TESSERA: MAXIMIZING PV YIELD PERFORMANCE WITH SIZE FLEXIBILITY FOR BIPV

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ABSTRACT: Application of PV in the built environment, both as BAPV and BIPV, requires improved aesthetics, decreased operating temperatures of the modules and diodes, improved output under partial shading and reduced production costs while allowing the size and shape of the PV elements to be more flexible.
ECN presents TESSERA: a novel PV module lay-out which allows linear shade performance, while at the same time allowing size and manufacturing flexibility which also leads to improved aesthetics as entire roof and façade areas can be utilized. Temperature measurements on module diodes shows the diodes in these PV modules only reach a temperature of 40°C compared to 140°C for conventional ones. Mechanical load tests to rails glued to the rear of the PV modules shows the interconnections are stable, allowing vertical, frameless installation. Hence, these TESSERA elements allow broader application of PV in the built environment.
Keywords: BIPV, PV Module, Shading, System Performance

1 INTRODUCTION

The market for residential PV has grown significantly [1]. This is mainly field installations and roof top PV which is added to existing roofs (BAPV). Building integrated PV (BIPV) is still small, currently about 2% of the PV market [2]. This market is expected to grow to 13% of the PV market in 2021. However, to achieve this growth the following technological developments are required:

- The output of the PV system under shading needs to be improved.
- Flexible size and shape at low production cost.
- The operating temperature of the modules and diodes should be reduced.
- The aesthetics should be improved.

Improvement of the aesthetics is possible when the entire roof or façade surface area can be utilized, which can be done if partial shade does not significantly reduce the system output, and when size flexibility can be achieved. BIPV also requires size flexibility, as well as frameless modules and no overheating of diodes. Hence, the abovementioned development requirements can allow broader application of PV, both as BAPV and BIPV.

In this paper ECN will present the TESSERA concept, this is a novel module lay-out which consists of small building blocks with lower current and higher voltage. The building blocks can be placed in parallel allowing size flexibility and strongly improved shade performance. Because of the low current in the building blocks, small current diodes can be applied which do not overheat. Back rails have been glued to the PV laminates and various stress tests show the modules remain stable, meaning the elements can also be installed in vertical and frameless applications such as BIPV and facades.

2 MODULE DESIGN

A conventional solar panel consists of 60 or 72 cells, connected in 3 strings of 20 or 24 cells, where each string is protected by a bypass diode. All cells are connected in series, since parallel interconnection is not desirable due to the high current of up to 9 A. The drawback of series interconnection is that partial shading of one cell, can cause the current to flow via the bypass diode resulting in lost output of the entire string.

ECN has designed [3] a module building block (MBB) which is 32x32 cm, and has a current of 0.6 A and a Voc of 40 V. This can be achieved by cutting standard size solar cells into 16 mini-cells, and placing 64 of those in series. Per group of 16 mini-cells, an in laminate diode is present to protect the group. The cells are back contact solar cells, which are designed in such a way that each mini-cell has a plus and a minus contact. Interconnection takes place in the conductive back sheet foil, into which any interconnection pattern and contact to the diode can be applied. The MBB is shown in Figure 1A.

Full scale modules can be made by placing any number of these building blocks in parallel. This allows a great variety of module sizes, of which examples are shown in Figure 1B and 1C. The module has been named TESSERA, which is the latin word for ‘the building block of a mosaic’.

The advantage of this is:

- Excellent shade tolerance,
- Inverter always active: Stable Voc independent of nr of blocks or presence of shade,
- Size flexibility without additional manufacturing cost,
- No overheating diodes.

The size flexibility combined with mico-inverters resulted in easy system installation for which no shade analysis is required. Furthermore, entire roof areas can be covered also enhancing aesthetics.

