

OPERATIONAL BEHAVIOUR OF COMMERCIAL SOLAR CELLS UNDER REVERSE BIASED CONDITIONS

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ABSTRACT: The operational behaviour of 6 crystalline cell types was investigated under reverse biased conditions. These conditions occur within the interconnection circuit of modules when cells are mismatched or totally or partially shadowed, possibly leading to thermal overload (hot-spot heating). This study is focused on the electrical as well as the thermal characterisation of solar cells that are operated under the reverse biased conditions. This includes: a) measurement of the reverse IV-characteristics that are subject to a characteristic scattering, b) thermal imaging of individual cells at a constant reverse voltage of -10V to detect the distribution of leakage current, and c) detection of the critical reverse voltage for a cell type for which thermal breakdown of the semiconductor material occurs. From the results conclusions are drawn with regard to a test procedure for hot-spot safety testing in which the most critical cell in a module is selected by measurement of the reverse current. Finally on the basis of the measurements the effectiveness of bypass diode concepts in modules is discussed.

Keywords: PV-Modules - 1: Qualification and Testing - 2: Safety - 3

1. INTRODUCTION

The ability of a PV module to withstand the effects of periodic hot-spot heating that occurs when cells are operated under reverse biased conditions is one of the quality characteristics that are verified within IEC qualification testing [1,2]. The extent of hot-spot heating of solar cells is closely related to the properties of the semiconductor material. Locally concentrated shunt defects are caused by non-uniformity. The extent of defects is correlated with the slope of the reverse IV-characteristic.

Fundamentals on hot-spot heating are discussed in [3]. This publication also refers to the fact that the reverse IV characteristics of solar cells are subject to more or less distinct scattering that is specific for a cell type. Figure 1 illustrates this matter for a sample of 10 mono-crystalline cells. With increasing reverse voltage in the case of 3 cells thermal breakdown occurs that is indicated by a breakdown of voltage and a corresponding increase of current. A thermal breakdown of the semiconductor material means that the current is highly locally concentrated, causing point focal heating. To avoid this operating condition, the reverse voltage at a cell within the cell interconnection circuit of modules must be limited by use of a bypass diode. In the case of standard sized modules, bypass diodes concepts of 18 to 24 cells per bypass diode are commonly used, yielding a maximum reverse voltage in the range -10 V to -13 V.

On the basis of these facts in [3] a simplified test procedure for hot-spot safety testing was proposed using the assumption that the worst hot-spot cell which is the cell with the highest concentration of leakage current is correlated with the upper bound of the reverse IV characteristics (Figure 1: upper bound cell). If so, the worst case cell can easily be identified by current measurement at a constant reverse voltage.

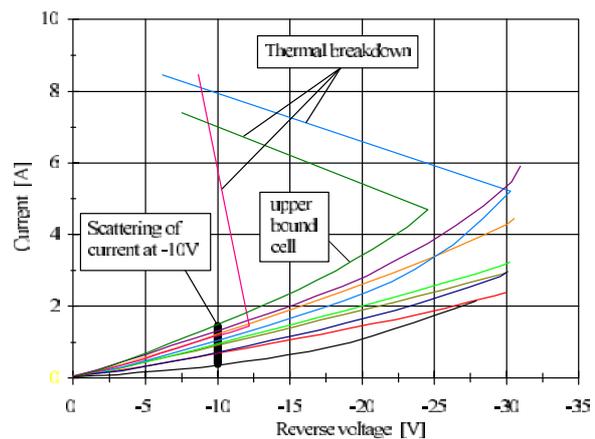


Figure 1: Set of reverse IV characteristics for a batch of 10 mono-crystalline cells (cell type: Astro Power)

In connection with reverse biased operating conditions this study is focused on the following points:

- To identify the cell parameters for a comprehensive description of the electrical and thermal operational behaviour. The knowledge of these parameters is important for design of effective bypass diode concepts in modules. A limited database for 6 cell types will be presented
- To discuss the applicability of the simplified method to select the worst case hot-spot cell in a module. The selection of this cell is the first step of hot-spot safety testing.

