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Performance Evaluation of Various Flat Plate Photovoltaic Modules in Hot and Arid Environment

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Abstract.. The present paper reports the results of a simplified method for evaluating the performance of selected photovoltaic (PV) modules in use in Saudi Arabia and makes a comparative assessment at standard reporting conditions. Experimental results, normalized to standard reporting conditions using the two-axis translation I-V model have revealed that all PV module parameters, except I_{sc}, decreased during the period the modules were exposed to outdoor environment. The degradation resulted in a decrease in the module efficiency of 0.22% to 11% depending on the make of the module. Moreover, the measured PV module parameters were found to differ from manufacturer's specified values yielding a decrease in efficiency.

Keywords. PV degradation, Photovoltaic modules, Two-axis translation I-V model, Solar cells.

Introduction

Saudi Arabia enjoys an abundance of sunshine having about 350 sunny days per year. This coupled with widely scattered remote areas has made photovoltaic applications attractive and practical. There are many applications of photovoltaic solar generators in Saudi Arabia [1]. They are utilized to power road signs, roadway lights, warning signs, tunnel light, traffic counters, and other devices. This is especially important in remote areas or in areas where electricity from the national electric grid system is quite expensive. Environmental conditions such as temperature and dust play an important role in the performance of photovoltaic (PV) modules and as such must be taken into consideration by the PV system designer.

Photovoltaic module degradation due to environmental factors has been the subject of many publications [2-7]. The main factors that contribute to the flat-plate PV module degradation are the increased lump series resistance, decreased shunt resistance, and the decreased short-circuit current [2,5]. Konar and Joshi [2] concluded that the increase in the series resistance is due to the effect of corrosion of the metallic grid interconnection and that the decrease in the short-circuit current is due to the change of the photostability and asymmetry scratching of the front glass. Som and Alawi [3] observed that PV modules exposed to outdoor environment suffered from effects varying from complete failure due to corrosion to degradation in efficiency. Dust caused degradation is a problem that exists in Saudi Arabia. Dust particles cause abrasion to the surface of PV module especially large particles [4]. Smaller particles seem to accumulate on the surface causing considerable deterioration of the PV module performance [5]. Machida et al [6] studied the field exposure of PV modules and observed that their maximum power output decreased 4.8% for single crystalline modules and 2% for polycrystalline modules in a period of five years.

The purpose of this work is to study the performance of selected PV modules in outdoor conditions and make a comparative assessment at standard reporting conditions (SRCs). Since performance (raw) data is obtained under various ambient conditions and insolation levels, it is necessary to normalize the data in order to compare modules with each other. This is achieved by translating the raw data into values under standard reporting conditions (SRCs). That is, the basis for performance comparison of the various modules is provided by the SRCs. The raw data was obtained by making I-V measurements, of selected modules along with some important data such as the temperature and insolation. The measured I-V curve is then extrapolated using a computer program, to the standard reporting condition of insolation (1000 W/m^2) and cell temperature (25^{o}C). Finally, a comparison is made at the SRC among the several modules to identify the differences in the performance parameters of each module, including any degradation during the period the modules were exposed to the outdoor environment and also to determine module performance differences between various manufacturers.

Imported PV modules as well as those assembled locally are designed and constructed with a particular environment in mind, namely that in the Western Hemisphere. As such their use in another environment may cause certain problems, the least of which is partial loss of output. However, these specifications are not necessarily as good as the manufacturer claims. Thus a need arises to verify the manufacturer specification sheet so that PV designers and users have the correct device specification. This would certainly save time, money and sometimes embarrassment due to a design based on inaccurate information.

Experimental

Figure 1 shows the PV module setup at one of the test sites. The evaluation tests were performed on five different modules made by various manufactures: ARCO, HOXAN, KYOCERA, SHARP and SOLAREX. The above modules are given test numbers (not in the same order above), TU13, TU15, TU18, TU21 and TU22 to mask their real identity. The properties of the modules under test are presented in Table 1. All modules are mounted at the tilt angle of 24° (the local latitude angle). Current-voltage measurements were made using PVI environmental data processor and the PVI curve tracer, which is operated by an HP program tape. In addition, the ambient air temperature (AAT) and plane of cell insolation (POCI) were also measured.

