Validation of a new measuring system for performance evaluation of a large module in a desert area

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The electrical performance of a module consisting of four identical large area multicrystalline silicon solar cell units connected in series has been studied in a desert area under ambient conditions. Each cell is of area 21cm×21cm with back contact technology where the current collected by the fine finger grid is led to the back side through 25 holes. On the back side there are 25 soldering pads for each polarity. Short circuit current and open circuit voltage have been measured to describe the module electrical performance. Short circuit current values are obtained by measuring the voltage developed across a known resistance using the current shunt measuring technique to avoid the problems encountered with traditional measuring techniques. Current shunt is not only very stable under a wide range of ambient temperatures but also it has an identical linearity equation, consequently it is safely used in desert areas to obtain the short circuit currents. Furthermore, applying it in the solar cell measuring circuit does not affect the cell temperature dependency due to its negligible temperature coefficient. For outdoor measurements, the module was installed in a tilted position at the optimum angle of the location. The measurements were carried out to assess the parameters and the output performance of this type of solar module. Module performance as a function of incident solar radiation is demonstrated.

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1. Introduction

Solar cells industry has grown rapidly in recent years due to the great need for these cells in massive applications [1]. Multicrystalline silicon is an important and dominant material in photovoltaics due to its low production costs and readily abundance. Therefore, it is currently the dominant solar cell material for commercial applications [2-5]. There are many types of solar cells that are used in different life applications. One type of the solar cells is manufactured using a back contact technique [6-8]. Back contact solar cells hold vital promises for increasing photovoltaics performance in the near future. They eliminate shading losses altogether by putting both contacts on the rear of the cell. These cells are much better than usual solar cells, which are of electrical, economical and aesthetic nature [9,10]. Characteristics of these back contact solar cells are studied to enhance their performance [11,12].

As large sized solar modules produce high currents at low output voltages, some problems arise regarding accurately measuring the high short circuit current of such modules using one or more of the traditional measuring techniques [13]. For example using digital multimeters in measuring the high short circuit current at low output voltage gives inaccurate and non real values of the modules' current and this is attributed to the multimeter high internal resistance. To avoid such problems and due to the necessity of measuring the solar cells' high output currents; a current shunt is used to measure such high currents via measuring the voltage across the terminals of a highly precision calibrated resistor of a very small ohmic value.

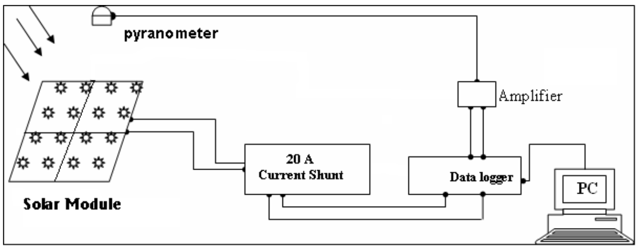
Current shunt measuring technique was previously used to study the electrical performance of one large area multicrystalline silicon solar cell at outdoor conditions. It is proved that current shunt is not only very stable under a wide range of ambient temperatures from 5ºC up to 50ºC but also it has an identical linearity equation for all tested temperatures. Therefore, it can be safely used in the desert area to get the solar cell high short circuit currents from its investigated linearity equation. Moreover, applying it in the solar cell measuring circuit does not affect the cell temperature dependency due to its negligible temperature coefficient [13,14].

In this paper, current shunt measuring technique is used to study the electrical performance of a module in a desert area under ambient conditions. This module consists of four identical large area multicrystalline silicon solar cell units connected in series. The outdoor module electrical performance is studied by measuring both short circuit current (I_{SC}) and open circuit voltage (V_{OC}). The current shunt is used as a sensor to obtain the module's short circuit current by measuring the voltage developed across its known resistance. Also, the cell open circuit voltage of the module is measured to get the module output power.

2. Characteristics of the solar module

The solar module consists of four similar back contacts multicrystalline silicon large area of 21 cm × 21 cm connected in series. The module is installed in a tilted position at the optimum tilt angle of the location of study [15], in the outdoor. Each cell current is collected by the fine finger grid which is led to the back side through 25 holes.