2. EXPERIMENTAL APPROACH

As the thermal and electrical operational behaviour of cells under reverse biased conditions is subject to a more or less dispersion it is necessary to investigate a batch of cells to characterise the cell type. A number of at least 10 test samples will lead to a statistically significance. The following test program was elaborated:

- The reverse IV characteristics are measured in the dark by means of an electronic power supply. The measuring time is approx. 5 sec, so that heating effects could be neglected. If thermal breakdown occurs this condition is temporally limited so as to prevent irreversible damages of the cells. For electrical characterisation of the cell type the scattering of the set of reverse IV characteristics is noted.
- For thermal characterisation of the cell type infrared (IR) images of all cells of the batch are taken at a fixed reverse voltage of -10 V applied constantly to the cell. From a practical point of view, this voltage corresponds approx. to the max. reverse voltage for a bypass diode concept of 18 cells per diode. The amount of power dissipation depends on the respective reverse current. From these measurements non-uniformity of the current density can be identified. Peaks in the temperature distribution correspond to concentrations of leakage current. The max. observed cell temperature is taken to be a characteristic of the cell type.
- A second parameter for electrical characterisation is the critical reverse voltage at which thermal breakdown occurs. The critical reverse voltage is the lowest breakdown voltage for the whole batch of cells. Measurement is performed as follows: Starting from ambient conditions, the reverse voltage is increased slowly so that the cell is heated up continuously. At thermal breakdown of the semiconductor material the current is limited to the value of the short circuit current I_{SC} at STC, which is the highest current to be expected in practice. Possibly this measurement will lead to irreversible cell damage causing a change of electrical reverse parameters. Accordingly, this is the final measurement for cell characterisation.

Manufacturer	Cell type	Cell size	crystalline structure
ASE	EFG	4 inch	mc-Si
Astro Power	AP 106	6 inch	cz-Si
Kyocera	PSC100	4 inch	mc-Si
Kyocera	PSC150	6 inch	mc-Si
Photowatt	PWP4CP3	4 inch	mc-Si
Siemens	Powermax	5 inch	cz-Si

Table 1: Commercial cells used for the measurements

Table 1 gives a survey of the 6 commercial crystalline solar cells that were subjected to the test program. To avoid any abnormal influence by the soldering or melting of cell connectors on the measurements, only cells with tabbing

were used. For this purpose commercially manufactured cell strings of 10 cells were cut.

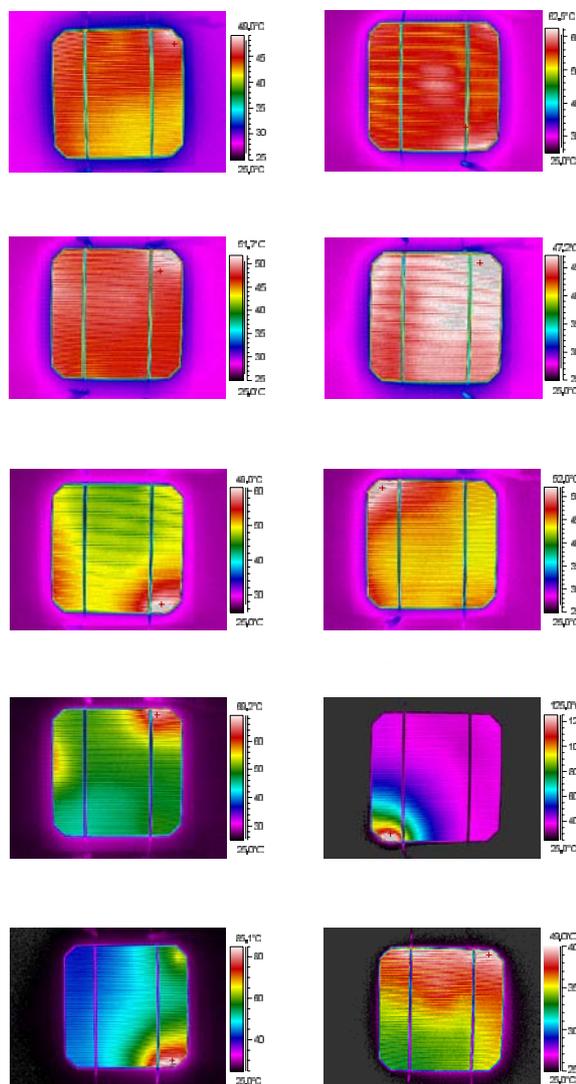


Figure 2: Thermal images of a batch of 10 mono-crystalline cells of type Astro Power taken at -10V reverse voltage

3. RESULTS

As an example, figure 1 shows the measured set of reverse IV characteristics of the 6 inch mono-crystalline solar cell AP106 from Astro Power. The dispersion of power dissipation at -10V reverse voltage is in the range of 5W to approx. 14W. The corresponding thermal images for the batch of cells are shown in figure 3. In the case of 4 cells a local concentration of the current density tends to appear in the cell corners. The max. cell temperature of 125°C was measured at cell no. 8 (worst case cell). For this cell a max. temperature difference of 88°C across the cell was measured. Cell no. 8 also showed also the lowest reverse voltage at which breakdown occurred (-12.6 V). Against this the upper bound cell no. 9 assumed rank 2 with regard

to max. cell temperature (85°C) and rank 2 with regard to thermal breakdown (-24 V).

