Module Design for Lowering Field Operating Temperature

Project results and lessons learnt

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Executive Summary

Solar panels spend their entire operating lives out in the sun! Yet If the operating temperature for solar panels is too high, it has a negative impact on how much electricity the module can produce. Higher operating temperatures can also shorten the lifespan of the solar panels.

In this project, the methods and benefits of different module cooling technologies were investigated. Models and simulations were used to expand on previous research to discover and improve ways for lowering operating temperatures of modules.

The project supported a desktop study at UNSW, co-sponsored by the Australian Renewable Energy Agency (ARENA), materials manufacturer 3M Ltd and Australian Innovator 5B Pty Ltd to deliver modelling and optimisation for module and system design for lower field operating temperature.

Research focussed on conduction of heat, managing air flow and the reflection and radiation of light to reduce temperature effects. Models were built that looked at a whole-of-system analysis to develop practical, cost-effective and innovative module designs.

Initial studies have been completed and resulted in impressive outcomes that have prompted the filing of three related patents, significant interest at an international PV Module Reliability Workshop (NREL, March, 2018).

The improvements modelled will result in better module materials and changes to the way modules are manufactured and/or deployed, with a target cost of 5 to 10 USD per 1.5m2 of module.

Project Overview

Project summary

Operating temperature has a significant effect on both output power at temperature and the long-term durability of solar modules. A ten degree lowering module operating temperature in the field is projected to lead to a doubling in the module lifetime.

Success will see the delivery of cost-effective and innovative module designs to change to the way modules are manufactured or deployed.

Project scope

This project targeted support of a solar-module design study, targeting lower field operating temperatures. Through simulation of enhanced conduction and convective cooling, we have been able to model complex systems for subtle outcomes that would be difficult to measure in the field.

Outcomes

The project brought together the established expertise in cell and module design at UNSW, with the materials science and manufacturing expertise of partner 3M Ltd and innovators at Australian company 5B Pty Ltd.

Models were developed that assessed the different proposed technologies for module cooling, including the addition of mechanical fins (Vortex Generators) on the back of modules, the attachment of thermally conductive tape, the texturing of glass surfaces, mounting designs and ground covers.

The leading approaches of Vortex Generators and glass texturing were costed using established methods to assess for their manufacturing viability.

Transferability

Designs and methods modelled in the desktop study will be tested experimentally in an experimental stage of work, currently in progress.

Conclusion and next steps

A key output has been new partnerships with materials and module manufacturers with an interest in manufacturing and deployment tests of new designs. Building on the existing project partnerships, we have been able to design and propose a second experimental stage of work to take the module cooling methods to the next stage of development.

Success will see the delivery of cost-effective and innovative module designs to change to the way modules are manufactured or deployed.

Technology Summary

A high level summary of six of the models and simulations developed is outlined below, followed by a summary of the levelised cost of electricity analysis report.

Module Level Flow Simulation

Covering the rear surface of a PV module with small fins that act as vortex generators was simulated to estimate the cooling effect of a full-size module.

Simulating a full-size module allows for lateral flow which could reduce the effectiveness of vortex generators. This was not anticipated in the initial stage of the research which only investigated a 'slice' of the module (sub-module).

A new simulation method was developed in the second stage of the desktop study to manage the computational demands the for a full-size module.

The modelling showed that VGs can deliver a cooling benefit of 2-3 °C.

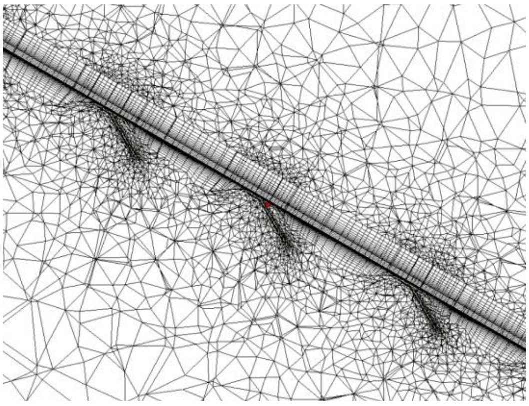

Figure 1: Simulation Mesh detail of the laminated module layers with rectangular fins/VGs

Surface-Surface Radiation Simulation

The impact of different ground conditions on PV module temperatures was investigated using models that assess how ground conditions affected the operating temperature and performance of the module taking into consideration different ground materials and water content. Thermal conductivity and the thermal mass are higher for the wet soil and therefore the ground surface temperature is lower throughout the day.

