PORTABLE LED FLASHER WITH IMPLEMENTED BYPASS DIODE TESTER

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ABSTRACT: A new LED based photovoltaic module flasher is presented to perform nominal power measurements at 1000W/m^2 within a flash period of 10ms, together with low light measurements. Additionally performance tests of the typical 3 bypass diodes of a standard 6" crystalline silicon PV module are performed during three flasher periods within totally 2 seconds. Thus the flasher setup (2.2m x 1.5m x 0.1m, weight 50kg, including power electronics) is placed in a distance of a about five centimeters direct onto the PV module, which remains mounted in the same position as it is operated in the outdoor PV plant. The LED flasher is equipped with 2400 single blue LEDs and 1440 IR LEDs. The total flasher area is divided into twenty individually controlled subsections with an area of 0.13m^2 each. During one flasher period different values of intensity and color composition are able to be controlled independently. Two LED colors are used at 455nm and 850nm. A standard crystalline module is typically divided in three sub-module areas, protected by one bypass diode for each sub-module. Thus the intensity of these three sub-module areas relative to each other is varied. During a single flash up to four different intensity patterns are applied. The complete measurement system was successfully qualified by test sequences performed on standard modules, equipped with different defect bypass diodes. The fast method may also be applied as a new module end test in a production line as well as a new PV field test method performed within a few seconds by the mobile LED flasher.
Keywords: Bypass Diode, PV Module, Module Manufacturing, Electrical Properties, Defects, Crystalline, Qualification and Testing

1 INTRODUCTION

Several methods are available to measure the nominal power P_N of the PV generator of a power plant. Often natural sunlight is used with a relatively high uncertainty of the analyzed nominal power. Infrared inspection is applied to detect a wide range of local faults but without measuring P_N. There are mobile flashers available, which are able to measure P_N with a lower uncertainty close to the values of stationary test labs, but it is necessary to dismantle the modules [1, 7] or without dismantling and the usage of a diggers crane boom [8].

The new developed LED flasher presented here is suitable to measure the nominal power P_N without dismantling the modules operated by two persons (Fig. 1). In addition, the LED flasher is used to verify the correct operation of the modules bypass diodes. The proper functioning of all bypass diodes is imperative. On the one hand these diodes reduce drastic power losses in a typical string operating a partial shaded module or even prevent the string from a total shut down. On the other hand they protect the shaded cells from overheating close to the temperature of delamination, powered by the other non-shaded cells. There are several reasons why bypass diodes do not work correctly. Possible reasons could be a connection problem, an overheating of the diodes [2] due to current flow or lightning [3, 5]. Typically, Schottky diodes are used as bypass diodes in PV modules. Schottky diodes are very susceptible to static high voltage discharges and mechanical stresses. So they must be handled with care and human contact without grounding must be avoided [5]. A solar plant running with modules which have defect bypass diodes could significantly reduce the energy yield. Despite the fact that a defective bypass diode in a PV module may possibly lead to a fire, very little work has been done to detect these defects in an easy and reliable way once installed in a PV system [5]. In Japan 1272 mono-Si PV modules of a power plant have been tested and it was found that 47% of the modules have defect bypass diodes [6].

The correct functionality of the bypass diodes and part of the connections can also be tested by applying a reverse voltage on the modules. But not all necessary connections are tested by measuring the current in this reverse voltage mode. A new method is presented here to test all the relevant electrical connections including the interconnections from the diodes to the string (Fig. 3). The described portable LED flasher is suitable to perform outdoor measurements on ground mounted PV plants as well as flat roof PV installations without dismantling each PV module. Thus the modules are tested disregarding the solar radiation in case of fluctuating weather conditions or even at night. The flasher is also suitable to be run as part of a PV module production lines and indoor laboratories. There are already LED flashers on the market, but they do not test bypass diodes and are typically not able to be easy handled by two persons in the field [7], [8].

Figure 1: LED flasher in operation on a PV power plant, cover profile on the top was removed to show the power electronics on the opposite side of the LEDs

Figure 2: Side view of the LED Flasher in operation, in the upper part of the image the blue LEDs is shown. The solar module is positioned in the lower part of the image.