(a)



(b)

Fig. 1. (a) Multicrystalline silicon solar module in the outdoor located at optimum tilt angle with the radiation meter; (b) Block Diagram of the measuring system using the current shunt.

On the back side there are 25 soldering pads for each polarity. The outdoor module electrical performance is studied by measuring both short circuit current and open circuit voltage in the tilted position at Helwan, Egypt. The incident radiation is recorded by using CMP3 Kipp&Zonen pyranometer. The CMP3 is used in order to measure solar radiation with high quality blackened thermopile that provides a flat spectral response for the full solar spectrum range. It is also used for the reflected radiation measurements. Multicrystalline silicon solar module in the outdoor located at optimum tilt angle with the radiation meter is shown in Fig. 1-a and the block diagram of the measuring system using current shunt is illustrated in Fig. 1 (b).

3. Characteristics of the location

One of the methods for increasing the efficiency of the solar energy system is to use the optimum orientation and tilt angle specific for the considered location [16,17]. Preceding work has been done on predicting the optimum tilt angle for each month of south facing photovoltaic modules by field testing measurements in the outdoor conditions at Helwan (Latitude $29^o52'$ N). Optimum tilt angles at Helwan are derived from analysis and estimating equations of the experimental results and summarised in Table 1. The optimum tilt angle was defined by searching for values at which cell performance is a maximum for a specific period.

Since changing the tilt angle to its daily and monthly optimum values throughout the year does not seem to be practical, another possibility, such as changing the tilt angle once per season was considered. Using the predicted and experimental values in degrees given by Table 1 the optimum tilt of a photovoltaic collector for use during the winter season is approximately 43.33^o for the Helwan site. The optimum tilt of a photovoltaic collector used during the summer months is 15^o for the same site. Finally, the optimum tilt angle of a photovoltaic collector continuously mounted at a fixed angle throughout the year in Helwan is 28.75^o and oriented towards the south [15,17].

Table 1. Predicted and experimental values of the optimum tilt angle in degree for Helwan.

Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Predicted	55	45	30	15	5	5	5	15	25	40	50	55
Experimental	51	48	35	21	4	4	7	20	32	48	53	55

4. Module electrical measurements

In the course of this work, a 20 Ampere Holt HCS-1 current shunt is used as an accurate sensor to obtain the equivalent voltage drop across its known resistance when the short circuit current passes through it. The obtained voltage is then applied to a 14 bit data logger, which is directly connected to a PC to compute the corresponding short circuit current using the shunt input-output linearity equation. The computed short circuit current values are obtained from the shunt voltage signals transferred to the PC through the data logger.

It is experimentally investigated that the output voltage is linearly proportional to its input current with approximately the same linearity equation at all temperatures from 5ºC to 50ºC [14].The linearity equation that relates the input current to the output voltage is given by [14]:

$$V_{out} = 0.0517 \times I_{in} + 8 \times 10^{-5} \quad (1)$$

where V_{out} is the output voltage drop in volts across the current shunt resulted from applying input current source I_{in} in Ampere. Moreover, the open circuit voltage of the module is received by the data logger to be transmitted to the PC. The daily profile of the solar module short circuit current, open circuit voltage and electrical power is illustrated in Fig. 2. The data has been recorded on 15th September 2012 at optimum tilted angle of 32° at this location.

