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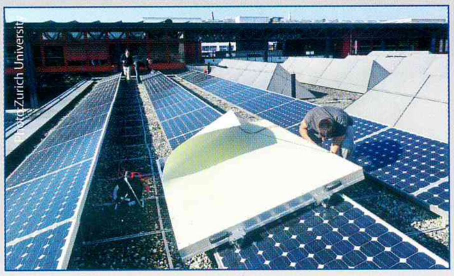
Markets & Trends

Israel: A potential star of the Middle East, Israel's solar sector is facing a series of stress tests. *Page 22*



Applications & Installations

Mobile LED flashing: Examining a portable technique for testing bypass diodes using LEDs. *Page 60*


Photo: Nidec

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pv magazine

PHOTOVOLTAIC MARKETS & TECHNOLOGY

The Array Changers

50 key components making PV shine

Photo: Tesla

The mobile LED flasher, developed by Franz Baumgartner and Daniel Schär at the Zurich University of Applied Sciences, Switzerland, in action flashing a rooftop array.

From farm to flash

Bypass diodes: The Zurich University of Applied Sciences has developed a new mobile LED flasher that can test module nominal power in the field, rather than in the lab. This flasher can also detect faulty bypass diodes quickly and easily. **pv magazine** was invited along to see the system in action at a German array.

Quedlinburg is one of those typically curious towns of former East Germany: dilapidated but decorous, part deserted but humming with purpose, and cast in an old-world exterior shot-through with the trappings of modernity. It is an intriguing kind of place.

Nestled in a no-man's land midway between Berlin to the east and the Harz mountains to the west, the town is nondescript yet charming in equal measure. And like all good German conurbations, it prides itself on efficiency (the Harz-Elbe Express rail service trundles like clockwork into the town station every 20 minutes) and the warm embrace of technology, which explains why many of the farmhouses that dot the fields around the town boast solar PV arrays atop their roofs.

At one farm, the pursuit of even greater levels of efficiency and output is being taken to the next level. On a bright March morning, a team organized by PI Berlin and the Zurich University of Applied Sciences is busy removing the solar modules from barn roofs and transporting them to a temporary lab located in one corner of the farm. Inside the barn, the tinny strains of the local radio station do their best to fill the cool air. A van stuffed with high-vis vests, boxes of cables, a mattress and a laptop is parked at one end, while a crate filled with iced lattes, soft drinks and shrink-wrapped sandwiches lies marooned in the middle of the floor. It may not look high-tech, but the module testing taking place inside this cavernous building is state-of-the-art.

Daniel Schär of the Zurich University of Applied Sciences observes as the team loads another crystalline module on to the crudely-constructed temporary wooden platform. The panel is laid flat, and then a LED-based mobile PV module flasher is rolled across it, emitting a barely-conceivable series of quick-fire flashes.

The team is performing nominal power measurements of the module at 1,000 W/m^2, within a flash period of 10 milliseconds (ms). Positioned five centimeters above the module, the 50 kg LED flasher measures 2.2 meters long, 1.5 meters wide and 0.1 meters thick. Unwieldy as it may appear, the LED flasher can be operated in the field by a team of just two people, meaning module testing can take place with the panels left in situ – an attractive proposition for owners of large-scale or rooftop systems who wish to test the output performance of their installation at the lowest possible cost.

Today, however, the team must remove the modules from the 1.2 MW rooftop array before testing, due to concerns over the structural integrity of the barn roofs. Furthermore, Schär's team is not simply testing for nominal power output, but is also using the LED flasher to test the three bypass diodes that are typical for standard crystalline silicon PV modules of this type. It is this testing procedure that has the potential to explore the boundaries of portable LED flashing.

LED by example

Developed by Franz Baumgartner, a pioneer in module flashing over the past few years, the portable LED flasher is equipped with 2,400 single blue LEDs and 1,440 infrared (IR) LEDs. Schär explains why he and Baumgartner opted for LED over the more traditional Xenon flashing technology.

"With LEDs, we can flash the modules from a distance of just 5 cm, whereas with Xenon we would need more space, perhaps at a distance of around five meters," Schär explains. "This would make mobile, portable testing directly on the modules very difficult."

Citing a daily cost of "around €2,000 currently", and a team of two able to test up to 500 modules a day, the testing process is by no means cheap, but Schär hopes that with PI Berlin's

AT A GLANCE

- Mobile LED flashers can be fitted just 5 cm above solar panels, meaning they can perform tests in the field, rather than the lab.
- The use of LED enables testing of bypass diodes – an often-overlooked area of module maintenance and testing.
- PI Berlin is working with the Zurich University of Applied Sciences to verify the mobile LED flasher results, prior to a potential commercial rollout later this year.
- Costs are currently high and the system – though portable – is a little unwieldy, but improvements in these areas are attainable.
- Such technology is likely to become more sought after as PV arrays age and system owners begin thinking about repairs and replacements.

Photo: Ian Clover/Solarpraxis AG

At the farm in Quedlinburg, Schär and a small team from PI Berlin work fastidiously in testing the solar panels, delivering a series of flashes designed to assess nominal power, bypass diodes and low-light performance.

involvement, this close-to-commercialization technology can be brought to market within the year at costs some way below that.