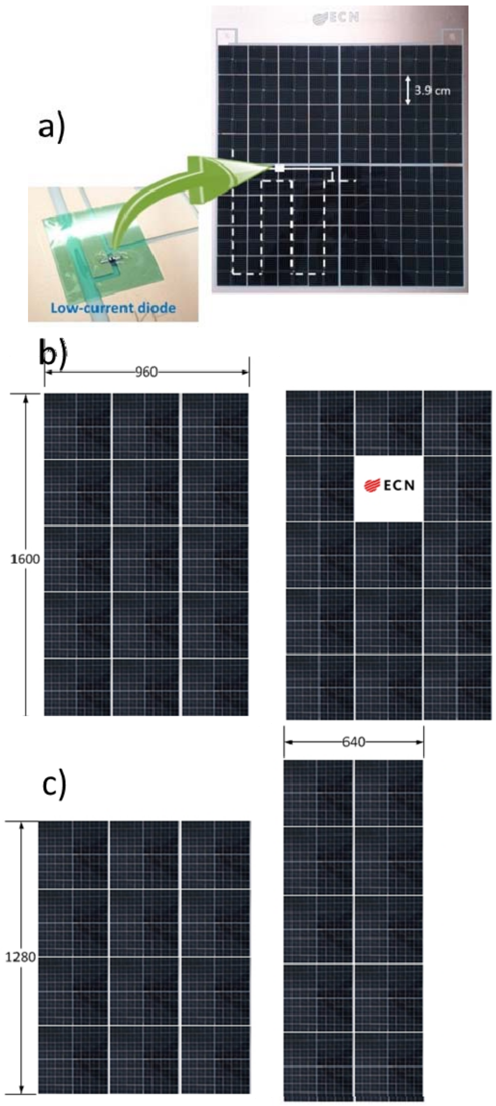

Figure 1: a) A module building block (MBB) of 32x32 cm, consisting of 64 minicells, of which 4 groups of 16 are each protected by a low current diode. Modules can be made by placing any number of MBBs in parallel, in b) 3x4 such blocks have been placed together and in the right one MBB has been left out, this area can be used for windows, chimney pipes or placing a dedicated pattern or company logo. Other examples in c) are 3x3 or 2x4. A convential module size would correspond to 3x5

3 EXPERIMENTAL

3.1 Module manufacturing

The modules were manufactured on the Eurotron back contact module line using standard MWT module materials and processing [4]. MWT solar cells were cut in 16 mini-cells using laser cutting. In-laminate diodes are soldered on the conductive foil.

3.2 Output measurements and yield calculations

The power output of the modules was measured on a flash tester (AAA) (Pasan SA). Three controlled partial shading types were applied to modules: a tree shade, a pole shade and a dormer shade [5]. The shade performance (SP) of the modules was then calculated: SP = $Mpp_{\_shade}$ /$Mpp_{\_STC}$. A fully shade linear module only loses x% of power when x% of the area is shaded. Hence, the shade linearity (SL) is defined as the ratio of MPP power under shade and MPP power of a perfectly shade-linear module under shade.

The IV curves served as input for the yield calculations performed using PV Syst [6]. In PV Syst, two specific systems were defined, one consisting of conventional modules and one consisting of TESSERA modules. Each module had its own micro-inverter, so the yield effects are compared on the module level.

3.3 Temperature measurements

The operating temperature of diodes was measured using a thermo-couple. Infra-red images were taken to examine the heat distribution. Test samples were made consisting of a junction box laminated to a glass plate. Three diodes were placed in the junction box. The test samples were placed in a lab at ambient temperature. The short circuit current was then passed through the diodes, either through one, through 2 or through all 3 diodes, for 1 hour to simulate diode activity in real conditions, e.g. in a solar panel next to a dormer.

3.4 Back rail strength measurements

Back-rails with a cross-section of 375 mm^2 were adhered to the 4-cells laminates using tape or adhesive. The back-rails were placed between solar cells, covering the back-contact or front-contact connection areas. Tensile stress tests were conducted, applying normal, shear and torsional stresses (see Fig. 2) up to 4000 N (10.7 MPa). The PV modules were placed under load (current) and while applying the stress, the voltage was measured.

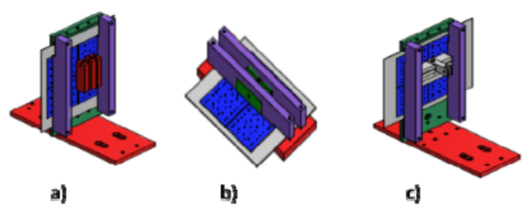

Figure 2: Measurement of stress on back contact 2x2 solar modules, (a) shear, b) normal, c) torsion

4 RESULTS AND DISCUSSION

4.1 Module performance

The shade performance and shade linearity have been determined for standard panels and TESSERA panels using the power measurements performed in the Pasan flash tester. The results are summarized in Table I.

Table I: Shade Performance and Shade Linearity of standard PV panels and TESSERA PV elements for three shade cases

	Pole	Dormer	Tree
Shade Performance (%)			
- Standard Module	17	26	53
- TESSERA	67	64	73
Shade Linearity (%)			
- Standard Module	20	38	66
- TESSERA	76	92	92

Figure 3 shows the power graphs as a function of voltage for the TESSERA modules in case of no shading and for the three shade cases. It can be seen that the TESSERA modules operate at a very similar Vmpp, regardless of the presence of shade. This means the inverter is always activates, and very minimal Mpp tracking is required.

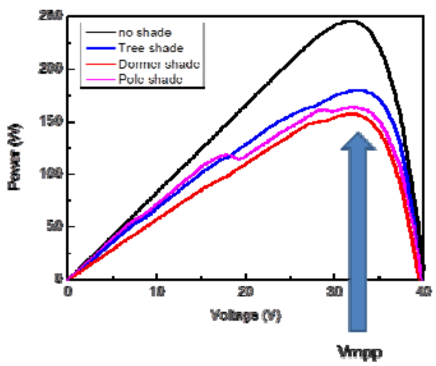

Figure 3: Power as a function of voltage for the TESSERA modules in case of no shading, and in case of presence of tree-, dormer- or pole shade

4.2 Annual Yield Calculations

The annual yield has been compared between a system with conventional modules and a system with TESSERA modules in Amsterdam, The Netherlands. The systems consisted of 18 modules and had a nominal power of 4.7 kW. To calculate the annual yield, a specific shade case was defined as shown in Fig. 4.

