Lessons Learnt

Lessons Learnt Report: *Cell-To-Module yield: A framework– for better performance prediction*

Project Name: *Photovoltaic Modules for the Australian Environment (PV-MATE)*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	Canberra ACT, Coledale NSW

Key learning

We have developed a framework for predicating the performance of a PV module and/or array. It integrates yearly optical, electrical and thermal gains and losses, which are computed based on the physical setup of the module and IV measurements of the PV cells it is comprised of. The optical losses are computed using PV Lighthouse module ray-tracing software, that enable angular and wavelength resolved parameterisation for the gains and losses. The environmental inputs for the simulations are interpolated from the Bureau of Meteorology weather data for 16 different sites across Australia. Wavelength and angular data is generated with SunCalculator, employing SMARTS modelling of cloud opacity. Indicative results generated from this framework are:

- That temperature losses correlate to the average temperature of a location at 3pm, when not accounting for varying wind speed in convective cooling,
- Non-linear losses attributed to low-light irradiance, in Australia, correlate with the recorded number of cloudy days,
- The use of half cells instead of full cells, improves both standard-test-condition power and the CTMy ratio,
- In agreement with the simulations by ISFH ; glass-glass module construction without an encapsulant underperforms traditional encapsulant filled modules due to enhanced angular losses occurring that the internal glass-air interface,

Implications for future projects

The CTMy frame work can be used to better quantify cell and module changes and the value in terms of increases kWh yield and ultimately the impact on the cost of energy. There are many aspects of the framework that can be improved, developed and tested. Future projects could consider a deeper physical analysis of second and third order effects such as:

- The impact of thermal mass
- The impact of different cloud opacity models on different technologies
- Physics based models for degradation and wear out

Knowledge gap

Accurate module performance prediction requires from measurements of fielded modules, or numerous advanced indoor measurements. While fielding and advanced testing of modules gives great assurance to project designers on the yield of their planned systems, it creates a long feedback loop for module and cell designers. Our procedure develops a method to estimate module performance based on its design for different locations.

Background

(For references and an expanded description please see: "Impact of PV module configuration on energy yield under realistic conditions" (DOI: 10.1007/s11082-017-0903-0), Journal of Optical and Quantum Electronics)

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 electricity (LCOE) generated by PV 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 and HOMER . In the case of PVsyst, it uses an input .PAN file to describe the PV module performance. Accurate .PAN files are generated from measurements of fielded modules with advanced monitoring and metrological measurement equipment. 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 configuration and components such that it can be computed for different locations. Specifically, we use a similar methodology to the Cell to Module power analysis of Haedrich *et al.*, which computes module power for a given cell type and setup under standard test conditions (STC). The procedure is extended to predict fielded module yield in comparison to the ideal power yield of the cells. The simulated yield gains and losses are attributed to: parasitic optical effects, enhanced light trapping, light concentration from gaps between the cells, thermal, and electrical losses. All power losses and gains are determined for realistic environmental conditions and are compared to the STC reference.

Objectives or project requirements

A key object of the PV-MATE project that this work addresses is to:

“Quantify operating conditions specific to Australia that will effect the performance of PV”

CTMy framework is a useful tool for quantifying the impact of operating conditions specific to Australia that are identified in the project.

Process undertaken

Key to determining CTMy is the identification of methods to realistically evaluate the optical, thermal and electrical losses generated within the module model. We now outline our procedure for calculating CTMy. The module model is comprised of 3 elements: 1) layers which are described by their refractive index or spectroscopic specular/diffuse reflection and thermal resistance, 2) a solar cell which is described by its STC IV parameters, spectral internal quantum efficiency (IQE), and temperature coefficients, and 3) the electrical connectors, the parameters necessary to determine their resistivity, and the impact of the bussing ribbon on shading. A sketch of our model depicting data flows is presented in Figure 1.

In order to fully describe the optics of the module and interaction with the cell we use a ray-tracing software to provide optical lookup tables (LUT) describing the angular and spectroscopic: reflection, absorption and transmission in each layer. The module ray tracer program is provided by PV Lighthouse.

The yield is calculated by combining the environmental data and the module configuration. 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 calculated from the thermal properties of the module, where in this case we consider linear adjustment of the nominal cell operating temperature (NOCT), ignoring thermal capacitance and wind effects. In this study we focus primarily on impact of module optics on yield.

Finally, the circuit elements determine the current-voltage (IV) output of the module as a function of time. Our method allows implementation of iterative solvers e.g. to account for any power losses due to operating temperature when determining the cell temperature.

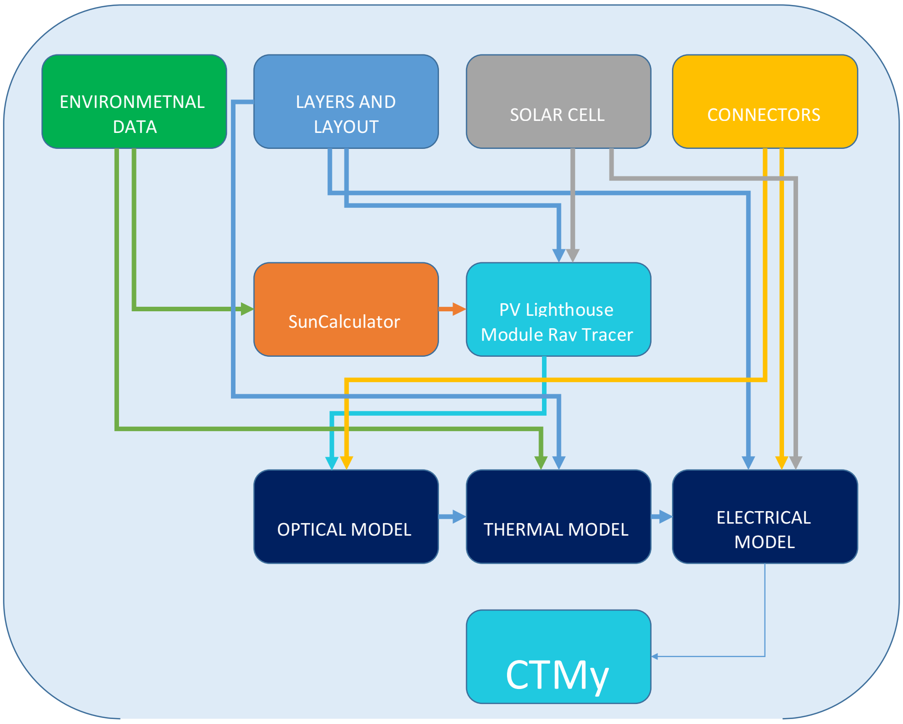

Fig. 1 Schematic of the CTMy model depicting the data flow and calculations performed to determine location specific losses.

Supporting information

A full write up of this work can be found in:

"Impact of PV module configuration on energy yield under realistic conditions" (DOI: 10.1007/s11082-017-0903-0), Journal of Optical and Quantum Electronics