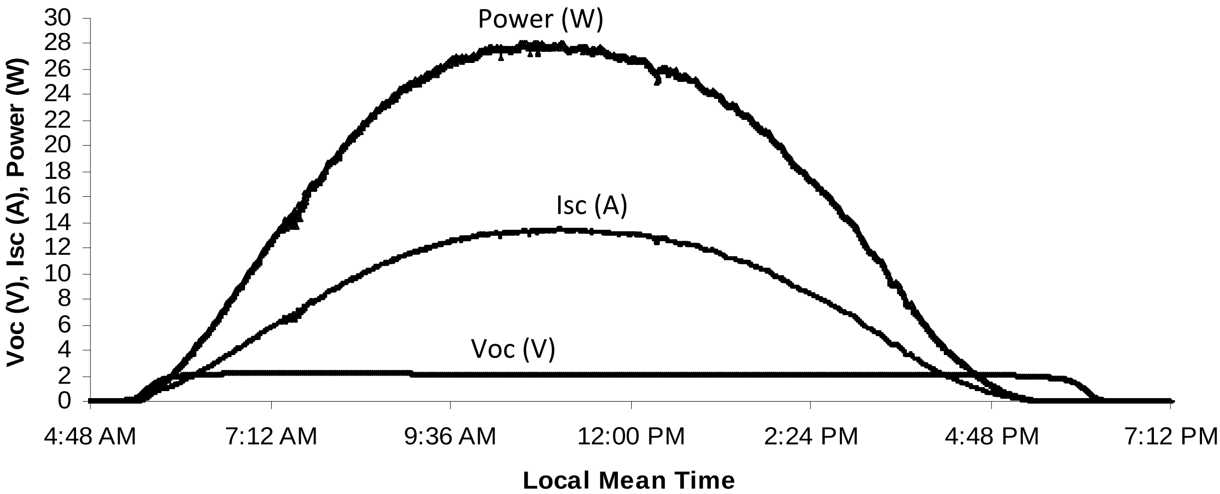


Fig. 2. Daily profile of the measured solar module short circuit current, open circuit voltage and output electrical power.

The maximum module open circuit voltage value is about 2.2V for the series connection of the four solar cells (V_{oc} of each cell is ~ 0.55 V). In the meantime, the module reaches its maximum short circuit current (~14A) to achieve about 28 W output power around the true noon time. Fig. 3 demonstrates the module electrical output power P_{out} along with the solar radiation intensity incident P_{inc} on its module surface in case of the optimum tilted orientation.

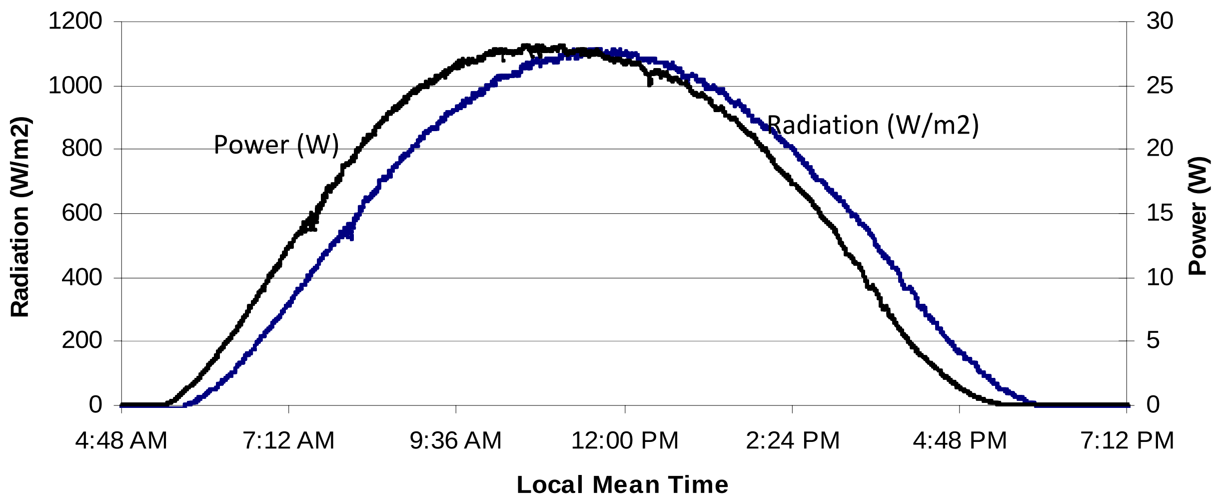


Fig. 3. Daily profile of incident solar radiation along with module output power.

5. Analysis

To justify the varying performance of the current shunt when used with one cell and four series cells, V-I curves are obtained where they are merely calculated with a simple diode model under the assumptions that (i) I-V characteristics of each of the 4 cells are identical and (ii) the resistance due to the external wiring for measurements is the same regardless of the number of cells connected in series. An interconnection resistance of 100 mΩ value is assumed, including the wiring resistance as well as the shunt resistance values.