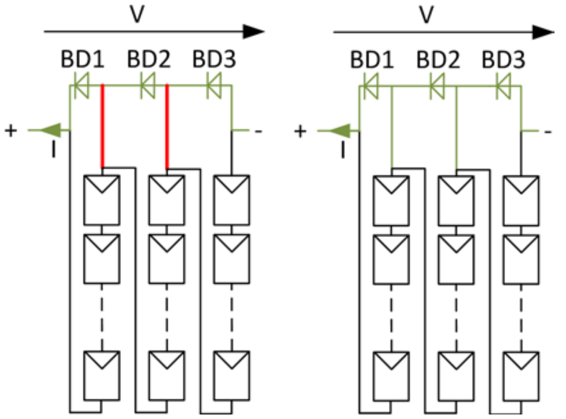

Figure 3: Left: circuit diagram of reverse voltage test of the three module bypass diodes - red coloured electrical connections are not able to be tested. Right: new method described here to test the three bypass diodes including the red interconnectors shown in the left part.

In the following section, we describe the characteristics of the Portable LED Flasher and the four different measurement setups with a focus on the bypass diode measurement setup. Finally, the measurement results of three out of four measurement setups are presented.

2 PORTABLE LED FLASHER SETUP

The setup has an active optical area of 2.00m x 1.27m with 20 subsections. The total dimensions are 2.21m x 1.50m x 0.10m at a weight of 50kg. Totally 2400 blue LEDs and 1440 IR LEDs (Fig 2.) are integrated. The LED's are powered by controlled discharge of several capacitors by 12kW to perform the electrical output of the crystalline silicon module corresponding to 1000W/m^2 irradiance conditions. At a maximum optical power up to 2.8 times of the standard STC (Standard Test Conditions) current of the module is able to be measured within the 10ms flasher period. Using only the blue LEDs 1.2 times and using only the IR LEDs 1.6 times the STC short circuit current I_{sc} of a standard crystalline silicon module is generated (Table I).

Table I: LED flasher characteristics

Active optical area	2.00m x 1.27m
Total dimensions	2.21m x 1.50m x 0.10m
Weight	50kg
Number of LEDs	2400 blue and 1440 IR [10]
Wavelength of LEDs	455nm and 850nm
Power of LEDs	Are able to generate 2.8 times the ISC_{STC} of a crystalline module (blue only: 1.2 times, IR only: 1.6 times)
Number of subsections	Intensity levels of blue and IR LEDs light are controlled for 20 subsections individually
Flash duration	10ms, but expandable to several 100ms
AC Supply	115/230VAC, max. 230W

Four different measuring programs controlled by an ARM Cortex-M3 micro controller are available: Standard I-V, bypass diode measurement, spectral characteristics and low light measurements. The measured data are stored on a standard SD-Card and they are also shown on an integrated small display in order that no external computer have to be used in the regular field measurements.

Two people are needed to handle the flasher onto the modules to be tested (Fig. 1). It can also be used in an indoor laboratory or a production line. The four different measurement modes are described in the following subsections.

2.1 Standard I-V measurement mode

This setup uses a 10ms flash to illuminate homogenously the total module area. During this time, a voltage sweep on the module connection is performed to measure the current-voltage characteristics (I-V curve), the short circuit current, the open circuit voltage and the maximum power point of the module. The intensities of both LED colours are controlled independently. A pause of around 1s is needed between two flashes to recharge the capacitors powering the LEDs.

2.2 Bypass diode measurement mode

The correct connection and the operation of the bypass diodes of a photovoltaic module is tested by applying 3 different light intensities in the 3 sub-module areas of a standard crystalline silicon module marked in Fig. 4. The pattern of the current flow through the solar cells and the individual bypass diodes are illustrated in Table II and Fig. 4. Two diodes will be tested by applying one given irradiance pattern. The illumination pattern has to be changed in subsequent measurements to get the final test results of all 3 bypass diodes. During a third test, which is chronologically the first one, a homogenous illumination similar to the Standard I-V measurement setup is applied and the regular I-V curve close to STC is measured. If PV modules consist of other numbers of bypass diodes the test sequences have to be adapted.