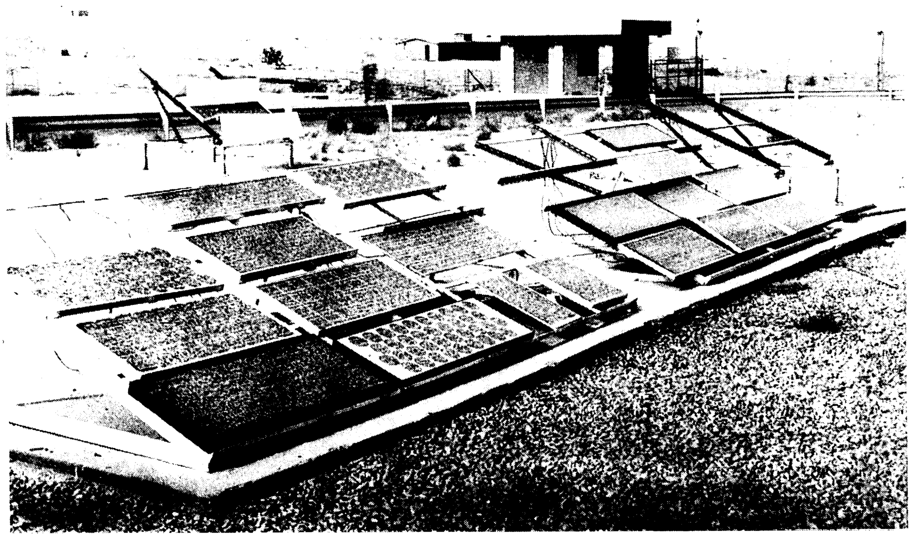

Fig. 1. The PV module tests site.

Table 1. Properties of PV modules under test

Private test unit #	No. of Cells	Rated power (W) at SRC	A_M (m^2)	A_{TA} (m^2)
TU 13	36	40	0.3274	0.3274
TU 15	36	30	0.4048	0.2787
TU 18	36	44	0.4350	0.3600
TU 21	36	40	0.3806	0.2827
TU 22	40	35	0.4753	0.4000

A typical test starts with cleaning the surface of the module under test. The module is then connected to the curve tracer (PVI), which in turn is connected to the computer (HP). The total normal insolation is measured by placing the KIPP and ZONEN (K&Z) sensor on a surface next to and at the same level of the module under test to avoid shading it. Current-voltage, insolation and temperature measurements were made using the PVP-4 environmental data processor (EDP) and the PV-200-40 IEEE 488-based curve tracer. A

HP-85 program tape is used to operate both the EDP and the curve tracer through an IEEE 488 interface. Thus an accurate and convenient means to acquire the I-V curve, and to normalize it to a set of standard reporting conditions is achieved.

The EDP acquires insolation and temperature data from the K&Z sensor and the digital thermometer and performs all necessary calibration and compensation functions. It then digitizes the processed measurements and outputs the digitized data onto the IEEE 488 bus.

I-V Curve extrapolation

Two approaches to extrapolation were considered here: (a) the Single Exponential I-V Model (SEIVM) which makes use of a single exponential equation representing the solar cell equivalent circuit [8] and (b) the Two-Axis Translation I-V Model (TIVM) [9]. The later model was used because it is more exact than the single exponential I-V model. The TIVM extrapolates an I-V curve defined at a contained set of insolation and cell temperature conditions to another user-specified conditions. Major inputs to the model are the I-V curve (28 points) at a set of insolation values, cell temperature or ambient air temperature, and other cell characteristic such as nominal operation cell temperature (NOCT), series resistance, temperature coefficients of voltage and current. Physical module parameters such as the module area, total active area, and cell total active area A_M, A_{TA}, and A_{TAC} respectively and number of cells in series N_s must also be input. Major outputs are I-V and P-V curves, a tabulation of parameters such as the voltage and current at maximum power point, fill factor and the efficiency at user-specified conditions.

The TIVM is based on the following assumptions:(a) the short circuit current varies with both insolation and cell temperature, and (b) the open circuit voltage is inversely proportional to cell temperature [10, p. 92].

TIVM Mathematical relationships

Given a reference set of I-V points at any set of intensity/temperature condition, mathematical relationships used to arrive at I-V points at another condition are listed below. Subscript 1 (condition 1) in the equations denotes the reference or test I-V curve and subscript 2 (condition 2) the extrapolated value.

The change in current between new (extrapolated) and reference conditions is obtained from the relationship.

$$\Delta I = I_{sc1}\left(\frac{H_2}{H_1} - 1\right) + \alpha(T_2 - T_1) \quad (1)$$

Where,

α : The current coefficient in (A/°C), H : the incident insolation in (W/m^2) and T : the cell temperature in (°C).

The current I, at the new condition is obtained from,

$$I_2 = I_1 + \Delta I \quad (2)$$

The change in voltage ΔV is given by,

$$\Delta V = \beta(T_2 - T_1) + \Delta I_{sc} R_s + \rho I_2 (T_2 - T_1) \quad (3)$$

Where,

β: the voltage coefficient in (V/°C), R_S : the series resistance in (Ω) and ρ : the curvature coefficient in (Ω/°C).

