Module Characterization
Temperature Response of FS Series 4V3 PV Modules

Purpose

The information presented in this document provides supplemental information about the performance of First Solar FS Series 4V3 PV modules at different temperature conditions. The data is intended to support the proper design of systems using FS Series 4V3 PV modules as well as the development of more accurate models for energy prediction.

Scope

All data reported in this document are based on measurements of a population of modules which represents the range of First Solar Series 4V3 products. This data will be updated periodically and without notice to best represent the current module production as First Solar continues on a roadmap to higher efficiencies. Some variation of temperature response among sample modules of the same rated power is normal, and to be expected. Typical variance of temperature coefficients is in the range of +/- 0.04%/°C.

Results

To a first approximation, the electrical parameters of FS Series 4V3 modules vary directly with module temperature. Good estimates of module performance can be obtained using temperature coefficients which are determined by performing linear regressions on the measured responses $\mathbf{P_{MPP}}(\mathbf{T_{MODULE}})$, $\mathbf{V_{OC}}(\mathbf{T_{MODULE}})$, etc., where $\mathbf{T_{MODULE}}$ varies over the range of expected operating temperature for a specific climate, array orientation, and mounting method. The temperature coefficients reported for $\mathbf{P_{MPP}}$, $\mathbf{V_{OC}}$, and $\mathbf{I_{SC}}$ on the First Solar datasheet for FS Series 4V3 products (document PD-5-401-04-3) are based on an operating temperature range of 25°C to 75°C, which is appropriate for many installations of FS Series 4V3 PV modules using a variety of orientations and mounting methods.

At module operating temperatures of less than 25°C, the temperature dependence First Solar Series 4V3 module output differs from that seen in the 25-75°C range. As a result, use of the temperature coefficients illustrated in this document may not be suitable for applications of First Solar Series 4V3 products in low-temperature climates. It is the system designer’s responsibility to determine the expected module operating temperature range for a particular application. This process includes consideration of local climatic conditions, module orientation, and module mounting details.

Modification of the nominal of temperature coefficient values may be necessary to obtain the best estimate of module output and energy yield for applications in which a significant portion of annual operation occurs with module temperatures less than 25°C.

It is also important to examine the behavior of $\mathbf{V_{OC}}$ with temperature in order to evaluate the maximum system voltage in worst case design conditions and ensure that it remains below the inverter’s maximum input voltage. The dependence of V_{OC} upon temperature is shown in Figure 5.

Table 1 summarizes the relative performance of First Solar Series 4V3 PV modules at three different operating temperatures, and also provides the temperature coefficients for the primary electrical parameters of the module. The temperature coefficients are provided at the operating temperatures 45°C (approximately equal to the normal operating cell temperature, or NOCT) and 65°C.

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FS Series 4V3		Relative Electrical Ratings				Temperature Coefficient	
		1000W/m2			800W/m2	45°C	65°C
		25°C	45°C	65°C	45°C	%/°C	%/°C
P_{MPP}	W	100.0%	95.2%	89.5%	75.9%	-0.28%	-0.29%
V_{OC}	V	100.0%	94.5%	89.2%	93.4%	-0.29%	-0.29%
V_{MPP}	V	100.0%	94.4%	87.7%	94.5%	-0.28%	-0.31%
I_{SC}	A	100.0%	100.9%	101.6%	80.0%	0.04%	0.03%

Table 1. Relative performance and temperature coefficients of First Solar FS Series 4V3 PV modules.

This table also illustrates the relative performance of the modules when they are operated at an irradiance level of 800W/m^2 and a module temperature of 45°C. Such conditions are more common in actual module operation than are the standard reporting conditions (1000W/m^2 irradiance & 25°C module temperature). Ratings at these more common conditions provide a good estimate of typical module parameters observed in the field.

Figures 1 and 2 provide I(V) and P(V) (Power vs. Voltage) curves which have been normalized to the PV modules' performance at the standard reporting condition of 1000W/m^2 irradiance and 25°C module temperature, and correspond to the conditions specified in Table 1. It is clear from the curves that like most PV modules, the temperature dependence of FS Series 4V3 PV module output is dominated by changes in the voltage developed by the module.

