

PV MODULE PERFORMANCE AFTER 30 YEARS WITHOUT WASHING

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ABSTRACT

The performance of a Solarex 40 watt mono crystalline PV module is examined after 30 years in use without washing. After washing the module efficiency improved from 8.04% to 10.06%. Efficiency calculations were carried out at the National Renewable Energy Laboratory. Comparisons of the module short circuit current shows a 22% decrease from the original readings made in 1983 to the measurements before the module was washed and 4% decrease if the comparison was made after the modules were washed. Details of the analysis will be given in the article.

1. INTRODUCTION

One question that is often asked is how often should one wash their solar photovoltaic (PV) modules? As the modules are often on roof tops or situated out of the way, it often takes some effort to clean these modules. Rain does some cleaning, but even after a good rain some residue remains. Another concern is how much does the output of a PV module decrease from year to year and how much is the decrease after 30 years in the field. While accelerated testing can be used to answer some of these questions, long-term studies are really needed to convince some people.

In an effort to answer this question, monitoring of the short circuit current on several Solarex 40 watt PV modules commenced in 1983. To evaluate soiling, one module was not washed. After six years, a comparison study was made between a module that was washed regularly and the module that was never washed. The results were published [1] and showed that soiling was decreasing the module's performance by about 1 to 1.5% per year. While further study

of the modules was planned and the modules were monitored, time was never allotted to do a follow-up study.

In 2012, the University of Oregon was selected to be one of the hosts for the National Renewable Energy Laboratory (NREL) PV module testing facility. This project located a high quality PV test facility in different parts of the country with very high quality instrumentation to test module performance in different climates to provide a consistent dataset that could be used to test, validate or help modify existing models of PV performance [2]. The facility had room to test 15 modules and the fifteenth slot was vacant and this provided the opportunity to do high quality tests on the unwashed module that had been on the roof of Pacific Hall at the university for over 30 years.

A little over halfway through the 13 months that the test facility was at the university, the unwashed module was shipped to NREL for testing and cleaning. First it was tested in the unwashed condition and then it was thoroughly washed and tested again. The module was later re-installed in Eugene at the PV test facility after the cleaning to continue to provide data for analysis. This enabled analysis of the effect of cleaning both at NREL and at Eugene.

This article is broken into five sections. The first section briefly describes the NREL PV test facility and the instruments used to measure the data. Then the PV test methodology used at NREL is described and the results from the test are presented. This is followed by an examination of the module short circuit current before and after the cleaning. In addition the short circuit current at the PV test facility is compared with the short circuit current measurements taken when the module was first installed. The results of the tests are then discussed along with implications of the test results.



Fig. 1: The NREL PV test facility in Eugene. Picture shot from the lower room and these trees do not shade the modules. The unwashed module is in the upper right hand corner in front of the automatic tracker that can be seen in the background.

2. NREL PV TEST FACILITY

The NREL PV test facility consists of 15 different PV modules mounted at an angle equal to latitude (Fig. 1). Eugene's latitude is 44°. The plane of array (POA) irradiance was measured by a Kipp & Zonen CMP 22 pyranometer and a LI-COR 200SA pyranometer. The CMP 22 is a secondary standard pyranometer that is the most accurate way to measure total irradiance by a single instrument. The 200SA is a photodiode base pyranometer that is often used to evaluate the performance of PV modules. The direct normal irradiance (DNI) data comes from a Kipp & Zonen CHP1 pyrhelimeter mounted on an automatic tracker. The global irradiance on a horizontal surface (GHI) is measured using a CMP 22 and the diffuse irradiance is measured by another CMP 22 pyranometer that has a shade ball to block the sun, as can be inferred in Fig. 1 (see top right).

Other meteorological data, wind speed, wind direction, precipitation, ambient temperature, relative humidity, and barometric pressure, were measured using a Vaisala WXT520 Weather Sensor. The irradiance and other meteorological data were recorded and stored on a Campbell CR1000 data logger once every five seconds. Maintenance and cleaning of the instruments were done five days a week, mostly in the early morning hours.

