



TECHNICAL REPORT

SHADING

Photovoltaic panels based on crystalline silicon cells are sensitive to shading. The cells are connected in series, so the same current flows through all the cells. If a cell is shaded, it stops producing energy and behaves like a resistor, strongly decreasing the energy production of the entire panel. To avoid, or better, to mitigate this problem, bypass diodes are used in panels as an alternative path for the current that cannot flow through shaded cells. Another important task of bypass diodes is to decrease the risk of hot-spots.

To understand the effect of shadowing and the behavior of panels with bypass diodes, let's consider two SP100 connected in series as example. The SP100 is a panel composed of 32 SunPower cells in four strings (column), and its nominal electric parameters are: $P_{max} = 102 \text{ W}$, $V_{oc} = 21.8 \text{ V}$, $V_{mp} = 18 \text{ V}$, $I_{sc} = 6 \text{ A}$, $I_{mp} = 5.7 \text{ A}$.¹ It contains two bypass diodes, one for the 16 cells on the first and second string and the other for the third and fourth string.

By connecting in series two equal panels we expect to double the voltage and the power, leaving the current unaffected.

The series of two SP100 is measured with a sun simulator in different shading conditions.

¹ V_{oc} = Opens Circuit Voltage
 V_{mp} = Voltage @ Maximum Power
 I_{sc} = Short Circuit Current
 I_{mp} = Current @ Maximum Power

1) Two SP100 in series without shading

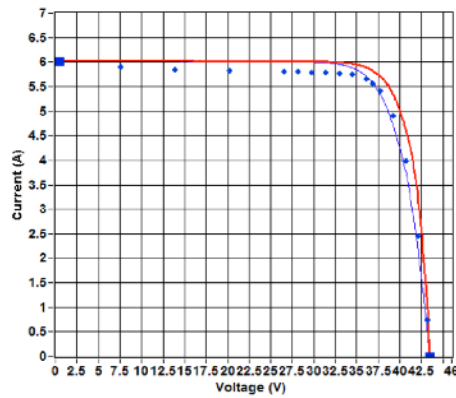


Test equipment: SUN GEN FMT-350



Device ID: 2xSP100 Device Temperature: 19.83 C
 Cell Area: 153.00 cm² Number of Cells: 64

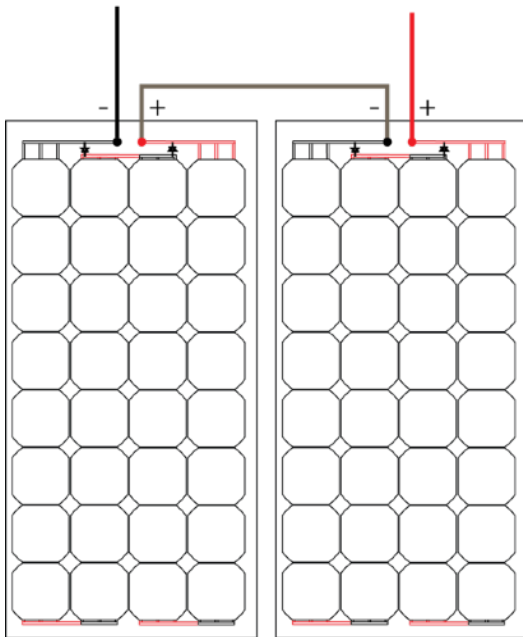
Jsc, Voc IV Points Suns-Voc Modeled



| | |
|--|--------------------------------|
| V _{oc} = 43.4734 V | I _{mp} = 5.58 A |
| I _{sc} = 6.02 A | V _{mp} = 35.81 V |
| J _{sc} = 6.02 A/cm ² | P _{nc} = 205.39 W |
| Fill Factor = 78.46 % | Efficiency = 20.98 % |
| R _s = 0.28 Ohms | R _{sh} = 1859.59 Ohms |

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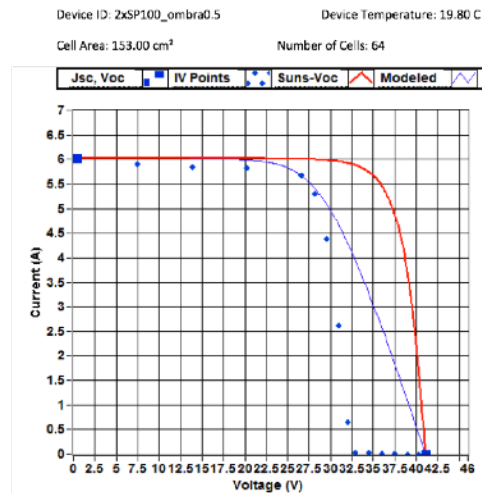
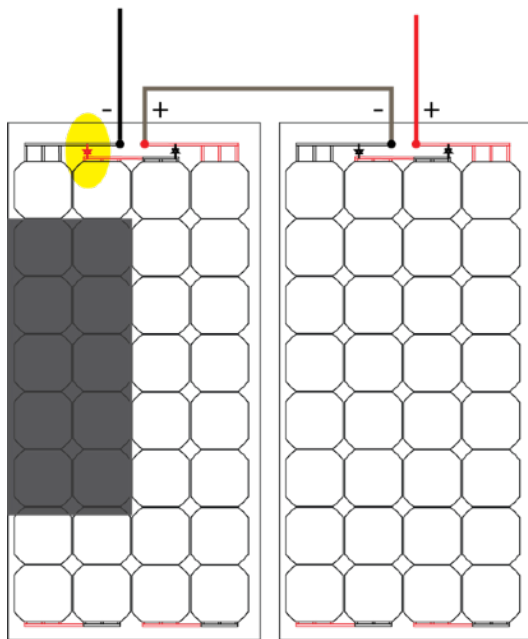
The 2 panels are working as expected: Pmax, Voc and Vmp are the double of the single panel values