Table II: Three different measurement periods combined with a tailored illumination pattern is needed to test the correct operation of each of the 3 bypass diodes. The measurement procedure is performed within three subsequent 10ms flashes in total 2.0 seconds (recharge time between flashes about 1s). Only in the last two of three sessions the 3 bypass diodes are tested by the use of two different illumination patterns.

	Area 1 of the module	Area 2 of the module	Area 3 of the module
	measurement period 1/3		
illumination pattern	1000W/m^2	1000W/m^2	1000W/m^2
objective of the test	Measure regular I-V curve, I_{SC}, P_{MPP}, U_{OC}		
	measurement period 2/3		
illumination pattern	1000W/m^2	800W/m^2	600W/m^2
		BD 2 is tested? Yes	BD 3 is tested? Yes
	measurement period 3/3		
illumination pattern	600W/m^2	800W/m^2	1000W/m^2
	BD 1 is tested? Yes	BD 2 is tested? Yes	

Figure 4: Bypass diode test with a 60 cell crystalline silicon module with 3 correct working bypass diodes. There are different illumination values in the 3 different sub-module areas (see Table II). The length of the arrows indicates the magnitude of current for the applied load according to the I-V scan

2.3 Low light measurement mode

The low light measurements are an important part to calculate the annual energy yield of solar modules in regular outdoor operation [9]. The measurement setup of the LED flasher is nearly the same as it is for the standard I-V measurement (see section 2.1). The differences are the several 10ms flashes with different intensities which are performed automatically. The benefit using this LED flasher in contrast to sets of standard outdoor measurements, are constant irradiance and spectrum during one I-V measurement and the short time to get the final results. The results are several I-V curves at different short circuit levels. With this I-V curves the efficiency at different irradiance levels are measured. Additionally another setup will be offered, with adapted ratios between the visible and the IR part of the spectral, particular at low irradiance values. All measurement results presented in this work performed at constant spectra.

The minimum and maximum of the selected irradiance values may be defined during the initialization of the program as well as the number of intervals. To run a measurement sequence consisting of 12 I-V curves from 50W/m^2 to 1000W/m^2 takes about 8.5s.

2.4 Spectral characteristics measurement mode

This setup was developed to get information about the spectral behaviour of the Top and the Bottom layer of a tandem module in the same way as descripted in [4]. The intensity of the IR and blue LEDs will be modulated independently during the 10ms flash in 2ms time steps. In contrast to the other three measurement setups, the target is not to measure the I-V curve and therefore the load is held constant.

3 PORTABLE LED FLASHER MEASUREMENT RESULTS

3.1 Standard I-V measurement results

Due to the fact that only two LED lines are used, the IEC 60904-9 standards for solar simulator spectrum requirements are not fulfilled. Nevertheless a cross comparison of nominal power measurements of three different standard crystalline silicon modules shows deviations of about 1% (Table III). Precise results can be achieved because the quantum efficiencies of the different modules from the same type are very similar. Thus, a calibration measurement of the LED Flasher was done by a standard polycrystalline 6 inch 60 cell module (Sunways Module SM 210 U) which was prior measured by the use of the Swiss Mobile Flasher Bus (SMFB) equipped with a high quality Pasan industrial Flasher [1]

Table III: Comparison of the measured nominal power of three standard crystalline silicon modules by the use of the SMFB and the LED Flasher. The SMFB precision nominal power measurement was performed at an uncertainty level of 3% (k=2). The LED Flasher was calibrated with the Sunways Module SM 210 U prior measured by the SMFB.

	Pn [Wp]	Deviation Portable LED Flasher / Swiss Mobile Flasher Bus
Sunways SM 210 U	230	0.10%
LDK 250P-20	250	1.10%
Pevafersa IP-170	170	-0.19%

