no load)).

Inserting equation (2) in equation (4), we get equation 5 below:

$$FF = \frac{I_m V_m}{I_{sc}V_{oc}} \quad (5)$$

For an ideal solar cell (see Fig 1 (b)), the fill factor should be unity (1).

2.2.3 Apparatus

The following apparatus were used: A monocrystalline Silicon PSS 1220 (20 W) solar panel, a muilticrystalline Silicon PSS 1240 (40 W) solar panel, both from a local distributor company, digital multimeters (Ammeter and Voltmeter), a rheostat (0-10 KΩ), connecting wires and a Switch.

2.2.4 Experimental Procedure

The number of solar cells in each panel were counted and noted. The circuit was then connected as shown in Figure 2 below.

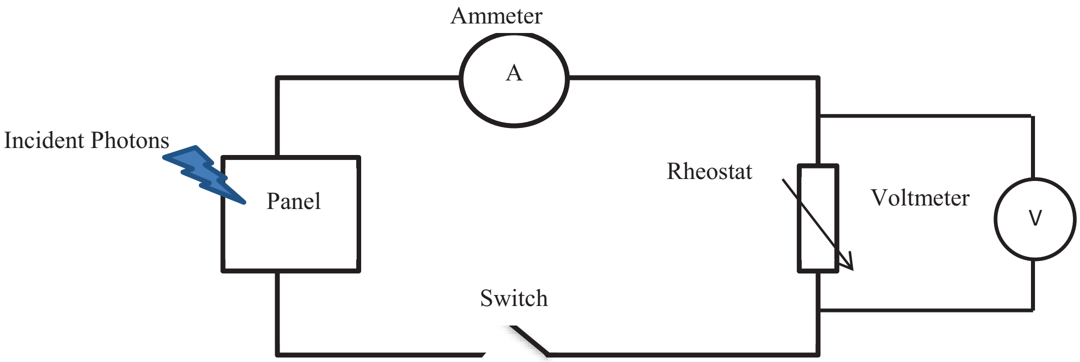


Fig. 2: The experimental set up for the solar panel characterization.

The resistance in the circuit was varied using the rheostat as the values of the current and the voltage were recorded and the data tabulated. The maximum power point was obtained from the product of current and voltage at each point. A graph of current versus voltage was plotted and the parameters FF, I_{sc},V_{oc}, I_m, V_m and P_m were obtained. The data was taken in two days that were clear and sunny.

2.2.5 Results and discussion

2.2.5.1. The 20 W solar panel

The solar panel had 36 solar cells.

Figure 3 below shows the variation of current and voltage for the 20 W solar panel (We show one curve here because all the other measurements generated similar curves). At zero voltage, the current flowing is maximum and the circuit is shorted. As the voltage is increased (by varying the resistance), the current reduces slowly up to a voltage of about 13 V when further voltage increase leads to a large current decrease, until there is zero current at the open circuit voltage, V_{oc}.

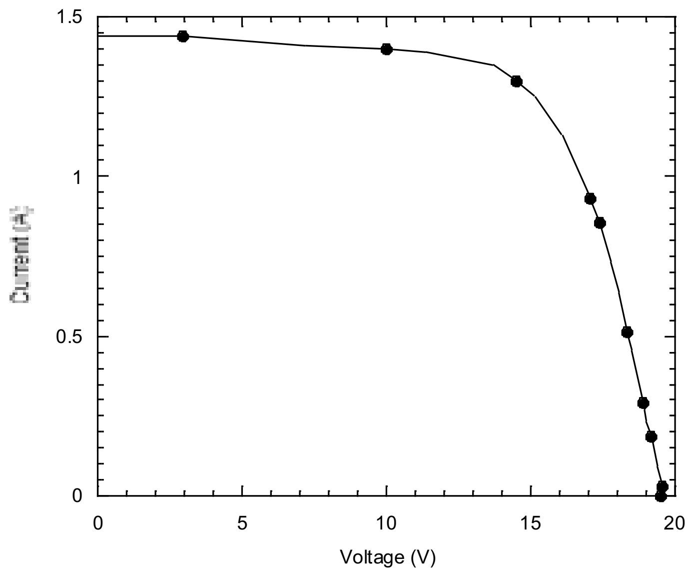


Fig. 3: Current –Voltage characteristics of the 20 W solar panel at 11.20 am of the first day.

Table 1 shows a summary of the solar cell parameters obtained from our I-V curve in Figure 3. The parameters do not show major differences from each other, because the time when measurement was done did not vary much and the weather was similar on both days and times. The manufacturer's values (rated) are shown to the extreme right of the table. As can be seen, there is quite good agreement between the experimental values obtained and the manufacturer's values.