2) Partial shading on the left rows of one SP100



Test equipment: SNT100 FM1-350



| | |
|------------------------------|--------------------------------|
| $V_{oc} = 41.0347 \text{ V}$ | $I_{mp} = 5.68 \text{ A}$ |
| $I_L = 6.03 \text{ A}$ | $V_{mp} = 26.54 \text{ V}$ |
| $J_L = 6.03 \text{ A/cm}^2$ | $P_{mp} = 150.70 \text{ W}$ |
| Fill Factor = 60.95 % | Efficiency = 15.39 % |
| $R_s = 1.48 \text{ Ohms}$ | $R_{sh} = 840.14 \text{ Ohms}$ |

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The shaded strings do not produce energy and thus their bypass diode is activated. The open circuit voltage is close to the sum of the two V_{oc} , as it must be when there is no current flow, but the V_{mp} is 75% of the sum of the V_{oc} , namely it correspond to one full panel + the half of the other panel. The highlighted bypass diode is activated and the two left rows are not contributing to the voltage and to the power, which is precisely 150 W (75% of the total power of the two panels).

A partial shading could give rise to any voltage² value between the 75% and 100% of the maximum value, namely, between 27 and 36 volt.

² We are considering values at standard condition, namely at 25°C of temperature. With higher temperature (the usual working condition) the values can be smaller, but the ratio between shaded and not shaded panel electric values remain the same.



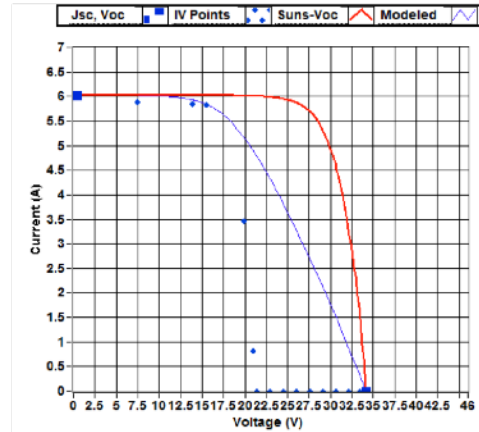
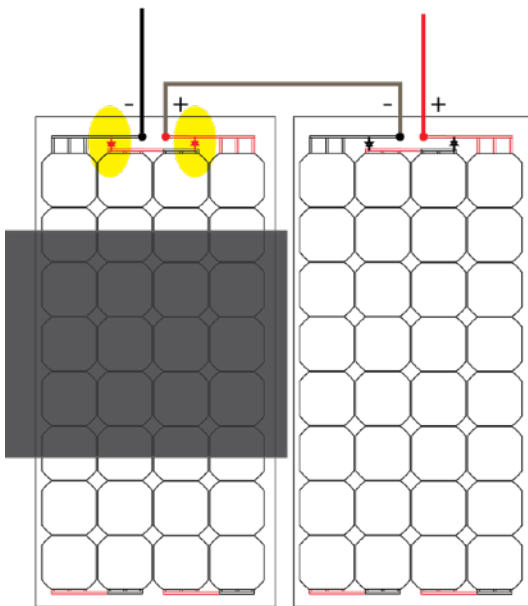
3) Shading on both strings of SP100 (which means total shading)



Test equipment: SNTON FMT-050



Device ID: ZxSP100_ombra1 Device Temperature: 19.83 C
 Cell Area: 153.00 cm² Number of Cells: 64



| | |
|--------------------------------|-------------------------------|
| $V_{oc} = 34.1165 \text{ V}$ | $I_{mp} = 5.84 \text{ A}$ |
| $I_{sc} = 6.03 \text{ A}$ | $V_{mp} = 15.43 \text{ V}$ |
| $J_{sc} = 6.03 \text{ A/cm}^2$ | $P_{mp} = 90.17 \text{ W}$ |
| Fill Factor = 43.85 % | Efficiency = 9.21 % |
| $R_s = 1.86 \text{ Ohms}$ | $R_{sh} = 48.47 \text{ Ohms}$ |

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The two bypass diodes are activated, the entire shaded panel is not working but the current flow is ensured by the two diodes. Power and V_{mp} are concerning the other panel, with a slightly voltage (and power) drop due to the diodes resistance.