Spectral data from a Yankee Solar Multi-Filter Rotating Spectral Radiometer (MFRSR-7) was obtained once a minute. The MFRSR-7 measures irradiance using six narrowband filters for spectral information and a photodiode for broadband measurements. Like other rotating shadowband irradiometers, the MFRSR has a shadowband that blocks the sun to obtain the diffuse measurement and then

subtracts the diffuse horizontal irradiance (DHI) from the global horizontal irradiance (GHI) to obtain the direct normal horizontal irradiance ($DNI_{\text{Horizontal}}$) for the spectral and broadband measurements. The $DNI_{\text{Horizontal}}$ irradiance is divided by the cosine of the incident angle to calculate the DNI irradiance.

A LI-COR 1800 spectroradiometer was also run periodically over the time period, both horizontally and in the plane of array. The 1800 provide spectral data from 300 nm to 1100 nm.

In August, 2013, a GPS based atmospheric water vapor sensor was installed. Data signal from the Zephyr Geodetic GPS Antenna and a Trimble Net9R Data Acquisition system are downloaded by the University Corporation for Atmospheric Research (UCAR) and processed to produce precipitable water vapor estimates on a half hourly basis.

The photovoltaic (PV) module performance is measured using a Daystar MT5 Multi-Tracer. The MT5 obtains current voltage (I-V) information along with module temperature. An IV curve is obtained once every-five minutes for each of the 15 modules. The irradiance and meteorological data that occurred during the IV curve measurement is reported along with the module performance data and variability and uncertainty information. For a more comprehensive review of the project see [2].

3. TESTING OF THE MODULE AT NREL

NREL maintains an ISO certified high quality facility for testing of photovoltaic modules. The NREL Device Performance group is one of only two laboratories in the world to hold an International Organization for Standardization (ISO) 17025 accreditation for primary reference cell and secondary module calibration. In addition it has accreditation for secondary reference cell calibration under American Society for Testing Materials (ASTM), and International Electrotechnical Commission (IEC) standards.

The group measures the performance of PV modules with respect to standard reporting conditions-defined at a reference temperature (25°C), total irradiance (1000 W/m²), and a standard spectral irradiance distribution (IEC standard 60904-3).

For efficiency estimates, the total area was calculated using the outside edge of the frame. The aperture area was obtained using the inside edge of the frame. The estimated total uncertainty at the 95% level is ±5%.

Two tests were conducted on August 23, 2013. The first

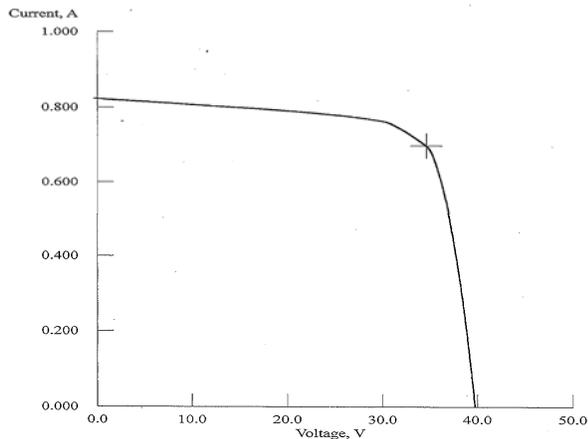


Fig. 2: Performance of unwashed Solarex PV module

was for the module as received in an unwashed state and the second was for the module after the front surface was cleaned and washed. The results of the test are shown in Figs. 2 and 3 and in Table 1. The unwashed module had an apparent efficiency (η) of 8.04% and after washing, the module efficiency increased to 10.06%. The washed module had an apparent efficiency 25% greater than the unwashed module. Given that the module was unwashed for 30 years, the build-up of dirt decreased the module's performance by about 0.8% per year.

In the original tests of the module in 1983, the short circuit current was measured. Therefore to determine the long-term degradation of the module as opposed to the decrease caused by the buildup of dirt, the short circuit current (I_{SC}) is evaluated. In Fig.4, the short circuit current for the module as measured using the NREL PV test facility is divided by the incident solar energy measured with the CMP 22 pyranometer mounted in the plane of array. This ratio is a useful way to study changes in I_{SC} since the I_{SC} is mainly a function of the incident energy and at large values of incident solar radiation is fairly constant. Data from the period before the module was washed are indicated by the black circles. Data from the period after the module was washed are represented by the red 'x's.