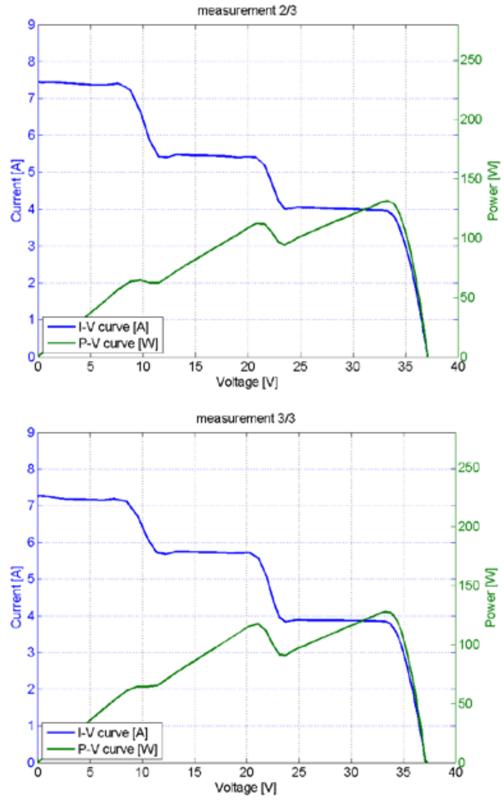

Figure 5: Bypass diode test, all bypass diodes are working correctly, lower graph with twisted illumination pattern

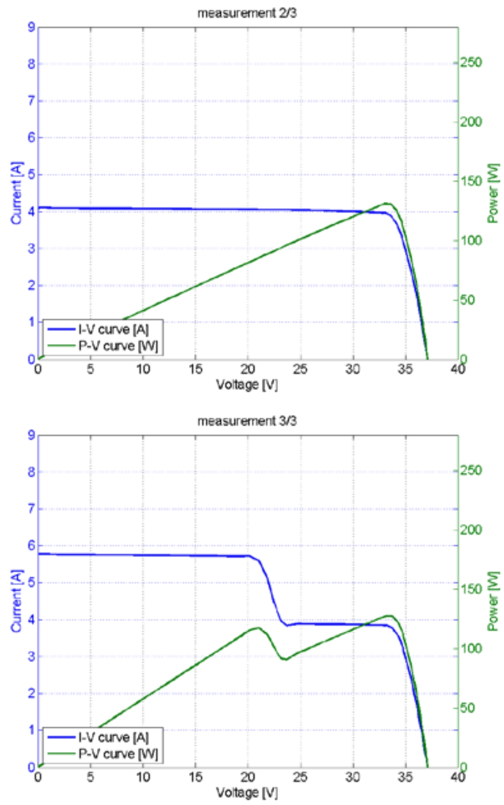

Figure 6: Bypass diode test, BD2 and BD3 are defect, BD3 is working correct, lower graph with twisted illumination pattern

3.2 Bypass measurement results

The results are based on test of a modified crystalline 60 cells module – the 3 bypass diodes can be disconnected to simulate the malfunction. If all three bypass diodes work well, and all inter cell connections of the module are working properly and the module is illuminated with different brightness levels at the three subareas of the module, the shape of the resulting I-V curve shows three stairs (Fig. 5). If one bypass diode works not correctly (not the diode which protects the most illuminated circuit) the shape of the I-V curve only has only two stairs. This method does not test the diode which protects the area that was the most illuminated module part. Therefore, a second measurement task at other distribution of the three different subareas is needed. In that second mode the most illuminated area before is now the least illuminated one (see Table II and Fig. 4). With this method, a defect bypass diodes is always detected reliably.

In Fig. 5 the results of a module with 3 correct working bypass diodes are shown. The upper and the lower part of Fig. 5 are similar although the illumination pattern is twisted in the lower part. In Fig. 6 a module with two defect bypass diodes is shown. In the Figures the number of steps can be easily counted by a local maximum detection, so the results of all possible bypass diodes malfunctions are evaluated according to Table IV.

Table IV: Evaluation of bypass diode malfunction according to the numbers of steps in the I-V-curve by applying the illumination pattern Tab. II and Fig. 4.

measurement period 2/3	measurement period 3/3	defect
3	3	-
3	1	BD1
2	2	BD2
1	3	BD3
2	1	BD1, BD2
1	2	BD2, BD3
1	1	BD1, BD3 or BD1, BD2, BD3

3.3 Low light measurement results

Eighteen I-V curves in the range of 3.5% to 150% of modules ISC_{STC} were measured (Fig. 7). This corresponds to irradiance between 35W/m^2 and 1500W/m^2 if assuming that the I_{SC} is proportional to the irradiance. Thus the low light efficiency relative to the STC efficiency is calculated (Fig. 8).

