BENCHMARKING OF THE SW80 POLYCRYSTALLINE SILICON MODULES USING THE SUN AS SOURCE OF LIGHT

by

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Benchmarking of modules it helps to note any changes on the operation of the modules in outdooroperations. The equipment needed to do this has been found to be very expensive hence the need of cheaper methods. This paper tries to show how this can be achieved using outdoor conditions and an I/V measuring instrument PVPM1000. SW80 photovoltaic modules were tested using outdoor conditions. The current and voltage measurements were taken at solar noon and converted to the standard test conditions (1000 W/m^2 AM 1.5 and 25°C). These normalized values were in turn taken as bench mark values of the modules.Future measurements can then be taken at solar noon and compared to benchmark values; any variations in performance can then be noted. The variations on benchmark values as compared to the manufacturer standard test conditions values for SW80 type module were noted. The measurements were carried out under typical South Africa meteorological conditions.

Key words: *benchmarking, simulator, PVPM-1000C, SOZ-03, module*

Introduction

Benchmark testing is essential for modules prior to their installation for experimental purposes. The outdoor conditions which include the irradiance and ambient temperatures have been found to vary constantly. The characteristics of the modules are often not known at such non-standard conditions.

The light source is very important when one wants to benchmark solar modules. Usually solar simulators are used to achieve this. However solar simulators are expensive, a full spectrum solar simulator cost € 25691.00 [1], and their light spectrum is close to that of the sun, but not the same. Also when the light is focused on the module it does not cast uniform light on all the solar cells. Use of the sun may give better details with regards to benchmarking of modules as it spreads uniform light on all cells in the module. This may be achieved by use of a PVPM1000C device, and it costs €6539.00. The device may be used for indoor and outdoor measurements. Several benefits on outdoor benchmarking of the module may be achieved and these include:

– no need to send the modules to distant measurement facilities. The modules may get damaged in transit,
– there is good light uniformity over the module and the pyranometer, and
– there is minimal stray light.

The SW80 Poly/RIA photovoltaic (PV) modules where used in this investigation. They are polycrystalline and their name plate ratings at STC conditions (1000 W/m^2, 25 °C cell temperature, and AM1.5 global spectrum) are as shown in tab. 1.

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Table1. The SW80 Poly/RIA corresponding STC values [2]

Short circuit current, I_{sc} [A]	4.82
Open circuit voltage, V_{sc} [V]	21.50
Peak current, I_{max} [A]	4.480
Peak voltage, V_{max} [V]	17.90
Efficiency, η [%]	11.14

PV modules are normally marketed basing on their STC values. These values give the module's performance rating [3]. However the actual solar irradiance conditions give different performance values hence the need to benchmark the modules.

The field measurements are taken and then normalized to STC levels using eqs. 1 and 2 [4]:

$$I_n = I_m \left(\frac{1000\,\mathrm{W/m^2}}{G} \right) \tag{1}$$

where I_n [A] is the normalized current, I_m [A] – the measured current, and G [W/m^2] – the measured irradiance on plane of PV module:

$$V_n = V_m + V_m\,[b(25°\mathrm{C} - \mathrm{T})] \tag{2}$$

where V_n [V] is the normalized voltage, V_m [V] – the measuredvoltage, b [°C^{-1}] – the voltage temperature coefficient for the module, and T [°C] – the mean measured module temperature during test.

Efficiency of a cell

The efficiency of a cell is defined as the ratio of energy output from the solar cell to input energy from the sun. This has been found to depend on the spectrum and intensity of the incident sunlight as well as the temperature of the solar cell [5]. The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$\eta = \frac{P_{out}}{P_{in}} \tag{3}$$

where

$$P_{out} = V_{oc} I_{sc} FF \tag{4}$$

The fill factor is given by:

$$FF = \frac{V_{peak}\, I_{peak}}{V_{oc} I_{sc}} \tag{5}$$

and

$$P_{in} = G A_{collector} \tag{6}$$

Therefore the efficiency of the cell is:

$$\eta = \frac{V_{oc}\, I_{sc}\, FF}{P_{in}} \tag{7}$$

Effect of temperature on a cell/module

Solar cells are sensitive to temperature changes [6]. Increase in temperature reduces the band gap of a semiconductor, thereby affecting most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Less energy is therefore needed to break the bond. This aspect is noted on the slight increase in short circuit current when the cell temperature increases and this follows the ideal equation of a cell given as:

$$I = I_L - I_o\left[\mathrm{e}^{\frac{qV}{mKT}} - 1\right] \tag{8}$$

where$m$ is the ideality factor ≈ 1, I_o– the saturation current of a diode, I_L – the ideal current source of a diode, and K is the Boltzman's constant.