Also the infrared images of the other cell types confirm that the leakage current at reversed biased conditions is individually distributed across the cell area at which the no. of local concentrations of leakage current is up to 4 in the corners and the edges. For each cell type the critical reverse voltage for thermal breakdown as well as the worst case cell parameters for continuous operation at -10 V are summarised in table 2. The max. no. of cells bridged by a bypass diode is approx. given by the expression: critical reverse voltage/0.5 V. For the Photowatt cell for example only 14 cells will be effective.

Table 3 shows the ranking of the cell that corresponds to the upper bound of reverse IV characteristics. In the case of 4 cell types investigated the cell with the highest reverse current at -10V was identified to be the most sensitive to thermal breakdown.

In figure 4 the max. cell temperature for all cells is plotted against the reverse current measured at -10V. Corresponding to the results of table 2 the diagram shows that in the case of 3 cell types the worst case cell corresponds to the upper bound cell. For the other cell types occasionally one cell shows a more intensive heating effect.

A comparison of the results of 4 inch and 6 inch polycrystalline cells of type Kyocera shows that the electrical behaviour under reverse biased conditions and the thermal images at -10 V are similar and that there is no negative effect due to cell size.

4. CONCLUSIONS

For all cell types the reverse voltages at which thermal breakdown occurs is spread over a wide voltage range and is specific to a cell type. To achieve complete protection against thermal overload due to hot-spot heating, the bypass diode concept in modules should be designed according to the critical reverse voltage. Because there is a lack of information about this cell, manufacturers should also provide information about the reverse operational behaviour of their cells.

There are no indications that measuring large 6 inch solar cells have a worse reverse operation behaviour compared to 4 inch cells. Accordingly, the bypass diode concept in modules need not be modified relative to smaller cells.

With a probability of approximately 0.5 in the case of reverse biased conditions the worst cell with respect to max. cell temperature is the upper bound cell of figure 1. Accordingly, the method to select the worst case hot-spot cell by current measurement at constant reverse voltage as proposed in [3] can only be used with restriction. Extension of the presented data base is necessary in order to achieve final conclusions.

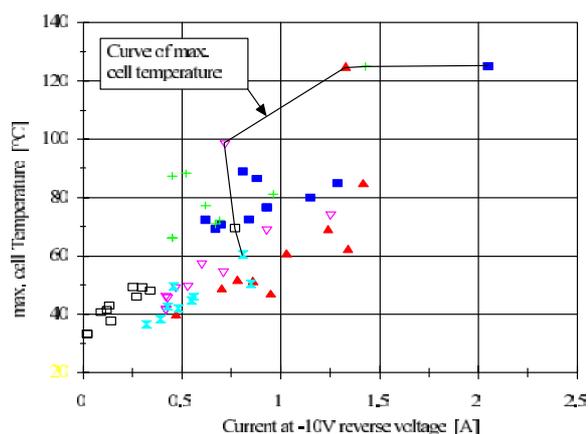


Figure 3: Max. cell temperatures plotted versus the measured reverse current at -10V

Cell type	critical voltage for thermal breakdown	worst case cell parameters at continuous operation at -10V	
		T _{MAX}	I _{-10V, dark}
ASE-EFG	-10.4V	125°C	2.05A
Astro Power	-12.6V	125°C	1.33A
Kyocera 4"	-15.2V	98°C	0.72A
Kyocera 6"	-25.2V	61°C	0.81A
Photowatt	-7.2V	125°C	1.43A
Siemens	-21.1V	70°C	0.77A

Table 2: Summary of test results from thermal imaging and thermal breakdown measurements

Cell type	ranking of the upper bound cell	
	Ranking A	Ranking B
ASE-EFG	1	2
Astro Power 6"	2	2
Kyocera 4"	2	1
Kyocera 6"	2	-
Photowatt	1	1
Siemens	1	1

Table 3: Ranking of the cell that corresponds to the upper bound of reverse IV characteristics (A: max. temperature ranking, B: thermal breakdown ranking)

REFERENCES

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