In the case of testing one single cell, a short circuit current of about 5 A was measured (I_1). This value is much smaller than the rated short circuit values of the cell being 14 A [13]. In the case of testing four cells connected in series, the measured short circuit current (I_2) almost matched the rated short circuit current of the four cells module. Fig. 4 shows the I-V characteristics for the single cell as well as the four cells module. The short circuit current at low irradiance is also calculated (I_3) where P_{inc}=0.25×AM1.5 (dashed lines). In this case, I_3 represents the short circuit current value regardless of the number of cells that are connected in series.

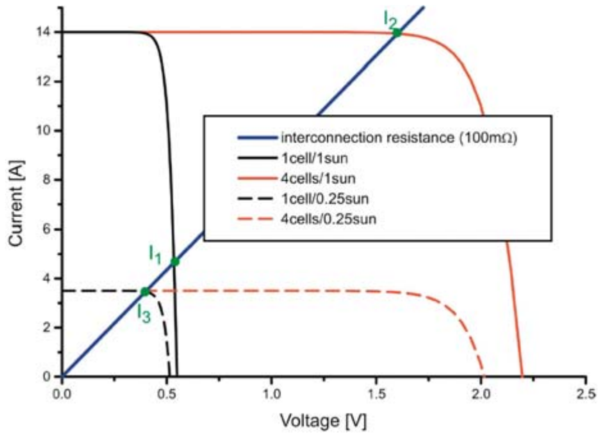


Fig. 4. Calculated I-V plot for multicrystalline solar cell and module assumption.

The linear dependence of the short circuit current values on the incident power could be strongly affected by both temperature rise and spectral variations of the incident light. Consequently the effect of temperature rise strongly considered, where it is taken into consideration that the encapsulated cells do not have any elements to efficiently remove heat and that the shunt resistor is keeping its characteristics at high temperatures [14]. Fig. 5 correlates the measured voltage signal with the global irradiance. This gives the expected linear slopes with almost identical values of 2782 Wm^{-2} /V. Other correlation of the measured voltage signal with the cell's current output is also shown. For the single cell, a simple linear dependence was found giving a shunt resistance value of 52mΩ in agreement with equation 1. For the series arrangement a surprising large hysteresis is present. This simply proves that I_{SC} varies with incident power in a strict linear way at a constant temperature. More precisely a linear temperature correction must be applied as follow:

$$I_{SC}(T)=I_{SC}(STC) \times (1+\alpha\Delta T) \quad (2)$$

$$V_{OC}(T)=V_{OC}(STC) \times (1-\beta\Delta T) \quad (3)$$

$$\Delta T = T - 25^{o}C \quad (4)$$

where,

α: temperature coefficient of the short circuit current,
β: temperature coefficient of the open circuit voltage,
STC: standard test conditions.

Fig. 6 shows a plotting of the short circuit current against the intensity after taking into consideration the effect of temperature rise. For the single cell the correlation obeys the linear dependence up to intensities of 300Wm^{-2} and then saturates. This is not a physical phenomenon and could be predicted from Fig. 4, which illustrates that at higher intensities the interconnection resistance is too high to measure the short circuit current correctly.

