Performance and safety aspects of PV modules under partial shading: A simulation study

E.E. Bende, N.J.J. Dekker, M.J. Jansen
ECN, P.O. Box 1, 1755 ZG Petten, the Netherlands; bende@ecn.nl; Tel. +31 88 5154122; Fax +31 88 5158214

Introduction
Wohlgemuth et al. [1] noticed that the worst-case power dissipations were not covered by the existing IEC 61215 hot spot test and therefore they proposed a new improved methodology to determine which cells in a module should be tested and what fraction of a cell shall be shadowed. This work corroborates the experimentally demonstrated worst-case power dissipations and the conditions under which they can occur by the use of electronic circuit simulations.

Purpose of the work
This works helps to better understand the behaviour of PV modules under partial shading and the consequences for safety, reliability and performance. It can be useful for the determination of module and cell specifications and it can help in defining better test procedures for future cells and modules.

Approach
We used the electronic-circuit simulator package SPICE to simulate a PV system. We have limited ourselves to shade scenarios where only one cell in the system, comprising 20 conventional 60-cells modules, was shaded. We assess the module and system power as well as the dissipated power of the shaded cell for different operating conditions as well as for different break-down voltages, shunt resistances and shadow fractions.

Scientific innovation and relevance
This work shows that an unfavourable combination of shading conditions, module lay-out and solar cell properties can lead to a power dissipation amounting to 95W per cell. This can bring about irreversible module damage and might even lead to fire. Obviously, this poses a safety and a module reliability problem to manufacturers and confirms the need for a modified standard of the IEC 61215 hot spot test.

Results and conclusion
• Power dissipations up to 95W poses a great safety and reliability problem, particularly if this dissipation occurs in local hot spots.
• Solar cells with a high shunt-resistance and a high break-down voltage (i.e. higher than the voltage of the string) show a maximum dissipation point (MDP) at a shading fraction between 15 and 18%.
• Solar cells with low shunt-resistances and high break-down voltages show a maximum in power dissipation plateau at high shading fractions.
• These results are qualitatively in agreement with the experimental observations of Wohlgemuth et al. and confirms the need for a modified standard of the IEC 61215 hot spot test.
• For solar cells with high shunt-resistances and high break-down voltages, the power dissipation in the shaded cell is proportional to the cell’s photon current, up to the MDP. For cells with a high shunt-resistance, but with a low break-down voltage, the power dissipation is lower but is then independent of the shaded cell’s photon current. In practice this means that the power dissipation in the latter case in dependent of the shading fraction.
• In case of partial cell shading, power optimization on module level (e.g. micro-inverters) is favourable compared to power optimization on system level both from the viewpoint of performance and safety. In the former case and for cells with high break-down voltages, shaded cells get into reverse at higher shade fractions and the dissipated power is considerably less.
• Since the PV market develops towards production of high efficiency cells (usually with high shunt-resistances), one needs to realize that these cells are more vulnerable to low shadow fractions (soiling, bird droppings etc.) and inter-
cell mismatches. This might require innovative solutions like parallel connections, small cells, and hence low-currents, as well as low break-down voltages to prevent undesired high dissipation occurrences.