When the temperature of the cell increases, current I_L increases due to narrowing of the band gap. Electrical efficiency of the photo voltaic cells has also been found to follow eq. 9 [7]:

$$\eta_{el} = \eta_o[1 - \beta(T - 25\,^\circ\mathrm{C})] \tag{9}$$

where η_o is the efficiency of the module at STC, β– the coefficient of temperature and its value is equivalent to 0.0045 °C^{-1} for crystalline silicon cells, and T– the temperature of the module.

Methodology

To carry out the benchmarking exercise, the following procedures were carried out; the current/voltage characteristics of the two modules were measured on a clear day. The measurements were taken around solar noon. A PVPM 1000C system was used to determine I/V characteristic. The PVPM uses the principle of capacitance load to measure the I/V characteristic. The insolation was measured in the plane of the module using a SOZ-03 class1 pyranometer (ISO9060) [8]. The insolation values ranged from 900 to 1030W/m^2. The back of the module temperatures for the control module M1and prototype system module M2 were measured. The pyranometer's cell temperature was also recorded for comparison purposes. The SOZ-03 has a temperature sensor Pt 1000 embedded on it to monitor the sensor's cell temperature. The cell on the SOZ-03 is a silicon cell and its temperature response is more or less the same as the SW80 modules which are also silicon types. The SOZ-03 and the PVPM are shown in fig. 1.

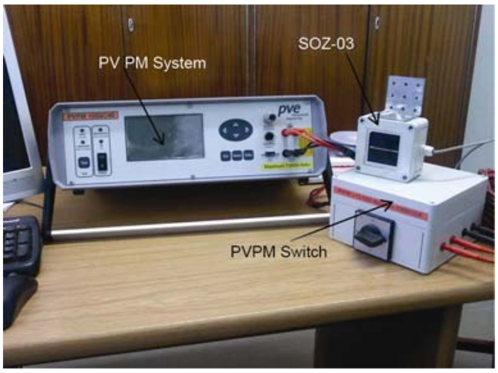

Figure 1. PVPM 1000C system and the SOZ-03

The PVPM system measurements have an error of ±1% [9], while the pyranometer SOZ-03's accuracy was noted to be ±5% [8].

Figure 2 shows the modules M1 and M2. Modules M1 and M2 are silicon polycrystalline photovoltaic modules, product SW80 manufactured by Solarworld, a German company. M1 is the module without water container at the back, while M2 is the module with water container fixed at the back.

Figure 2. Set up of modules under test, M1 LHS and M2 RHS

M1 is used as the control of the investigation while M2 is the module under test. Three type K thermocouples were attached at different points at the back of module M1 to determine the average back of the module temperature.M2 had two sets of thermocouple sensors at the back of module, one monitoring input and output air temperatures, and the other set monitoring back of module temperatures on parts without the water container, see fig. 3.

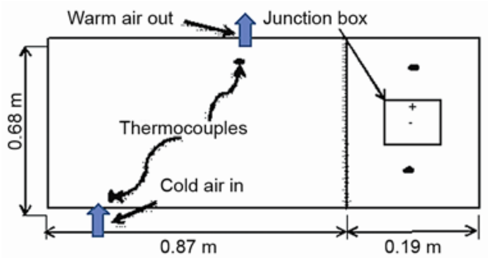

Figure 3. Thermocouples at the back of the module with water container

The PVPM was used to monitor I/V characteristic of the modules for the whole day each minute, while the data logger was used to log the ambient temperature and back of module temperatures each minute from morning to sunset. The solar noon measurements were then used in the normalization process to determine the benchmark values.

Results and discussion

The measurement results for the modules were as shown on tab. 2. Considering solar noon measurements, M1's measurements were taken at an irradiance of 1012 W/m^2 and module temperature of 49.5°C at 12:12p.m., while M2 measurements were taken at an irradiance of 1013 W/m^2, module temperature 50.7°C at 12:15 p.m.

Table2. Measurements on modules M1 and M2 on 21/03/2011

	I_{sc} [A]	V_{oc} [V]	$I_{\max}$ [A]	$V_{\max}$ [V]	$P_{\max}$ [W]	η [%]
Measured (M2)	5.57	18.98	5.10	14.4	73.44	10.07
STC PVPM	5.50	21.4	5.03	16.3	82.0	11.24
Measured (M1)	5.73	19.9	5.26	15	78.9	10.80
STC PVPM	5.66	22.4	5.20	16.9	87.8	12.20
STC rated	4.82	21.5	4.48	17.9	80.2	11.14

The corresponding I/V characteristic for module M2 was as shown in fig. 4.

As shown in fig. 4, the I/V characteristic indicate a drop of current due to a mismatch of the cells. The module was inspected to find out the cause of the mismatch and according to visual inspection no cell appeared to be faulty. Current/voltage measurements were taken for the whole day and used to establish the I/V response of the module from morning to sunset. The response showed no current drop in the early hours of the morning up to around 08:00 as well as in late hours of the day from 15:00 to sunset. At these times the irradiance was noted to be less than 400W. It was therefore concluded that the current drop was due to mismatch of cells caused by temperature differences in the cells. Theoretically, mismatch of cells due to temperature differences have an effect on the current generated by a module [10]. Figure 5 shows I/V characteristic of M2 module at 15:11 indicating no drop in current.

