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Impact of (Multi-) Busbar Design on the PERC Cell-to-Module Yield under Realistic Conditions

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Cell-to-Module (CTM) analysis has presented a valuable method for optimizing solar cells and solar modules in terms of their performance under standard test conditions (STC) [1, 2]. In recent years the focus in solar module development is shifting from optimizing the module power for STC to maximizing the annual yield under different climatic conditions [3, 4].

To overcome the limitations of testing and modelling under standard test conditions, we developed a holistic Cell-to-Module-Yield (CTMY) methodology to predict the annual yield of crystalline silicon solar modules for varying module configurations and environments using a time step simulation approach [5]. Our model considers the interaction of optical, thermal and electrical effects in the module and combine it with an angular, spectral and time resolved light source. This detailed modelling approach allows us to understand and quantify the effects of using different module materials and different solar cell types on the annual output of a crystalline solar module under field exposure in various climatic locations.

Here we apply our model to study the impact of the busbar layout on monocrystalline silicon PERC solar cell modules. Our baseline is an industry-standard 21.2%-efficient five busbar (5BB) PERC solar cell implemented into a 72-cell module. We vary the module design by adding a light-redirecting film (LRF) to the five ribbons and replacing the ribbons with round wires.

Model

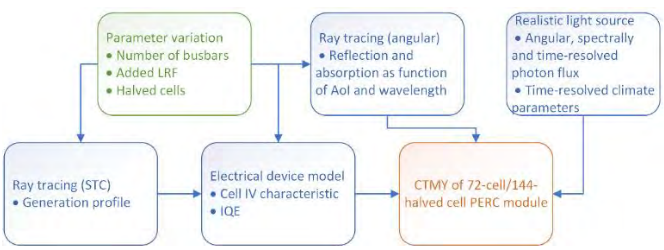

Figure 1. Illustration of the CTMY modelling flow.

Figure 1 illustrates the modelling flow. Initially, we setup our baseline model for a 5BB monocrystalline PERC solar cell. Electrical device modelling under STC is performed in Quokka3 [6] using a photo-generation profile generated by ray tracing in SunSolve [7] considering optical shading losses at the front metallization. After embedding we simulate the cell-to-module performance and determine a nominal peak power rating of 360 W for a 72-cell module using these 5BB PERC cells.

Following our method in Ref. [5] we perform ray tracing before and after module embedding with varying angles of incidence (AoI). Using SunCalculator [8] we generate angular, spectral and time-resolved realistic light sources for several locations in Australia.

The results from optical ray tracing, realistic light source and climate data and electrical device modelling are used as inputs to our CTMY analysis. Critically, our model considers the impact of optical effects (such as optical gain from LRF or wire structures and effective width), electrical effects (such as resistive and thermal losses) as well as angular and spectral effects.

Initial Results

Figure 2 (left) shows the cell-to-module yield gains and losses (solid bars) and compares them to cell-to-module ratio under STC conditions (hatched bars). The biggest increase in module yield of 3.1 % is caused by the coupling gains at the cell front, which can be explained by the reduced reflection after embedding at high AoI. The deviation between the standard AM1.5G sun spectrum and the realistic spectrum caused another significant gain of 2.8 %.

In total, the module embedding absorbs and reflects 5.6 % of the total irradiance whereas 2.0 % is recycled by internal reflection at the backsheet, ribbons and front metallization. Critically, the reduction of internal reflectance losses at the cell surface after embedding accounts for yield gains of 3.1 % under realistic conditions while this gain is underestimated with only 1.8 % power gain in a Cell-to-Module analysis under STC conditions. Similarly, external ohmic losses of 2.5 %, which contribute significantly to the total energy yield, are significantly overestimated at 3.7 % under STC conditions. This can be explained with the average irradiance at the location in Melbourne which is lower than 1000 W/m^2 and limits the electrical losses under realistic conditions. Finally, module embedding is responsible for a total annual yield loss of 4.4 % under realistic conditions.