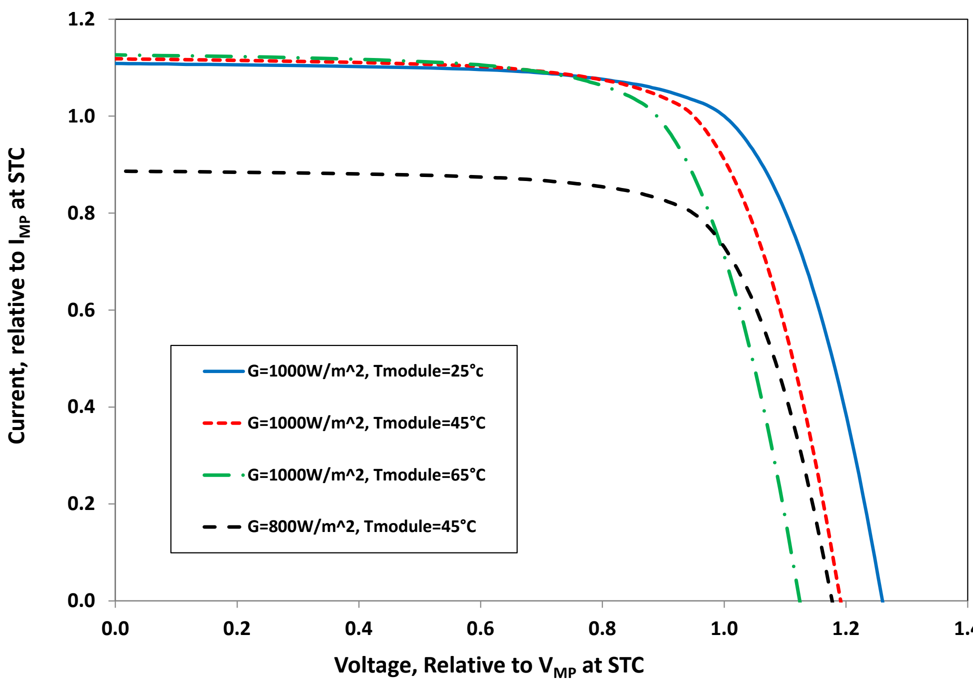

Figure1. Normalized I(V) curves of FS Series 4V3 PV modules operating with module temperatures of 25°C, 45°C, and 65°C and a total irradiance of 1000W/m^2. The I(V) curve for modules operating at 45°C with a total irradiance of 800W/m^2 is also shown.