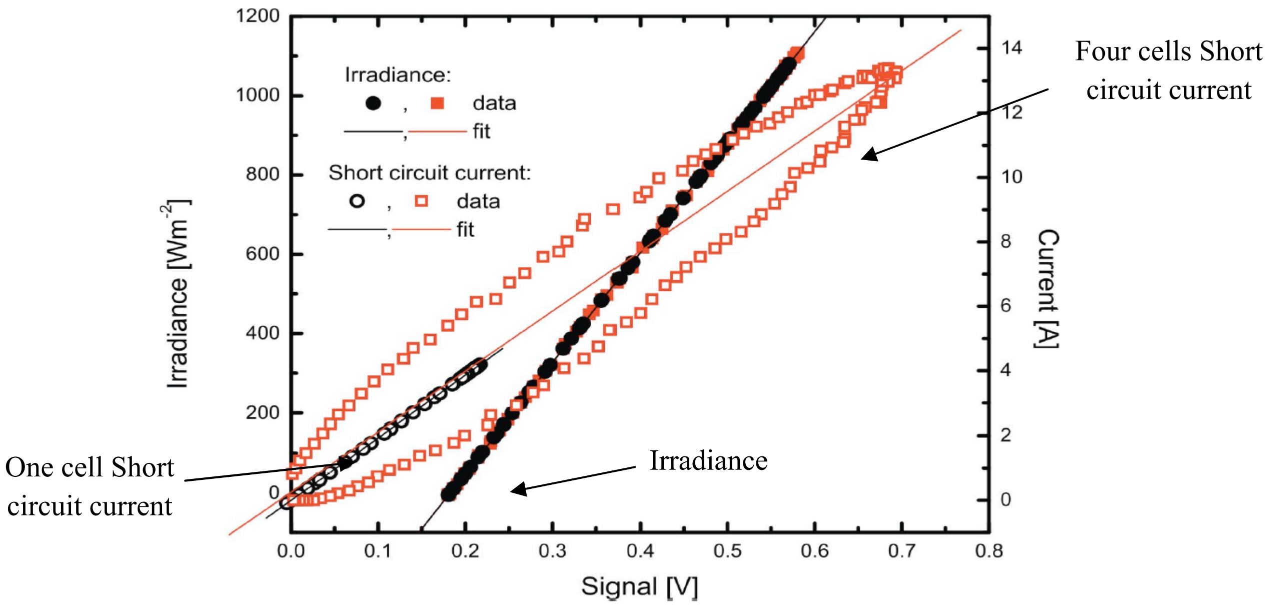


Fig. 5. Comparison between measured signal and physical units for both single and four cell arrangements.

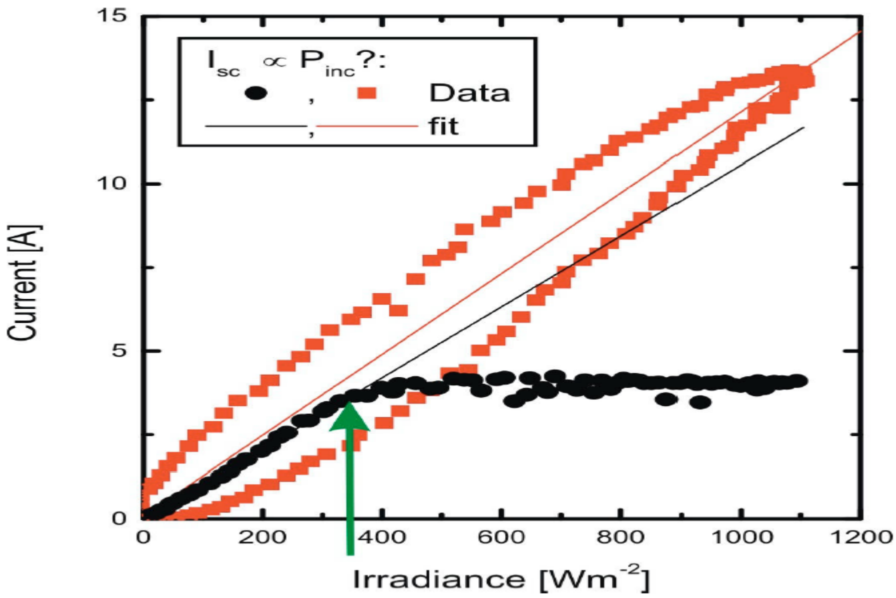


Fig. 6. Short circuit current as a function of intensity.

Fig. 7 shows a plotting of the open circuit voltage against the intensity after taking into consideration the effect of temperature rise. The expected correlation is very likely superimposed by the effect of rising temperatures, where a decrease in V_{OC} is observed for high P_{inc}. On the other hand, for a limited time-range where the temperature change is small, the expected variation of the open circuit voltage is recorded for both single cell and four series cells. The results plotted in figures 6 and 7 showed that, the values of α and β are approximately given as follows: $\alpha = 2\times10^{-4}$ K^{-1} and $\beta = 3\times10^{-3}$ K^{-1}. The experimental results also showed that the variation of I_{SC} with P_{inc} is 1% less than the variation of V_{OC} with P_{inc}.

