Location specific PV yield and loss simulation based on module stack and layout

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***Abstract*—PV cell and module manufactures optimise their products according to standard test conditions. The key parameter for financing of a solar farm is yield under field or realistic conditions. Field testing modules is expensive and time consuming. Hence we develop a methodology for simulating PV module yield based on the optical, thermal and electrical properties of the components and their stack ands layout. With our procedure we will model optical, thermal and electrical losses under realistic conditions for standard, half cell and encapsulant free modules in different locations. For now we quantify the losses for a standard module installed in Melbourne on a cloudy day. The largest loss factor is electrical, as the module voltage decreases with low irradiance.**

I. INTRODUCTION

The cost of renewable electricity produced from c-Si photovoltaic panels has reduced enormously in the past decade. In particular as economies of scale have driven down the Watt peak (W_p) cost of a solar panel. Now we are at a point where, in some regions, the levelised cost of energy (LCOE) is significantly lower than that produced by new build coal and other forms of conventional electricity generation. That is, grid parity is being achieved in regions with high insolation and/or high conventional electricity generation costs.

Effective financing of PV is necessary to continue market growth. Accurate prediction of yield is essential to the financial viability of projects. There are tools to predict yield that are well established in industry such as PVsyst [1] and HOMER [2]. In the case of PVsyst they use an input (.PAN) file to describe the module performance. The .PAN files are generated from measurements of fielded modules with advanced monitoring and metrological measurement equipment [3]. Fielding modules gives great assurance to project designers on the yield of their planned systems. However it creates a long feedback loop for module and cell designers.

We now focus on a procedure for yield estimation based explicitly on the module layout and components such that it can be computed for different locations. The yield calculation model is able to predict the module yield for varying module configurations. Therefor it can be used as a tool for module manufacturers to quantify the gains and losses generated by every module element (e.g. glass, EVA, ribbons, backsheets). This allows them to evaluate their materials economically without building and expose the modules in outdoor test condition. The generated yield losses and the final yield under real test conditions (RTC) are displayed separately for thermal, electrical and optical losses and are always referred to the module output which would be achieved by having the module exposed to STC conditions. In essence reducing the LCOE, by designing products that outperform similar STC W_p modules when installed in the field.

In the paper we will investigate two changes to module design: 1) the use of full 156 mm pseudo-square cells versus cut cells [4], and 2) conventional packaging using an encapsulant and backsheet versus the encapsulant free scheme of inserting the cells between two sheets of glass, similar to the NICE module concept [5] and the TPedge modules [6]. We predict the performance of these modules in different locations around Australia throughout a year and breakdown the losses according to temperature [7], optics [8, 9], and electrical mainly due to low light illumination [10]. For this abstract we outline our simulation methodology, and present calculations of loss mechanisms over a single day.

II. SIMULATION METHODOLOGY

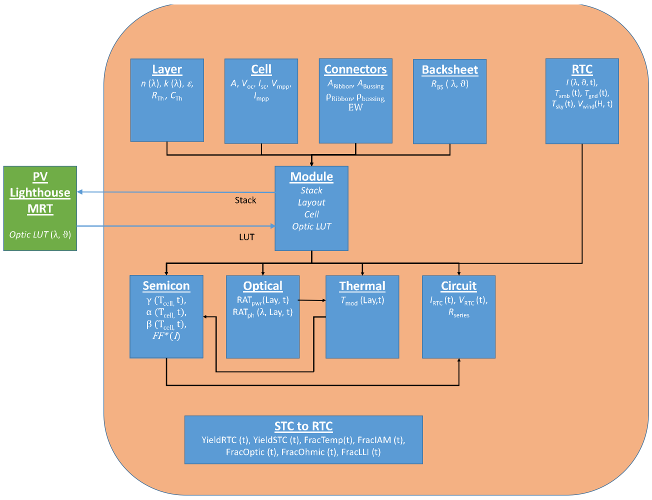

Fig. 1. Flow diagram for yield calculation.

Key to this work is the identification of methods to simulate the optical, thermal and electrical losses generated within the stack of conventional c-Si PV module technology.

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We now outline our procedure for calculating RTC yield. The flow is depicted in Fig 1. The module is comprised of 4 elements: 1) layers which are described by the their refractive index and thermal resistance and capacitance, 2) a solar cell which is described by its area, STC IV parameters and temperature coefficients, 3) the electrical connectors, the parameters necessary to determine their resistivity, and the impact of the bussing ribbon on shading, and 4) the backsheet, if applicable, which is described by its angular reflectance.

In order to fully describe the optics of the module we calculate a look up table (LUT) describing the reflection and transmission from the module and the absorption of light in each layer as a function of incident wavelength and angle from the optical properties of the stack of layers and the geometrical module layout using a third party module ray tracer program provided by PV Lighthouse.

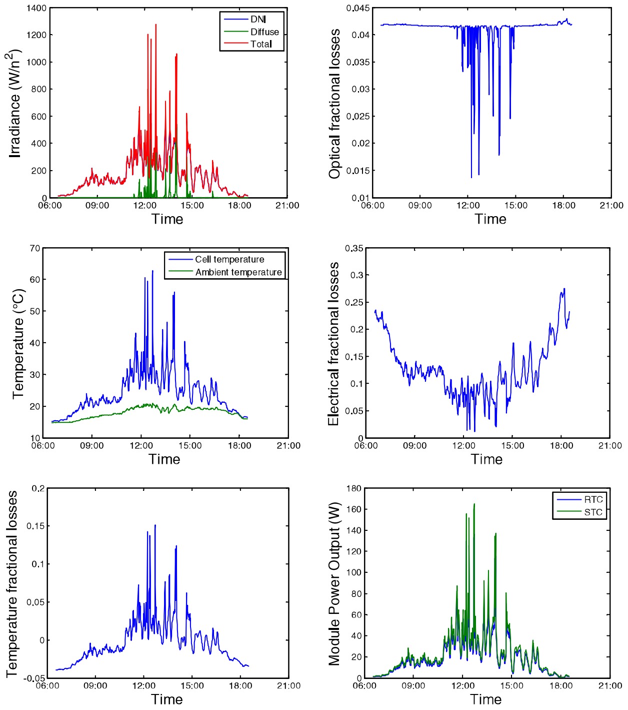

Fig. 2. Resutls of one day simulation for a standard module on a cloudy day in Melbourne.