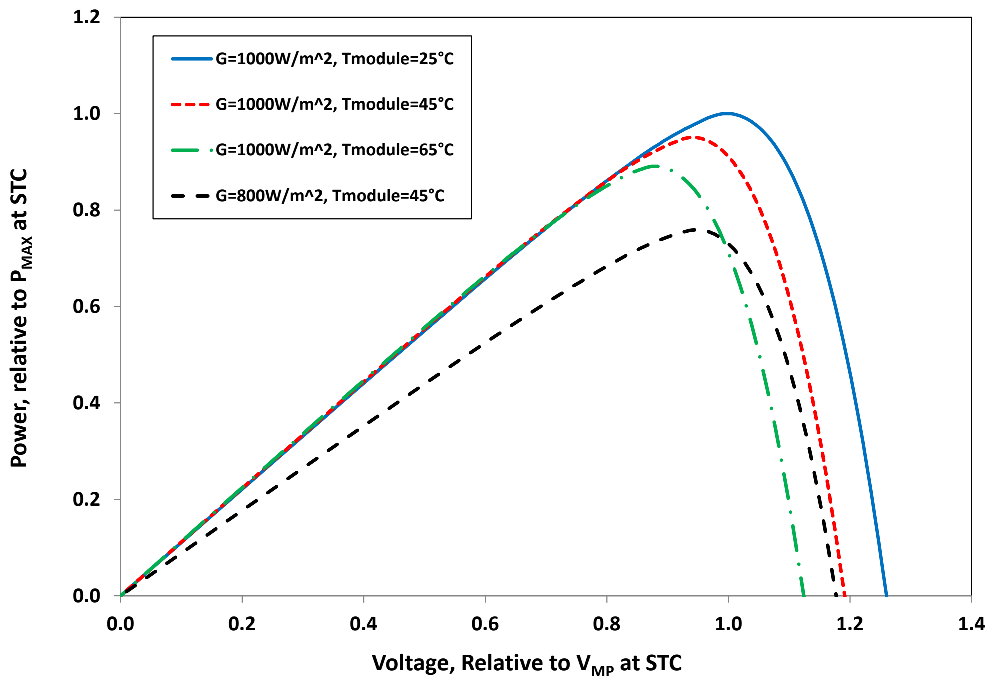

Figure2. Normalized P(V) curves of FS Series 4V3 PV modules operating with module temperatures of 25°C, 45°C, and 65°C and a total irradiance of 1000W/m². The P(V) curve for modules operating at 45°C with a total irradiance of 800W/m² is also shown.

While the curves in Figures 1 and 2 provide an indication of the overall changes in the performance of FS Series 4V3 PV modules with temperature, the temperature-dependence of specific electrical parameters are individually shown in the Figures 3-8.

Figure 3 shows the relative maximum power output $\mathbf{P_{MPP}}$ of the module, as a function of temperature. In order to estimate an effective linear temperature coefficient, a least-squares linear fit is made to the data over the temperature range of 25-75°C, and is illustrated in Figure 4.

Figure 5 shows the dependence of $\mathbf{V_{OC}}$ on module temperature over an operating temperature range of 15°C to 75°C. A least-squares linear fit is sufficient to predict $\mathbf{V_{OC}}$ response over the entire range of temperature.

The temperature-dependence of FS Series 4V3 PV module maximum power voltage $\mathbf{V_{MPP}}$ (Figure 6) shows very slight curvature, with a response similar to that shown in Figures 3 and 4 for $\mathbf{P_{MAX}}$. As was the case in Figure 4, a least-squares linear fit is made to the data over the temperature range of 25-75°C in order to estimate the effective linear temperature dependence of $\mathbf{V_{MPP}}$.

The short circuit current $\mathbf{I_{SC}}$ of FS Series 4V3 PV module shows a weak positive correlation with module temperature and is slightly non-linear. Figure 7 illustrates the temperature dependence of $\mathbf{I_{SC}}$.

