NOVEL ELECTRICAL APPROACH TO PROTECT PV MODULES UNDER VARIOUS PARTIAL SHADING SITUATIONS

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1. Introduction

PV modules are highly sensitive to partial shading conditions. Partial shading over a PV module can be generated by consistent shadings such as placement of obstacles on the active area of the module or by partial shading during different time of the day such as shadow of a chimney over a PV module. Partial shading can influence the performance, lifetime, reliability and energy yield of PV modules depending on type, duration and pattern of the shade. In the most extreme case, hot-spots form in shaded PV modules which lead to the failure of the PV modules. To avoid hot-spots, every 20-24 solar cells in series (one string) are protected by a bypass diode in a standard PV module. Since the current of each string is limited to the shaded solar cell, by shading of one solar cell 33.3% of module power will be affected. In this work, a novel interconnection design is developed for PV modules to increase the reliability, power and energy yield of PV modules under different partial shading conditions. In this approach, instead of using one bypass diode for every 20-24 solar cell, every individual solar cell is protected by bypass diodes to reduce the power loss and chance of hot-spots in PV modules.

2. Experiment and simulation

A 60-cell hot-spot free and a standard PV module designs are measured by Sun Simulator. The modules are fabricated from identical materials and solar cells. The only difference is in hot-spot free module, each solar cell is protected by a bypass diode while in standard module, and every 20 solar cell is protected by one bypass diode. Different shading patterns are applied to the PV modules in different sizes and directions. The modules are measured when just one solar cell is shaded from 0% to 100% (see Fig.1). Then, one row of solar cells located in different strings and finally multiple rows in both modules are shaded step by step and then measured and simulated by sun simulator and SPICE.

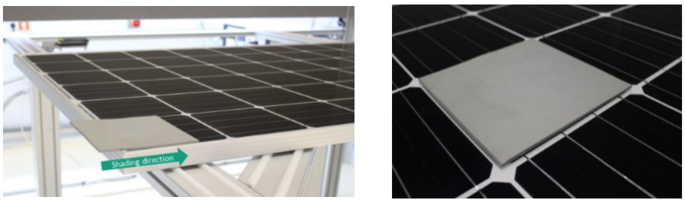

Fig.1. The shading direction and the shading object on a solar cell of a standard module (left) and a top view of a totally shaded solar cell of a hot-spot-free module by the shading object under sun simulator (right).

To ensure the reliability of the hot-spot free module, especially by considering the thermal expansion due to the high temperature of the module under partial shading conditions, a new testing setup is developed to measure the electrical properties and temperature of the module by switching the bias voltage and powering the module in forward and reverse bias.

3. Results

a) Partial shading conditions

The modules are shaded under partial shading conditions.

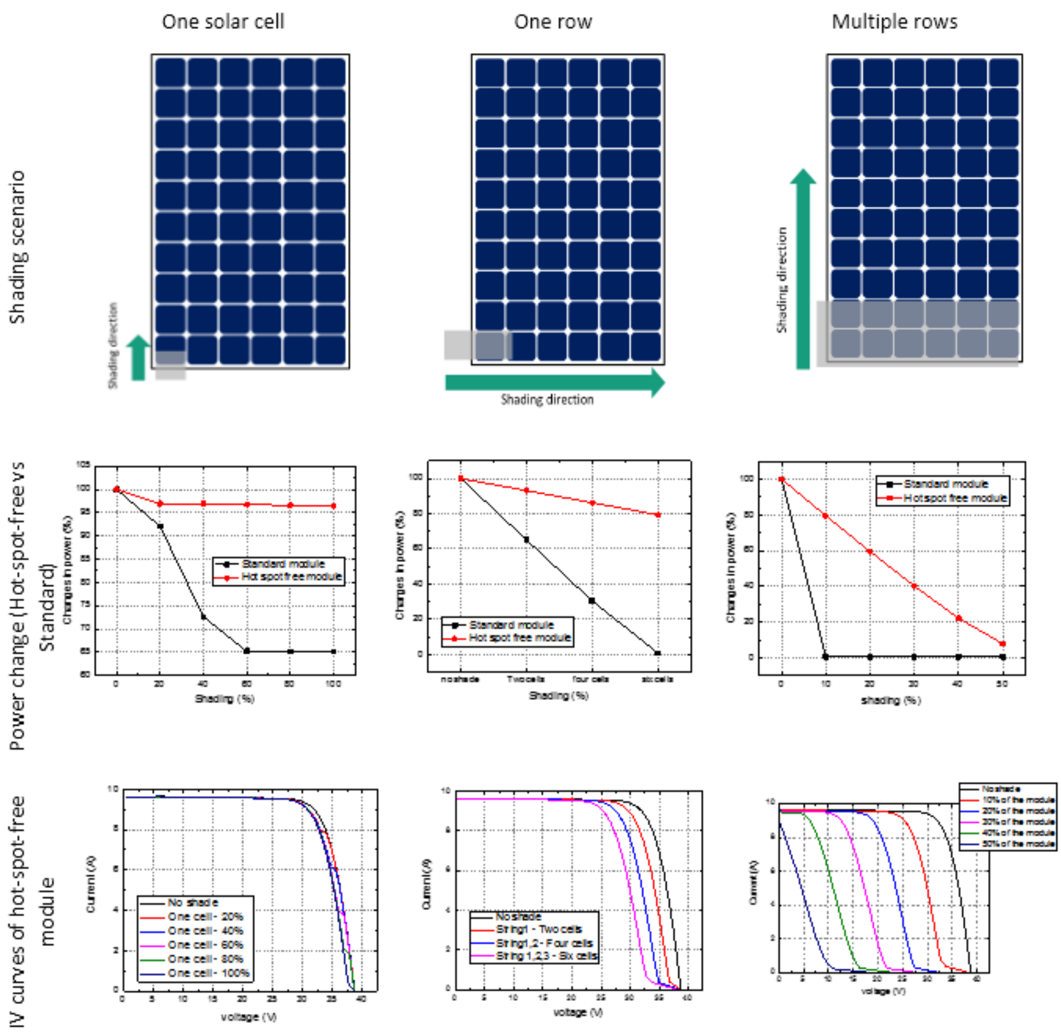

Fig.3. Comparison of shading scenarios, power change comparison in hot-spot free module and standard module and IV curve of hot-spot free module under different shading scenarios

The electrical measurement results with partial shading conditions show 32% and 80% extra power of hot-spot free module compared to the standard module by referencing the non-shaded module under partial shading conditions. By shading multiple rows, the standard module produce no power after shading of just 10% of the module while the hot-spot free module can produce power when almost 50% of the total module is shaded.

b) Stress test of hot-spot free module

To ensure the reliability of the module, the modules are tested in frequent switching between reverse and forward bias. In forward bias, the solar cells are in operation while in reverse bias the diodes are working. The PV modules are tested in 10000 cycles of 60 seconds in each direction. The IV measurement show 0.38% deviation from reference module before stress test and the EL test after the experiments show no visible defects on the module.

Conclusion

The results show that hot-spot free module with integrated bypass diodes for every single solar cell increases the performance and reliability of the module. In three different shading scenarios, the module show 32%, 80% extra power compared to standard module with reference of not shaded module under shading conditions of one solar cell, and one row. The hot-spot free can produce power even when almost 50% of total module area is shaded. We also show that the extra bypass diodes do not affect the reliability of the module and changes in power after 10000 bias cycles are below 1%.