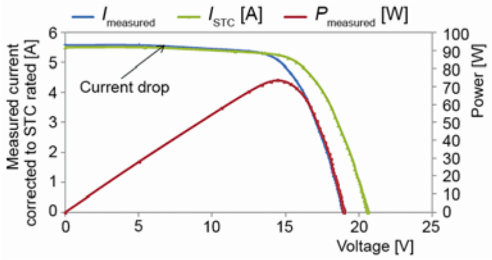

Figure 4. The I/V characteristic of the M2, PV module with a water container
(for color image see journal web-site)

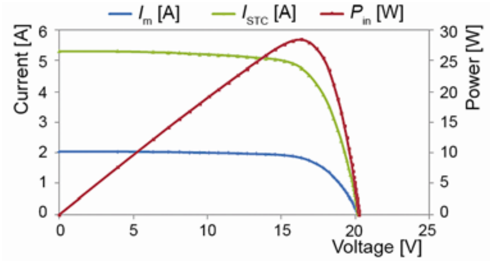

Figure 5. M2's I/V characteristic at around 15:11 hours showing no current drop
(for color image see journal web-site)

Figure 6 illustrates the average temperature profile of two parts at the back of the module M2, with two graphs indicating temperatures on one part covered with a box container and the other part not covered.

The area between the two profiles shows the difference in two temperatures contributing to the mismatch and to the drop in voltage. The area between the power curves shown in fig. 7 gave a power loss of 4.34 W.

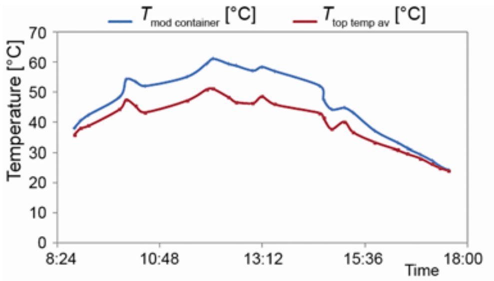

Figure 6. Temperature profiles at the back of the module(for color image see journal web-site)

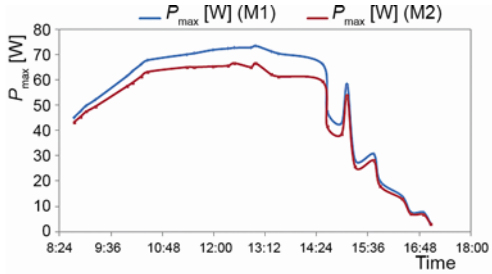

Figure 7. M1 and M2 modules' peak power output
(for color image see journal web-site)

The measured short circuit current was noted to be slightly higher than the short circuit current at STC for both modules. This was in agreement with the theory, which states that short circuit current slightly increases with increase in cell temperature while voltage decreases with increase in temperature.

Rated and measured values

The percentage difference of the rated and measured values of the modules was determined using the relationship:

$$\%\text{Difference} = \frac{I_{\text{STC rated}} - I_{\text{STC measured}}}{I_{\text{STC rated}}} \tag{10}$$

Table 3 shows the percentage difference.

The percentage difference for M1's short circuit current was found to be –17.4%, while for M2 was –14.1%, indicating a better performance of modules as compared to rated

Table 3. Values for rated and normalized current and voltage values

	Rated	Normalized module M1	Normalized module M2	% difference for module M1	% difference for module M2
I_{sc}	4.82	5.66	5.50	–17.43	–14.11
V_{oc}	21.50	22.40	21.40	–4.19	0.47

values. The percentage difference of M1's open circuit voltage was –4.19% and 0.47% for M2 showing a higher open circuit voltage for M1. The differences between the rated values and normalized values indicated the need to have benchmark values for the modules. The benchmark (normalized) values were noted to give a higher efficiency as compared to the manufacturer's STC values and this meant higher power output from the modules as compared to the ratings indicated on the module. With this kind of scenario, a new method of rating modules may be needed.

Conclusions

Higher normalized STC values were obtained for the modules as compared to the manufacturer values and these indicated higher power output from the modules. A power difference of 4.34 W was found between modules M1 and M2 due to differences in back of module temperatures. The study showed higher efficiency values for the modules as compared to the manufacturer STC values, with M1 showing higher efficiency as compared to M2. Cells under M2 where noted to have an I/V characteristic with a break point and this was noted to be due to temperature differences between cells in the strings. Cells under a box container had higher temperatures as compared to those exposed to natural cooling. Higher benchmark values for short circuit current, open circuit voltage and power were obtained for both M1 and M2. Incorporation of these values into photovoltaic economic evaluations may mean shorter payback periods for the modules if used in South Africa.

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