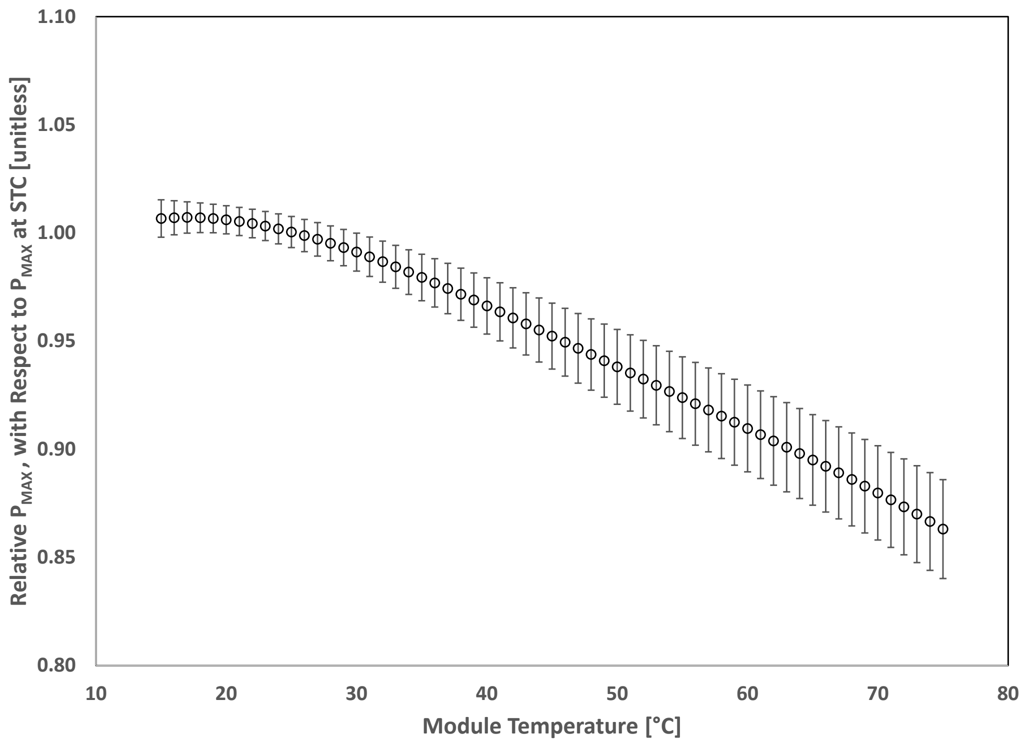

Figure 3. Dependence of maximum power (P_{MAX}) of FS Series 4V3 PV modules on module temperature. Error bars denote +/- two standard deviations about the mean response of the sample population.

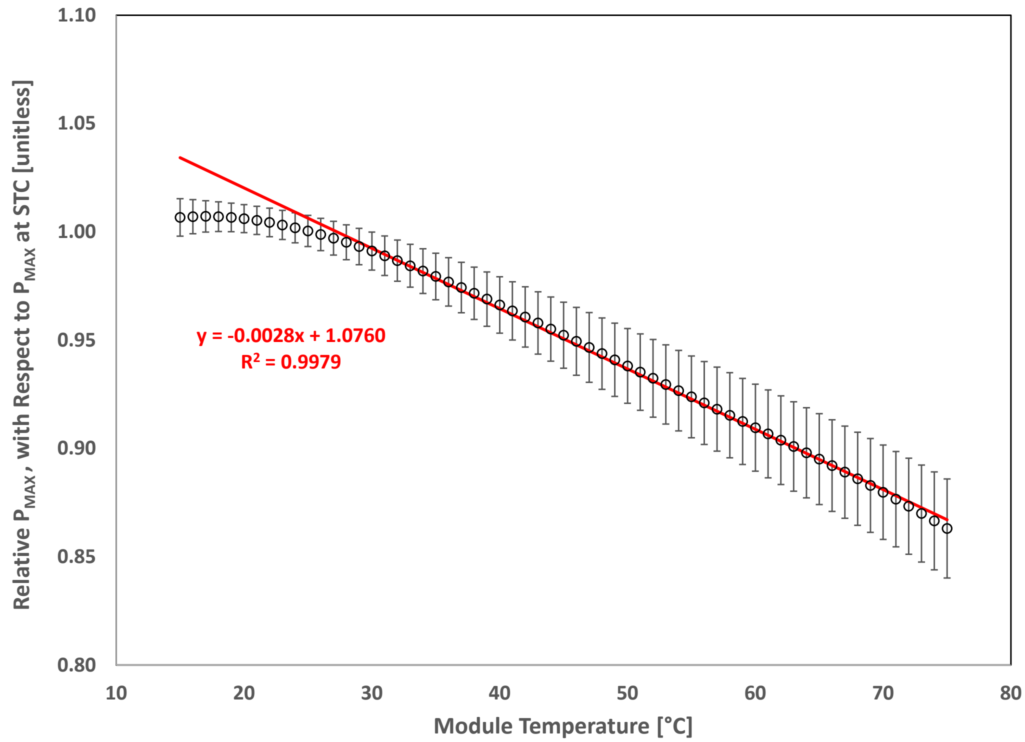

Figure 4. Linear least-squares fit made to FS Series 4V3 PV modules P_{MAX} over the operating temperature range 25-75°C.