"I imagine there will be demand for this product in every type of solar market," he says. "You can transport it easily and test most rooftops or ground-mounted arrays in the field. The ability to test bypass diodes is, I think, very exciting."

There are numerous methods available to PV system owners for testing the nominal power of their array, but the combination of accurate, swift testing onsite together with instant verification of which bypass diodes are working correctly and which need replacing is an interesting one.

Malfunctioning bypass diodes can seriously inhibit the power performance of a module. The diodes are designed to reduce drastic power losses in a typical string operating a partial shaded module, and can even prevent the string from shutting down altogether. Bypass diodes also protect shaded cells from overheating, delivering a layer of safety to the array. However, overheated diodes can fail, or be damaged by either current flow, a lightning strike or simply poor connection.

According to Schär, very little work has been done in the industry on detecting defect bypass diodes, despite their importance to safe and efficient module performance. A recent test of a PV plant in Japan found that of the 1,272 mono-Si PV modules tested, 47% had defective bypass diodes, according to the International Energy Agency.

Testing bypass diodes

The LED flasher is designed to test how the bypass diodes are connected within the module string. "When you have more light and current on one area, then in the first part of the IV curve – when it delivers the most current – it should show that two bypass diodes are working, which means your module has 1/3 of the voltage," explains Schär.

For a 60-cell crystalline silicon module with three parts, the LED flasher can flash high, medium and low light to test each bypass diode. Schär demonstrates how the first area of illumination is flashed with 1,000 W/m^2, the second at 800 W/m^2, and the third at 600 W/m^2.

"On a normal IV curve, we can see that where the droop [step] occurs means that the first two bypass diodes are working, producing no voltage," says Schär. "Then, the part of the module with high current cannot produce enough voltage, so it needs the next part of the module to produce more. This is where the stepped IV curve comes in."

The curve reflects the strength of illumination testing imposed by the LED flasher, which can be altered to test different strengths and even different sections of the module. "This is where LED is more flexible than other testing methods," says Schär. "With Xenon, you could perhaps place a piece of paper over parts of the module to cover the bits that you do not want to test, but this takes time." The LED flashing process performs three 10 ms flashes in two seconds, and can be independently controlled to test different intensity patterns.

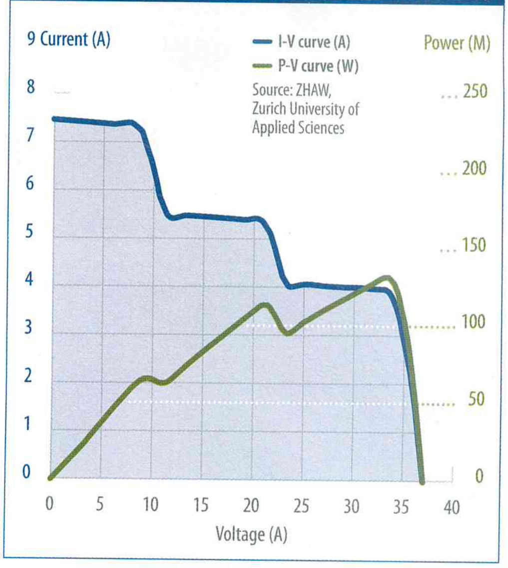
The first flash tests two diodes by applying one given irradiance pattern. The testers then change the illumination pattern in subsequent measurements to achieve the final test results of all three bypass diodes. The third test is actually – chronologically at least – the first test, and applies a homogenous illumination similar to a standard I-V measurement setup, measuring the typical I-V curve. The final two illumination patterns test the three bypass diodes.

Should one or more bypass diode be found to be faulty, the result appears in the I-V curve, which will produce fewer steps than a typical I-V curve where all bypass diodes are working correctly (the graphic to the right shows all bypass diodes working correctly, while the graphic on p. 64 shows faulty bypass diodes). In order to ascertain which bypass diode is faulty, testers simply retrace their steps and look for a correlation between the I-V curve and measurement period 2/3 or 3/3. Schär and Baumgartner's process for testing bypass diodes is a welcome addition to an industry that is maturing to the point where such solutions are becoming increasingly important. In Germany, which has more than 38.5 GW of solar PV installed, according to the latest EEG figures, as well as some of the oldest in-the-field arrays in the world, the question of operations and maintenance (O&M) is more pressing than almost anywhere else.

Preventing bypass diode failure will eventually be of paramount importance to cell and module manufacturers, but for now, the ability to accurately test and identify those bypass diodes that are faulty is a positive step.