Clearly, the cleaning has significantly increased the I_{SC} . Using the data between 998 and 1002 W/m^2 , the average

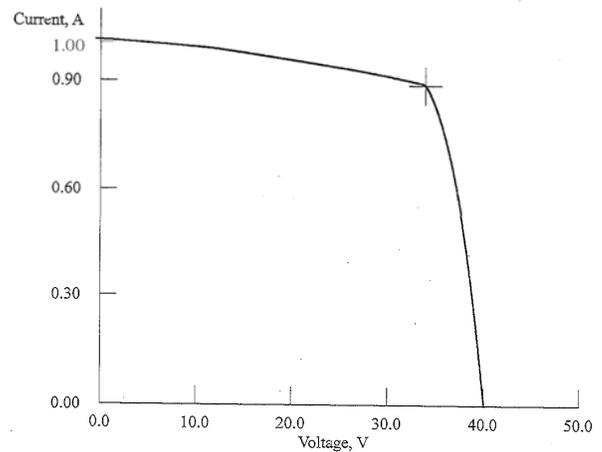


Fig. 3: Performance of Solarex PV module after it was washed.

ratio is 0.000834 ± 0.000011 Amps/ W/m^2 before cleaning. After cleaning, the ratio averaged 0.000980 ± 0.000004 Amp/ W/m^2 . This represents a 18% increase in the ratio of I_{SC} to POA irradiance.

By examining the change in the short circuit measured in 1983, one can estimate the performance decrease over time that is related to module degradation and the combined performance decrease due to the buildup of dirt and module degradation.

A plot of the ratio of I_{SC} to POA irradiance for the module in 1983 is given in Fig. 5. In 1983, the short circuit current was measured across a 0.2 Ohm resistor. The POA was measured using an Eppley PSP pyranometer. The array was tilted at 45°. In 1983, the data was integrated over a 5-minute period. The average I_{SC} to POA irradiance was 0.001016 ± 0.000012 Amps/ W/m^2 averaged between 998 and 1002 W/m^2 . Only August 1983 was used because the module was unwashed and the buildup of dirt during the latter part of the year would affect the short circuit current.

From 1983 to 2013, the ratio of I_{SC} to POA irradiance decreased by 22%. After washing, this decrease was reduced to just 4%. Therefore, for the long-term, the buildup of dirt decreased performance by about 0.6% per year and the degradation of the single crystalline module decrease by 0.15% per year.

TABLE 1: SOLAREX MODULE PERFORMANCE RESULTS—AUGUST 2013

Parameter	Area (cm ²)	Temp (°C)	V _{OC} (V)	I _{SC} (A)	FF (%)	V _{max} (V)	I _{max} (A)	P _{max} (W)	Aper. η (%)
Unwashed	2970.9	24.9	39.48	0.823	73.5	34.33	0.696	23.89	8.04
Washed	2970.9	24.7	39.78	1.014	74.1	33.65	0.888	29.89	10.06

4. DISCUSSION

The tests performed on the 30 year Solarex module represent one data point for the performance change

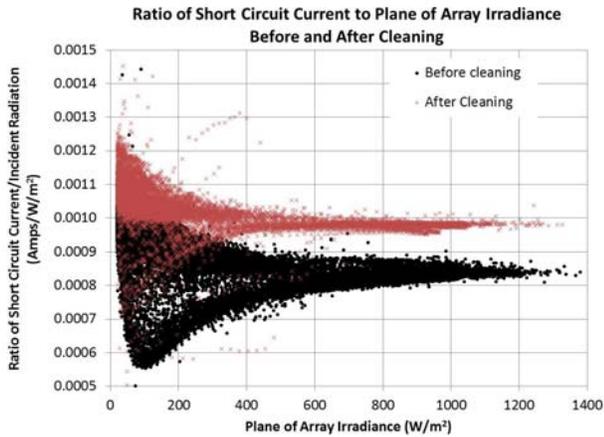


Fig. 4: Plot of the ratio of the short circuit current divided by the plane of array irradiance, 2013. The black circles are data gathered before the array was washed and the red x's are data gathered after the array was washed.

over a thirty year period. While these results are not directly applicable to newer module designs, it does give an order of magnitude idea of the effects that degradation and soiling can produce. Of course module design and solar cell fabrication have changed over the past 30 years and further changes are expected as new ideas and technologies are integrated into future modules.

