OUTDOOR I-V CURVES VS SIMULATOR MEASUREMENTS FOR CHARACTERIZING PV MODULES

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The Ben-Gurion National Solar Energy Center at Sede Boqer is located at a site that enables the performance of outdoor I-V measurements on photovoltaic modules with a precision that does not fall far short of that obtainable using solar simulator techniques. First, the latitude of 30.9 degN ensures that at solar noon the air mass seen by modules at normal incidence to the beam direction will always fall in the range 1.01-1.72, i.e. acceptably close to the AM 1.5 for which module parameters are usually specified. Secondly, the desert conditions provide a large number of cloud-free days throughout the year, the insolation on such days remaining constant to far better than 1% during the half-hour, or so, period around solar noon, and always close to the one-sun insolation levels.

In order to test this assertion a photovoltaic module was tested outdoors at Sede Boqer on a number of days and the resulting I-V curves were compared with solar simulator tests that Solarex Corp had recently performed on the same module.

Table 1 shows the results of six successive I-V curve measurements performed by Solarex Corp on October 5, 1993, together with their means and standard deviations. These measurements were performed on an SX-146 module (serial number 170193) at one-sun intensity and a module temperature of 22.8 ^{o}C, using their *sun simulator II* test facility. The tabulated values have been corrected to so-called *Standard Test Conditions*: (solar intensity 1000 Wm^{-2}, module temperature 25 ^{o}C) using temperature coefficients: $\partial V/\partial T$ = - 88 mV K^{-1}, $\partial I/\partial T$ = + 2.7 mA K^{-1}.

Isc [amp]	Voc [volt]	Ipp [amp]	Vpp [volt]	Pmax [watt]	FF [%]	h [%]
2.84	22.5	2.63	18.0	47.2	74	11.8
2.84	22.5	2.63	18.0	47.3	74	11.8
2.83	22.4	2.64	17.9	47.3	74	11.8
2.84	22.5	2.63	18.0	47.2	74	11.8
2.83	22.5	2.63	17.9	47.2	74	11.8
2.83	22.5	2.66	17.8	47.3	74	11.8
<2.835>	<22.48>	<2.637>	<17.93>	<47.25>	<74>	<11.8>
s=.005	s=.037	s=.011	s=.075	s=.050	s=0	s=0

This module was then shipped to Sede Boqer and subjected to the corresponding outdoor tests at the Ben-Gurion National Solar Energy Center on October 26, 1993.

The module was placed at normal incidence to the incoming solar radiation and a Daystar I-V curve tracer was used to make 6 successive measurements during the period 11:53-11:55 IST (AM1.39). Global irradiance, measured with a Kipp & Zonen CM-11 pyranometer, was 1045 ± 4 Wm^{-2}, ambient temperature was 31^{o}C, relative humidity was 36%, wind speed was a steady 1.0 ms^{-1}. During the successive tests the module temperature rose steadily from 49.6 ^{o}C to 52.5 ^{o}C.

Table 2 shows the module parameters resulting from this run, each corrected to STC using the module temperature recorded during the I-V curve measurement.

Isc [amp]	Voc [volt]	Ipp [amp]	Vpp [volt]	Pmax [watt]	FF [%]	h [%]
2.76	22.1	2.51	17.6	44.0	72	11.0
2.77	22.4	2.48	17.9	44.2	71	11.0
2.77	22.5	2.58	17.3	44.4	72	11.1
2.77	22.3	2.50	17.6	44.1	71	11.0
2.77	22.2	2.58	17.1	44.1	72	11.0
2.77	22.2	2.56	17.2	44.0	72	11.0
<2.768>	<22.28>	<2.535>	<17.45>	<44.13>	<71.7>	<11.0>
s=.004	s=.134	s=.040	s=.275	s=.137	s=.47	s=.04

The test was repeated November 9, 1993 in a similar manner. Measurements were performed during the 2 min time period around 11:43 IST (AM 1.50). Global irradiance on the module surface was 1066 ± 3 Wm^{-2}, ambient temperature was 23°C, relative humidity was 62%, wind speed was 3.0 ms^{-1}, module temperatures were 42.3 ± 1 °C. Table 3 shows the results of this run corrected to STC.

Isc [amp]	Voc [volt]	Ipp [amp]	Vpp [volt]	Pmax [watt]	FF [%]	h [%]
2.77	21.9	2.53	17.0	43.0	71	10.7
2.77	21.8	2.55	16.9	43.2	72	10.8
2.77	21.8	2.56	16.9	43.2	72	10.8
2.76	21.8	2.58	16.7	43.1	71	10.8
2.77	21.7	2.60	16.5	42.9	71	10.7
2.76	21.6	2.56	16.6	42.6	71	10.6
<2.767>	<21.77>	<2.563>	<16.77>	<43.00>	<71.3>	<10.7>
s=.005	s=.094	s=.022	s=.180	s=.208	s=.47	s=.07

Conclusions

1. Standard deviations for any given outdoor run are *slightly* larger than those from simulator measurements, typically at the 1% level.

2. Outdoor measurements are reproducible to within about 1% from one "hot, dry" day (26.10.93, AM 1.39) to another "cool, humid" day (9.11.93, AM 1.50).

3. The outdoor measurements disagree with the simulator measurements by less than 10%. This difference may be attributed to differences in pyranometer calibrations and spectral sensitivities. Comparison of FF (where pyranometer calibrations are cancelled out) indicates a 3% difference which is possibly a purely spectral effect. Comparison of Pmax indicates an 8% difference, 5% of which may come from the difference in pyranometer calibrations at the two laboratories.