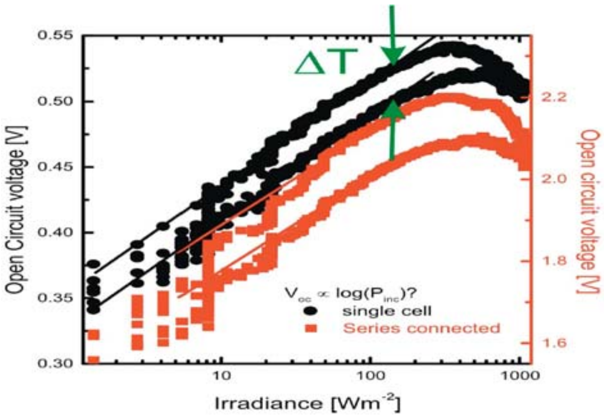


Fig. 7. Variation of V_{OC} with intensity. Temperature effects reduce V_{OC} towards high intensities.

The correlation of I_{SC} and V_{OC} is shown in figure 8. As long as the internal series resistance has slight effects, the function shall follow the same exponential dependence like that of the diode's I-V characteristics.

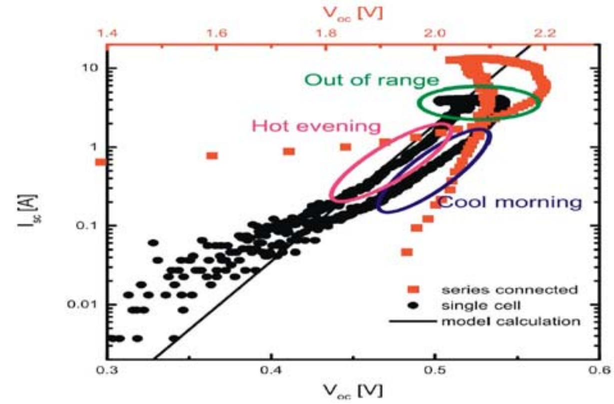


Fig. 8. I_{SC} (V_{OC}) dependence of a single cell and a series connection of 4 cells.

For the single cell measurement the interpretation is rather straight forward. In the cool morning an exponential increase of I_{SC} with V_{OC} is observed. The saturation at about 4 A is an effect of wrong I_{SC} scaling for P_{inc} > 300Wm^{-2}. In hot afternoon, I_{SC} (V_{OC}) curve is shifted to the left due to the decrease in $V_{OC}(T)$ but again exhibit the exponential dependence. The rather complex variation of I_{SC} with V_{OC} for the series connected arrangement is widely due to the calibration function of I_{SC}.

6. Conclusions

The short circuit current of a four series connected cells' module was measured using a current shunt of 52 mΩ, the results showed great success in measuring the full short circuit of the module being placed in a deserted area. A comparison study between the current shunt resistor's performance when used with a single cell and the above case is introduced. The study showed that the value of internal resistance including the used shunt resistor as well as wiring resistance estimated to be 100mΩ strongly plays an important role in the accurate measurements of the short circuit current. Where it succeeded in accurately measuring the full short circuit current of 14 A at maximum open circuit voltage of 2.2 V for the four series cells' module, while in the case of one single cell it only showed a value of about 5 A only at an open circuit voltage of 0.55 V. For a single cell measurement a smaller value of shunt resistance should be used. The effect of temperature rise on the measured values of both I_{SC} and V_{oc} was studied. The experimental results showed that the variation of I_{SC} with P_{inc} is 1% less than the variation of V_{OC} with P_{inc}. The temperature coefficients α and β were calculated using the experimental results giving values of 10^{-4} K^{-1} and 3×10^{-3} K^{-1} respectively. The effect of shunt resistance values on the accurate measurements of I_{SC} as well as V_{OC} is being considered for large scale modules as well as single cells.

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