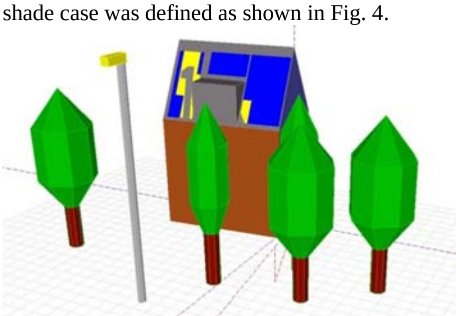

Figure 4: PV system and shade situation as used in the annual yield simulations, for the location of Amsterdam

For the conventional system, when the shade hits the modules the yellow areas in Figure 4 drop out, whereas for the TESSERA modules only the output of the shaded area is lost, indicated gray in Figure 4. The shading and intensity of light vary throughout the day and throughout the year. In some hours, the TESSERA system gain can be as high as 24%, and throughout the year the TESSERA gain is +4%. This is in line with calculations performed by MacAlpine and coworkers [7].

4.3 Diode Temperatures

An infrared image of a junction box with three diodes after passing the current for 1 hour is shown in Fig. 5.

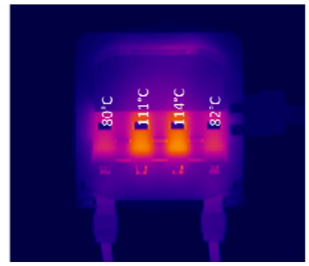

Figure 5: IR image of junction box with three diodes, through which the Isc has passed for 1 hour

The measured diode casing temperature was between 70-170 °C, depending on the type of diode and the number of diodes through which the current passed.

In contrast, the TESSERA diodes only need to transport 0.6 A when activated. This results in a much lower heat dissipation. On top of that, the diode is integration in a conductive backsheet, which can also dissipate any heat easily. Indeed, the maximum observed temperature was 40°C. This means the TESSERA module concept is inherently safer.

4.4 Back rail strength

The adhesive tape is the weakest link in this test set-up because it breaks before any changes could occur in the PV module. Based on IV, EL and IR measurements, no cracks in solar cells were noticed and the connection between solar cell and back-contact foil no release in contact was observed.

When using adhesive the maximum load could be applied under normal test conditions. At these conditions locally small cracks in solar cells were observed, but this did not result in any noticeable performance drop of the modules.

5 OUTLOOK FOR BIPV/BAPV

We expect TESSERA to allow a broader application of PV, because it allows entire area utilization. It can be manufactured either a PV module and used for building applied PV, or the TESSERA laminates can be integrated into building elements. The combination of scalability and the low diode current and heating make it suitable for BIPV. An example of a building onto which TESSERA like modules have been projected is shown in Figure 6.

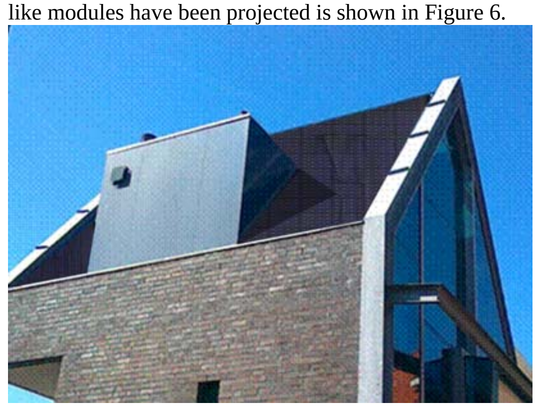

Figure 6: Example of a roof covered with TESSERA modules, allowing good aesthetics and where the shade does not hamper the PV system

In order to achieve large scale processing at low manufacturing costs the cutting and handling of solar cells into mini-cells needs to be automated, as well as the diode integration into the module. The module manufacturing line can already deal with various sizes, material supply such as glass at various sizes is also required. The manufacturing of scalable PV elements with nearly linear shade behavior for integration into building elements can then be carried out at the same costs as conventional modules.

6 CONCLUSIONS

ECN has developed the TESSERA module, this module is made up of several module building blocks. The building blocks are 32x32 cm and have a low current of 0.6A and a Voc of 40 V. Modules can be made by combining any desired number of building blocks.

The Shade Performance and Shade Linearity (SL) of the TESSERA module has been compared to a conventional module for three different shade cases. The SL of the TESSERA module is between 67-92%, compared to 20-62% for a conventional module. The Vmpp is very stable, regardless of the presence of shade or the number of building blocks, allowing easy tracking and a good match with inverter (inverter also activated at high shading).

The annual yield increase has been calculated for a system in Amsterdam, The Netherlands, and is +4% for a specific shade case.

The low current diodes do not overheat, after passing the Isc for 1 hour the TESSERA diodes reach 40°C, compared to 70-170°C for conventional diodes, making the TESSERA module inherently safer.

Back rails can be adhered to the modules without causing damage to the solar cell interconnection, this means the laminates are suitable for BIPV.

ECN expects TESSERA to allow broader application of PV, both for BAPV as for BIPV.

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