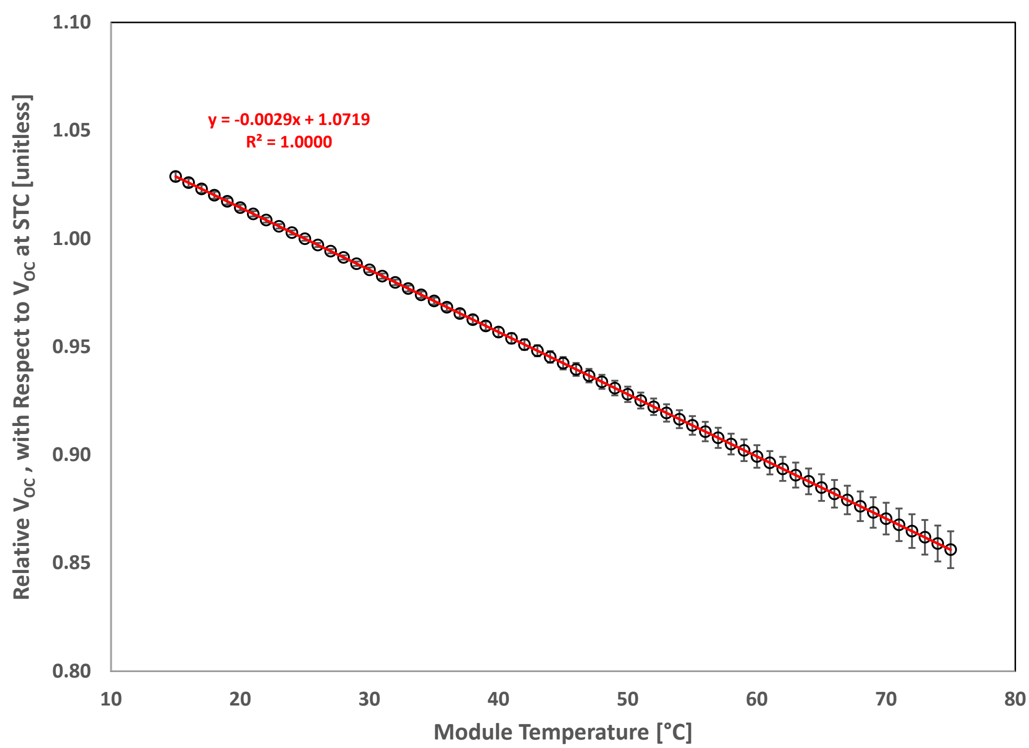

Figure 5. Dependence of open circuit voltage (V_{OC}) of FS Series 4V3 PV Modules on module temperature. . Error bars denote +/- two standard deviations about the mean response of the sample population. A linear fit is adequate to predict V_{OC} over the entire temperature range.