Importantly our real test conditions (RTC) data includes the total irradiance on the tilted panel including the intensity, direction and wavelength, temperatures of the ambient, ground and sky, as well as wind speed and direction for each time step. We generate the RTC data for various locations from one-minute data provided by high quality weather stations using the program SUNCALCULATOR[11].

The yield is calculated by combining the RTC data and module data. First, the optical absorption in each layer is determined at each time step using the optical LUT. Then, the operating temperature of the cell is the calculated from the thermal properties of the module layer stack. The impact of temperature on the electrical losses of the cell are determined by means of established semiconductor equations. Alternatively, a full electrical device simulation can be implemented. Finally, the circuit elements determine the IV output of the module as a function of time. Our design of the methodology further allows to implement iterative solvers e.g. to account for any power losses due to operating temperature when determining the cell temperature.

In order to isolate the impact of different effects on the yield the above procedure is repeated with different loss mechanisms turned off.

III. MODEL INPUTS AND RESULTS

The weather data usedin this initial study was a cloudy winter day in Melbourne measured by the Bureau of Meteorology weather station. The module parameters are representative of a 60 cell 260 W_p mc-Si module (details and sketches to be included).

The input irradiance and minutely results are plotted in Fig. 2. The graphs in Fig. 2 depict the following: top left, plots the DNI and GHI on the panel; mid left, plots the computed cell temperature and the ambient temperature; bottom left, plots the temperature loss; top right, plots optical loss; mid right, plots electrical loss; bottom right, plots the RTC and STC power.

Finally Fig. 3 plots the integrated losses over the day so that the significance of the loss mechanisms can be compared. In the paper we will calculate the losses for a whole year for several locations and the aforementioned variations to module design.

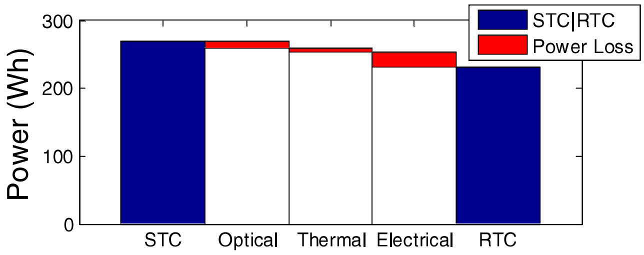

Fig. 3. Integrated losses for a standard module installed in Melbourne for one day.

REFERENCES

[1] A. Mermoud, "Pvsyst: Software for the study and simulation of photovoltaic systems," *ISE, University of Geneva, www. pvsyst. com,* 2012.

[2] P. Lilienthal, P. Gilman, and T. Lambert, *HOMER® micropower optimization model*: United States. Department of Energy, 2005.

[3] I. C. Tse, K. J. Sauer, and R. A. Desharnais, "Revisiting the model parameters of an existing system using the Photovoltaic System Analysis Toolbox (PVSAT)," in *Photovoltaic Specialist Conference (PVSC), 2015 IEEE 42nd*, 2015, pp. 1-6.

[4] S. Guo, J. Singh, I. Peters, A. Aberle, and T. Walsh, "A quantitative analysis of photovoltaic modules using halved cells," *International Journal of Photoenergy,* vol. 2013, 2013.

[5] J. Dupuis, E. Saint-Sernin, O. Nichiporuk, P. Lefillastre, D. Bussery, and R. Einhaus, "NICE module technology-from the concept to mass production: a 10 years review," in *Photovoltaic Specialists Conference (PVSC), 2012 38th IEEE*, 2012, pp. 003183-003186.

[6] M. Mittag, I. Haedrich, T. Neff, S. Hoffmann, U. Eitner, and H. Wirth, "TPedge: qualification of a gas-filled, encapsulation-free glass-glass photovoltaic module."

[7] M. R. Vogt, H. Holst, M. Winter, R. Brendel, and P. P. Altermatt, "Numerical Modeling of c-Si PV Modules by Coupling the Semiconductor with the Thermal Conduction, Convection and Radiation Equations," *Energy Procedia,* vol. 77, pp. 215-224, 8// 2015.

[8] M. Winter, M. R. Vogt, H. Holst, and P. P. Altermatt, "Combining structures on different length scales in ray tracing: Analysis of optical losses in solar cell modules," in *Numerical Simulation of Optoelectronic Devices (NUSOD), 2014 14th International Conference on*, 2014, pp. 167-168.

[9] N. Martín and J. M. Ruiz, "Annual angular reflection losses in PV modules," *Progress in Photovoltaics: Research and Applications,* vol. 13, pp. 75-84, 2005.

[10] N. H. Reich, W. G. J. H. M. van Sark, E. A. Alsema, R. W. Lof, R. E. I. Schropp, W. C. Sinke, *et al.*, "Crystalline silicon cell performance at low light intensities," *Solar Energy Materials and Solar Cells,* vol. 93, pp. 1471-1481, 9// 2009.

[11] M. Ernst, H. Holst, M. Winter, and P. P. Altermatt, "SUNCALCULATOR: A program to calculate the angular and spectral distribution of direct and diffuse solar radiation," *In preparation.* , 2016.