Table 1 Summary of the measured solar Panel parameters and the manufacturer's rating.

Parameter	Day 1			Day 2		Manufacurers Rating
	11.20 am	12.00 pm	2.00 pm	12.00 pm	2.00 pm	
Im (A)	1.25	1.31	1.33	1.14	1.35	1.2
Vm (V)	15.18	14.59	13.61	15.96	13.58	16.8
Pm (W)	18.97	16.49	18.16	18.15	18.26	20
Isc (A)	1.44	1.44	1.43	1.41	1.39	1.4
Voc (V)	19.67	19.48	19.53	19.23	19.28	21
FF	0.67	0.68	0.65	0.69	0.68	0.69

2.2.5.2. The 40 W panel

The experiment was repeated with a multicrystalline 40 W solar panel of 36 solar cells.

Figure 4 shows the current -voltage spectra obtained at 12.20 pm on the first day (Again we show one curve since the other curves were similar). As can be observed, the curves are similar to those for the 20 W except for the higher values of both current and voltage. The graph can be explained in the same way as for the 20 W solar panel above.

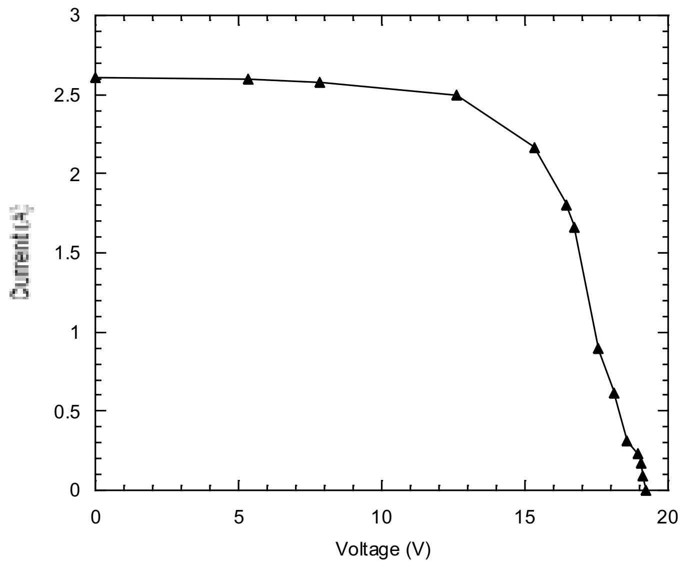


Fig 4: Current –Voltage characteristics of a 40 W solar panel: at 12.20 pm

In Table 2 below, the experimental values extracted from Figure 4 are displayed with the manufacture's rating appearing on the extreme right of the table. We notice a close relationship between our experimental values and the manufacturer's data. This consistency confirms the reliability of the experimental set up.

Table 2 Summary of the measured parameters for the 40 W solar panel and the manufacturers specifications

Parameter	Day 1			Day 2	Manufacturer's Rating
	12.20 pm	12.40 pm	2.50 pm	2.06 pm	
Im (A)	2.17	1.93	2.22	2.30	2.4
Vm (V)	15.33	15.60	13.53	13.27	16.8
Pm (W)	33.24	30.04	30.12	30.57	40
Isc (A)	2.60	2.56	2.40	2.59	2.75
Voc (V)	19.22	19.05	19.07	19.10	21
FF	0.66	0.62	0.66	0.62	0.698

3.0 Conclusion

A solar cell is the basic unit of the solar panel. A solar panel is therefore a combination of many solar cells. The solar panels used in our experiment had 36 solar cells. The current –voltage graphs obtained from the experiment were very similar in shape and values for each solar panel, though measured on different days and times, but similar climatic conditions in the sun.

The parameters obtained from the experiment for both panels were comparable to the parameters provided by the manufacturer, despite the fact that our measurements were done in real environment while the manufacturers was under STC (standard test conditions). Therefore, in Kenya and perhaps within the tropics, the experiment can be carried out successfully outdoors, eliminating the need for expensive equipment like the solar simulator. The experiment is recommended for senior undergraduate students.

References

1. www.energy.go.ke., 30th Sept 2015

2. http://www.erc.go.ke. 21st Sept 2015

3. Justus Simiyu, Sebastian Waita, Robison Musembi, Alex Ogacho and Bernard Aduda (2014),Promotion of PV Uptake and Sector Growth in Kenya through Value added Training in PV Sizing, Installation and Maintenance, Energy Procedia 57 , 817-825.

4. Martin Green (1992), Solar Cells; Operating Principles, Technology and System Applications, University of New South Wales, pge 62-84.

5. Sze S.M. (1969), Physics of semiconductor devices, Wiley - Interscience, Wiley International Edition, New York, Pg 132,640-653.