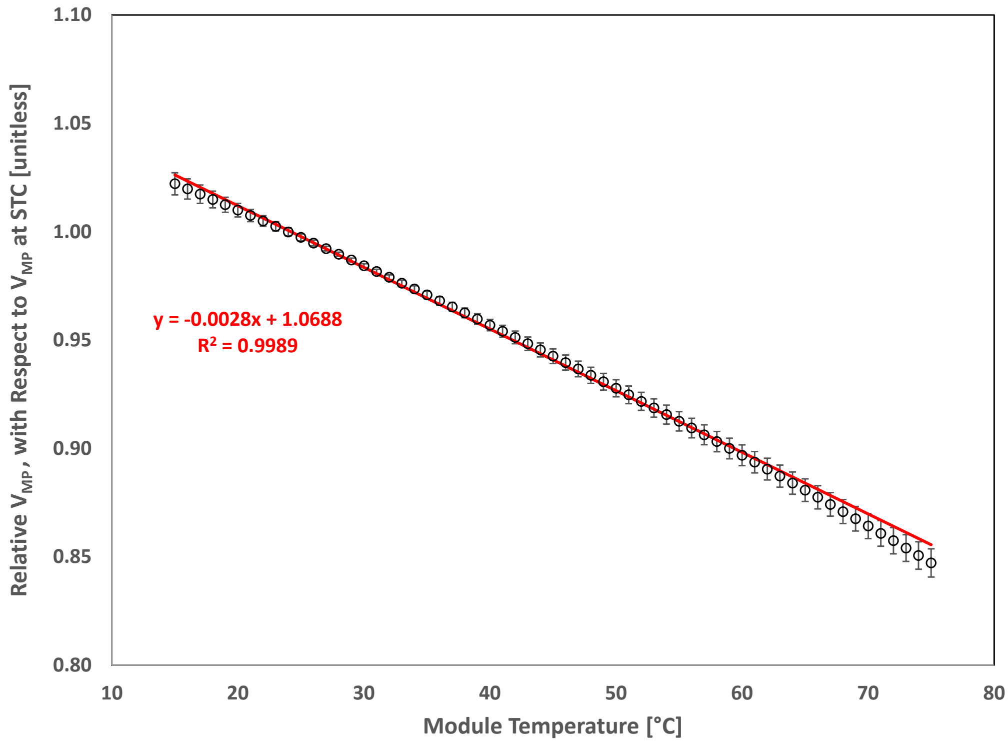

Figure 6. Dependence of maximum power voltage (V_{MPP}) of Series 4V3 PV Modules on module temperature. A Linear fit is made for the temperature range 25-75°C. Error bars denote +/- two standard deviations about the mean response of the sample population.

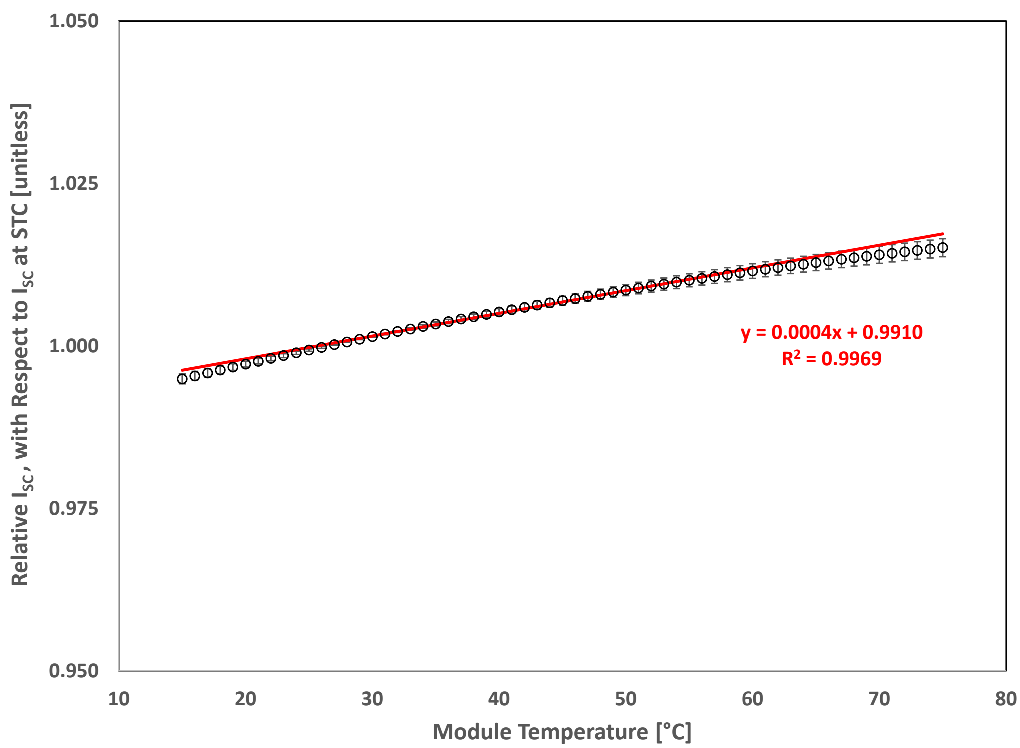

Figure 7. Dependence of short circuit current (I_{SC}) of Series 4V3 PV Modules on module temperature. A linear least-squares fit is made for the temperature range 25-75°C. Error bars denote +/- two standard deviations about the mean response of the sample population.