At lower values of the irradiances the V_{OC} of the module is decreased and the efficiency of the module is lower. At higher irradiances the efficiency of the module will drop due to the serial resistance effects. Thus, between 200W/m^2 and 1000W/m^2 a higher efficiency relative to STC efficiency is often measured which is typical for crystalline modules.

The low light behavior of a polycrystalline module was measured by the use of the Swiss Mobile Flasher Bus equipped with a high quality Pasan industrial Flasher [1] including the low light instrumentation of Pasan. These measurement results were compared with the results of the LED Flasher (Fig. 9).

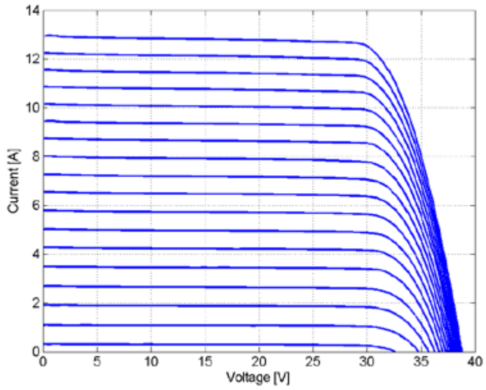

Figure 7: Results of the I-V curve measurements of the low light measurement with an I_{SC} of the module at STC of 8.7A (Device under test.: LDK-250P-20, poly crystalline module)

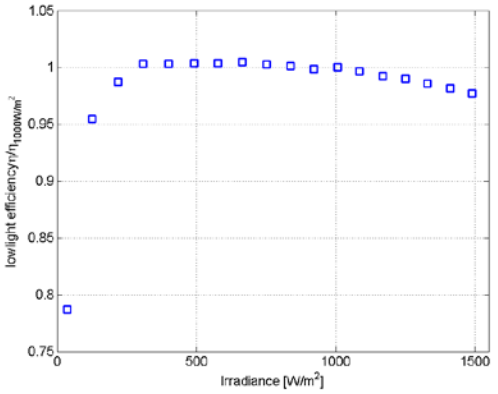

Figure 8: Module efficiency versus the irradiance which is calculated from the corresponding I_{SC} of the module (Device under test.: LDK-250P-20, poly crystalline module)

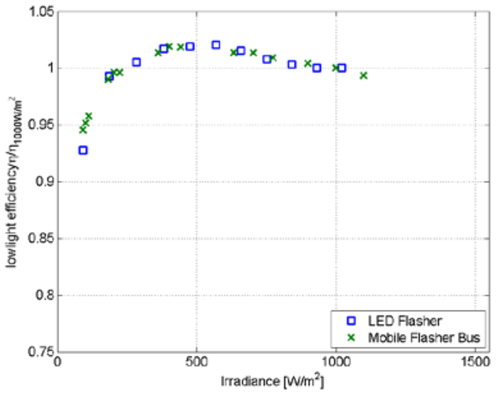

Figure 9: Module efficiency versus on the irradiance which is calculated from the corresponding I_{SC} of the module, comparison with the Swiss Mobile Flasher Bus (Device under test.: Sunways SM 210U, poly crystalline module)

4 CONCLUSION AND OUTLOOK

A new developed Portable LED Flasher was described and first successful tests were discussed. In particular all defect bypass diodes were detected within 2 seconds by applying three different intensity levels according to the three subsectors of a typical standard photovoltaic module. The Portable LED Flasher was placed by two operators several centimeters onto the device under test without dismantling the modules from the PV plant. This flasher can also be used in a stationary indoor laboratory or to perform the end test of the PV modules at the production line. In future the Portable LED Flasher may be extended with a battery pack such that significantly longer flashes are generated and that there is no cable needed during outdoor measurements.

The variety of different measurement methods together with the low weight of the total Flasher system offers PV system houses and PV installers a fast, efficient and economical way to perform the relevant measures of PV modules in the field or during the different steps of their distribution channels.

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