The NREL PV standard module performance tests give a very good idea of the magnitude of the effects of soiling on module performance. After washing the PV modules performance increased by 25%. The absolute accuracy of these measurements is on the order $\pm 5\%$, but the relative accuracy of the testing at NREL is likely to be much higher. The short circuit current as measured at NREL increased by 23%. (Note that the improvement in I_{SC} is slightly less than the improvement in efficiency.) These test were taken under controlled conditions and the results are reported under the standard terrestrial reporting conditions of 25°C and 1000 W/m² using IEC 60904-3 global reference spectrum.

These results show that the buildup of dirt on a solar module can significantly reduce its output over a 30 year period if it is not occasionally washed. The Solarex mono-SI

TABLE 2: EFFECT OF CLEANING ON I_{SC}

Module/year	I_{SC}/POA A/W/m ²	σ 998 - 1002 W/m ²	%Change from 1983
New 1983	0.001016	0.000012	na
2013 Unwashed	0.000834	0.000011	-22%
2013 Washed	0.000980	0.000004	-4%

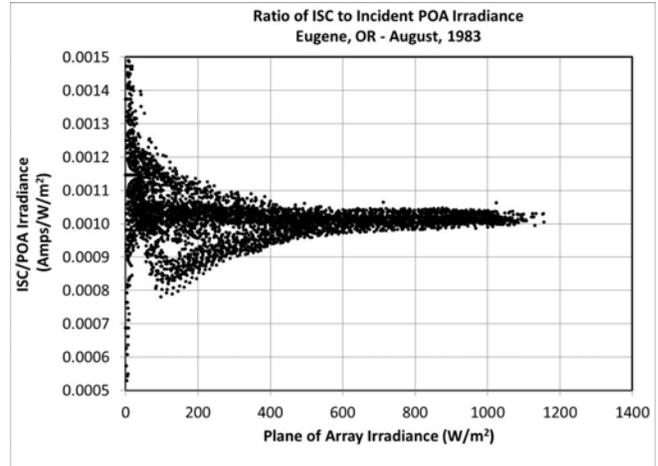


Fig. 5: Plot of ratio of short circuit current divided by the plane of array irradiance, August, 1983. (5-minute data)

module does have a lip that can result in an increase in the buildup of dirt along the lower row of cells. Most new module designs do not have this lip.

The I_{SC} measurements can carry a considerable uncertainty since they were conducted 30 years apart and using different methodologies. The measurement of the short circuit currents would be fairly accurate on the order of 0.5% or possibly better for the NREL PV test facility. The accuracy POA irradiance from the Kipp & Zonen CMP 22 is on the order of 1.5% as it is a secondary standard pyranometer and the uncertainty in the data from the Eppley PSP, a first class instruments, is on the order of 2.5%. This means that the uncertainties of the overall comparisons are on the order of 3 to 4%, about the same magnitude as the degradation in I_{SC} of the PV module assuming that the module was washed.

5. CONCLUSIONS

There are many solar systems set up in the 1980s and 1990s. These systems are reaching have been in the field long enough to provide some guidance on how these solar modules perform in the field after many years of service. While the accelerated testing does help identify failure modes and lifetimes there is nothing like actual measurements to convince conservative financial investors that standard photovoltaic modules do have a good 20 to 30 year lifetime and probably would last a lot longer.

Newer modules may or may not have such long lifetimes because new innovations are being incorporated into modules that reduce costs and boost performance. It can take years of experience before confidence in these innovations can be established. It is impractical to wait thirty years to

validate these innovations and probably not necessary. However, when new technologies are deployed, it probably would be worthwhile to periodically test these modules to make sure they are fulfilling their claims. This requires sound initial testing and a well-documented procedure to validate performance once in a while. Instrumentation and procedures are now becoming available that can provide these results.

6. ACKNOWLEDGEMENTS

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