The team is not alone in fixing its sights on this inherent PV problem, however. Measuring technology experts Testo have developed a technique for testing bypass diodes on PV modules using thermography. By using a substantially lower current than the module's nominal

I-V curve and PV curve with all bypass diodes working correctly



Graphics: Harald Schütt/Solarpraxis AG

Measurement periods for testing bypass diodes on a 60-cell module

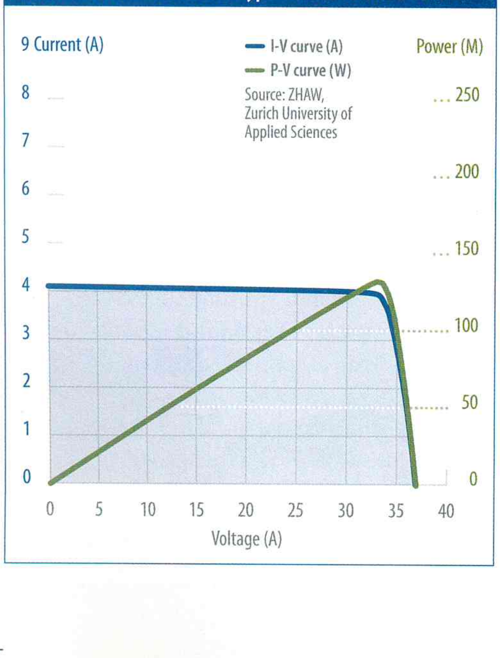
	Area 1 of the module	Area 2 of the module	Area 3 of the module
		Measurement period 1/3	
Illumination pattern	1,000 W/m²	1,000 W/m²	1,000 W/m²
Objective of the test		Measure regular I-V curve, Isc, PMPP, UOC	
		Measurement period 2/3	
Illumination pattern	1,000 W/m²	800 W/m²	600 W/m²
		Bypass diode 2 tested	Bypass diode 3 tested
		Measurement period 2/3	
Illumination pattern	600 W/m²	800 W/m²	1,000 W/m²
	Bypass diode 1 tested	Bypass diode 2 tested	

Photo: Ian Clover/Solarpraxis AG

Daniel Schär is confident that the flasher technology can be paired with robotic and even drone technology in the near future, delivering an even quicker way of testing arrays.

current, modern thermal imaging cameras can detect temperature differences of 50 mK, revealing the difference between energized and non-energized modules. According to Testo, when a bypass diode is short-circuited, the cells of the affected region of the module are bridged and do not heat up when a reverse current is applied, enabling testers to identify problem modules and, by association, the problem bypass diode.

I-V curve and PV curve with bypass diodes 2 and 3 defect



Low-light and spectral testing

The university's portable LED flasher is also adept at testing solar modules in low-light conditions, which is an accurate way of measuring the annual energy yield of a solar array, says Schär. Setting up the LED flasher in much the same way as when testing standard I-V measurements, the system delivers several 10 ms flashes of different intensities in nine seconds.

"The benefits of using LED rather than standard outdoor measurements is that it offers constant irradiance and spectrum during a single measurement and over a short period of time," said Schär. "The result is several I-V curves at different short circuit levels, and with these I-V curves we are able to measure the efficiency of the modules at different irradiance levels."

The portable LED flasher can also adapt the ratios between the visible and the IR part of the spectral, particularly at low irradiance values, delivering even more accurate results, claims Schär. For these particular modules, PI Berlin will transport a test sample to their laboratory in Berlin to independently verify the results, using a comparison between normal sunlight, the PI Berlin system and the results of Zurich University's mobile LED flasher.

Future developments

Weighing 50 kg and equipped with a small LCD screen displaying the test results, it is apparent that the portable LED flasher is in its early stages of development. Aesthetics and mobility aside, Schär, Baumgartner and the team have poured their efforts into the inner workings of the system, opting for two LED colors at 455 nm and 850 nm to provide a balance between affordability and performance.

"The flasher costs around €80,000 to build, and is the only one we have at the moment," revealed Schär. "You need around 4,000 high power LEDs per flasher, and they are expensive. When the price of LEDs comes down, then it becomes more affordable to produce."

Schär is confident, however, that he can work on delivering other areas of improvement. "The next step is to make it lighter. 50 kg is manageable, but a smaller, lighter system would be a huge improvement." This could be achieved by reducing the space in between the LEDs and using lighter materials on the casing, he says.

Glancing at the modules already tested, Schär adds that normally it is only necessary to test around 5% of an array and then use the resulting data as an average. However, this particular installation, a mere four years old, had been performing noticeably poorly, so the team decided to test a larger proportion of the array. "Most modules we have tested here have 20% less power today than when they were installed," he reveals. "It is a good idea to test modules before the end of the guarantee and the warranty of the power, so within 20 years of installation ideally."

Photo: Ian Clover/Solarpraxis AG

Each module's results are displayed instantaneously on a small LCD screen on the back of the flasher, and are also uploaded automatically to an online database that is sent to the system owner.

Schär also believes that the LED flasher could, in the not-too-distant future, also be adapted to the robotic solar panel cleaning technology currently in operation, further reducing the man-hours required to test nominal power output and bypass diodes. "And once the flasher is lighter and more portable, then you could even use a drone to test systems in the field, all done remotely, easily and quickly." And with that – as the talk of robots and drones jarred with the timeless surroundings of old church spires and this rather draughty barn – Schär grins, walks over to the now half-empty lunch crate, rummages through and sighs: "We only have decaff left, I'm afraid." ◆

Ian Clover