The voltage V at the new condition is obtained from,

$$V_2 = V_1 - \Delta V \quad (4)$$

Results

Figure 2 shows the I-V characteristic of a module under test. Both the measured (test) and extrapolated curves are shown. The new curve is the reference I-V curve extrapolated to the standard reporting condition (SRC) at an insolation (H) of 1000 W/m^2 and cell temperature (T) of 25°C. The effect of the temperature on the I-V curve is evident (see Fig. 2). The power versus voltage output and its extrapolated curve are shown in Fig. 3 for the same module. Table 2 lists the output parameters for both the measured and extrapolated I-V characteristics of a PV module under test.

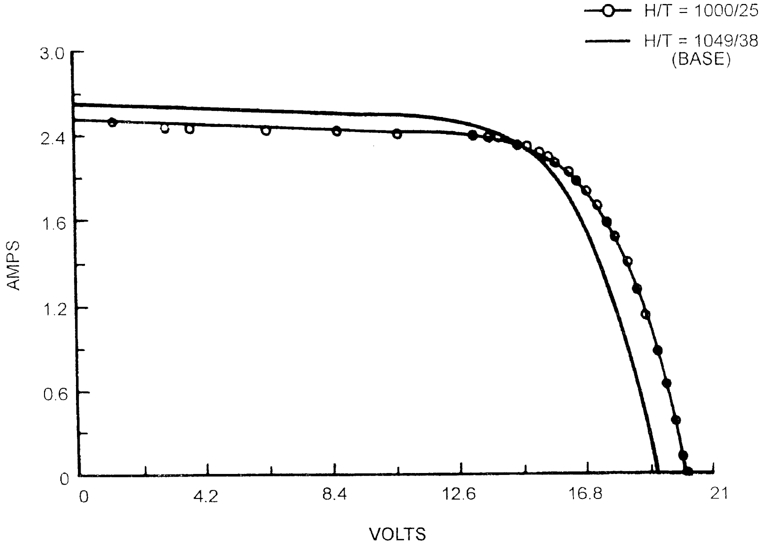

Fig. 2 The measured and extrapolated I-V characteristics of a PV module.

Table 2. Output parameters for TU13

Parameter	I-V output	
	H/T= 1049/38 (Base)	**H/T= 1000/25 (extrapolated)**
P_{mp}, watts	34.16	35.05
V_{mp}, volts	14.60	15.65
I_{mp}, amps	2.34	2.24
FF	0.67	0.69
η (%)	8.74	9.40
I_{sc}, amps	2.63	2.50
V_{oc}, volts	19.26	20.18
T_{am}, °C	1.29	-10.00

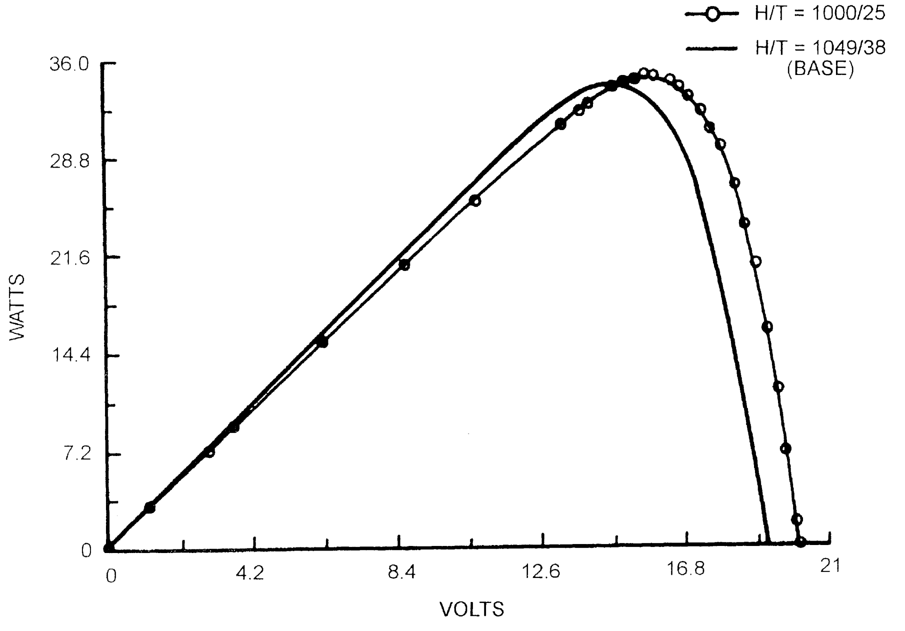

Fig. 3 The test and extrapolated P-V characteristics of a PV module .