In Figure 2 (right) we compare the normalized total annual yield for a 5BB PERC module with flat Sn ribbon against a theoretical Ag LRF ribbon with an optimized base angle of 30°. The ideal reference assumes that all light impinging on the ribbon is redirected onto the cell surface. The results show that such an LRF structure shows an 1.7 % improvement over a standard flat ribbon and falls less than 0.5 % short of an ideal structure with 100% light recycling at the ribbons was achieved.

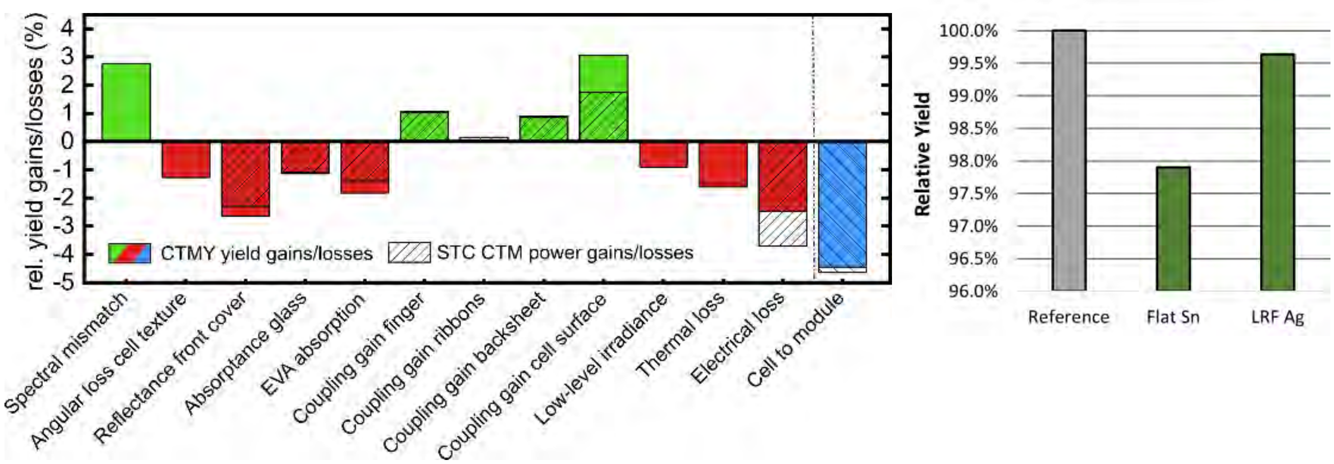

Figure 2. (left) Relative annual yield gains and losses for a 72-cell monocrystalline PERC module under realistic conditions in Melbourne. (right) Relative yield for the same module with flat Sn ribbons and LRF ribbons normalized to the ideal reference.

References

[1] Haedrich, I., Eitner, U., Wiese, M. and Wirth, H., 2014, 'Unified methodology for determining CTM ratios: Systematic prediction of module power', *Solar Energy Materials and Solar Cells*, 131, 14–23.

[2] Mittag, M. et. al., 2017, 'Cell-to-Module (CTM) Analysis for Photovoltaic Modules with Shingled Solar Cells', in *44th IEEE Photovoltaic Specialist Conference (PVSC) (IEEE)*, pp. 1531–1536.

[3] VDMA, International Technology Roadmap for Photovoltaic Results 2018, in: energytrend, 2017.

[4] Thomson, A., Ernst, M., Haedrich, I., Qian, J., 2017, 'Impact of PV module configuration on energy yield under realistic conditions', *Optical and Quantum Electronics*, 49, 82.

[5] Haedrich, I., Jordan, D., Ernst, M., 2019, 'Methodology to predict annual yield losses and gains caused by solar module design and materials under field exposure', *Solar Energy Materials and Solar Cells*, In press.

[6] www.quokka3.com, accessed 29/07/2019.

[7] PV Lighthouse: SunSolve™, accessed 29 July 2019, https://www.pvlighthouse.com.au

[8] Ernst, M., Holst, H., Winter, M., and Altermatt, P. P., 2016, 'SUNCALCULATOR: A program to calculate the angular and spectral distribution of direct and diffuse solar radiation,' *Solar Energy Materials Solar Cells*, 157, 913–922.