Table 3 shows the degradation of I_{sc}, V_{oc}, FF, P_{mp} and η after being exposed to the outdoor conditions for one year. These figures indicate that all of the module parameters, except I_{sc}, have degraded during the period the modules were exposed to outdoor environment.

Table 3. Degradation in PV Module output parameters after one year

Module No.	A_M (m^2)	% change in output parameters				
		I_{sc}	V_{oc}	P_{mp}	η	FF
TU13	0.3727	11	-5	-0.32	-0.22	-5
TU15	0.4048	2	-9	-11	-11	-4
TU18	0.4350	1	-6	-8	-8	-4
TU21	0.3806	2	-8	10	-10	-5
TU22	0.4753	5	-8	-8	-8	-4

Some older modules have shown physical degradation in addition to the performance degradation. Figure 4 shows the upper surface degradation of a module representing a group of modules that suffered from such an effect. High temperatures and sandstorms are believed to be responsible for the degradation in the outer surface of the module. This is evident because of the pitting effect of sand at the module surface and the cracks appearing on the surface because of heat effect.

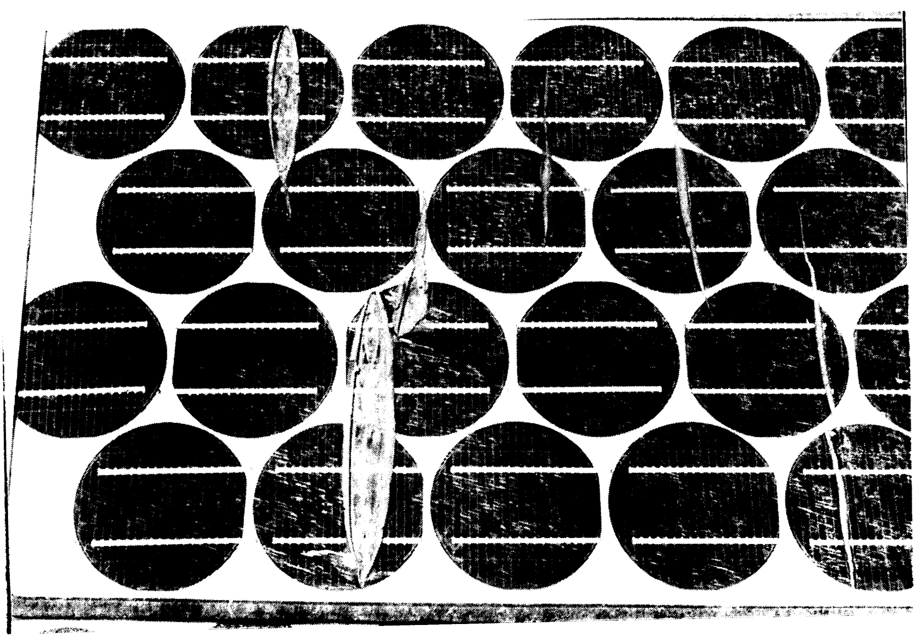

Fig. 4 A PV module showing physical degradation.

Conclusion

Flat plate photovoltaic modules of various makes were evaluated for one year, at standard reporting conditions, in a hot and arid environment characterized by dust storms. It was found that all photovoltaic module parameters, except the short circuit current, degraded during the period they were exposed to outdoor environment. The degradation resulted in a decrease in the module efficiency of 0.22% to11% depending on the make of the module. Moreover, the measured PV module parameters were found to differ from manufacturer's specified values.

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تقويم الأداء لألواح فوتوفلطائية مختلفة في بيئة حارة وجافة

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الرياض ١١٤٢١، المملكة العربية السعودية

(استلم في ١٨/٣/١٩٩٨م ؛ وقبل للنشر في ١٩/٦/١٩٩٩م)

ملخص البحث. تقدم هذه المقالة نتائج طريقة مبسطة لتقويم أداء وحدات (ألواح) فوتوفلطائية مختارة في المملكة العربية السعودية وتقوم بمقارنة تقديرية للأداء تحت ظروف التقرير العياري. بيّنت النتائج التجريبية، المنسقة للظروف العيارية التقريرية "SRC" أن جميع بارامترات الوحدة الفوتوفلطائية، عدا تيار القصر I_{sc}، انخفضت خلال فترة تعرض الوحدة للبيئة الخارجية. ولقد نتج عن ذلك انخفاض بكفاءة الألواح الفوتوفلطائية يتراوح بين ٠,٢٢٪ إلى ١١٪. ووجد أن بارامترات الوحدة الفوتوفلطائية المقاسة تختلف عن مواصفات المُصنعْ، بحدوث نقصان في قدرة الكفاءة.