While different ground conditions lead to dramatically different ground surface temperatures, it was found that impact on the module surface temperature was not significant.

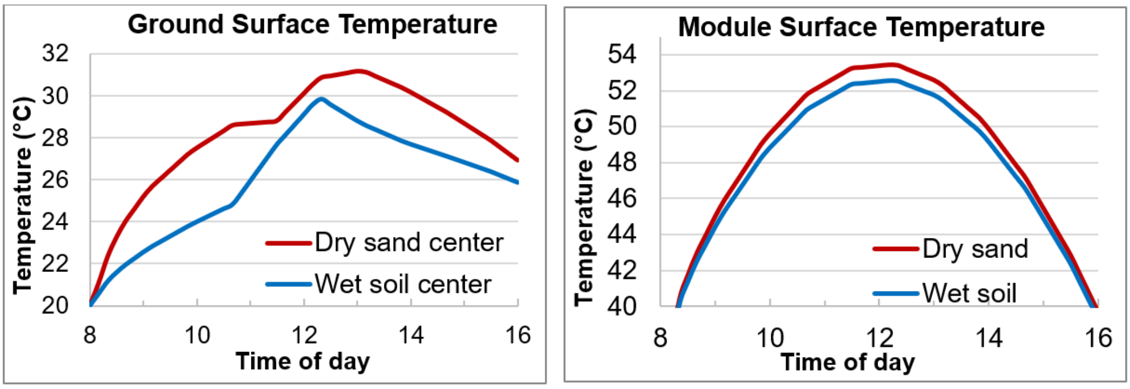

Figure 2: Modelled ground(left) and module (right) surface temperature as a function of time from 8 am to 4 pm (right). The maximum temperature difference at the module surface was found to be less than 1°C.

Module Thermal Emission Enhancement using Textured Glass

Differently textured glass was assessed to see the potential difference in radiative cooling. A ray tracing model evaluated the emissivity (spectral directional reflectance) of the glass.

Textured front glass increases the transmission of incoming solar radiation for PV modules. Mid-infrared thermal emission also increases for textured glass which lowers module operating temperatures.

The model found that there are more emissive front glass textures than the commonly used one in the industry (inverted pyramid). A dual sinusoidal and sinusoidal groove texture scheme were evaluated. Both performed better in terms of mid-infrared thermal emission and total solar transmission than the widely used inverted pyramid schemes and will be the subject of experimental study to lower module operating temperatures in future work.

Shape Optimisation for Vortex Generators on the Module Surface Rear

A model was used to further numerically determine the optimal shape of vortex generators. Previous reports gave only a partially optimised shape. The most recent model allows the shape of the vortex generator to be morphed in the direction which lowers the PV module surface temperature based on the sensitivity data generated. This technique was used to fine-tune the shape of the vortex generator. The trend between morphing methods is that the optimal shape is where the top of the vortex generator is thinned out, elongated, and bent towards the incoming flow, the side of the vortex generator is bent upward, coinciding with the flow direction.

Thermomechanical Stress Relief for Module Glass using Thermally Conductive Strips

The impact of thermally conductive ceramic strips when placed around the frame of a PV module was investigated using a thermal stress model. The thermally conductive strips not only reduce the temperature near the frame of the module, but they also reduce the local tensile stress on the glass. Reducing tensile stress could minimise the chance of glass shattering during operation. PV modules in the field will always suffer from inconsistent temperatures around the edge of the module. Glass breakage depends exponentially on the tensile stress of the glass. Therefore, reducing the temperature gradient with the thermally conductive strips can decrease the failure rate of the PV module. The thermally conductive strip not only increases the minimum temperature on the glass but also the temperature drops across a larger distance decreasing stress on the glass.

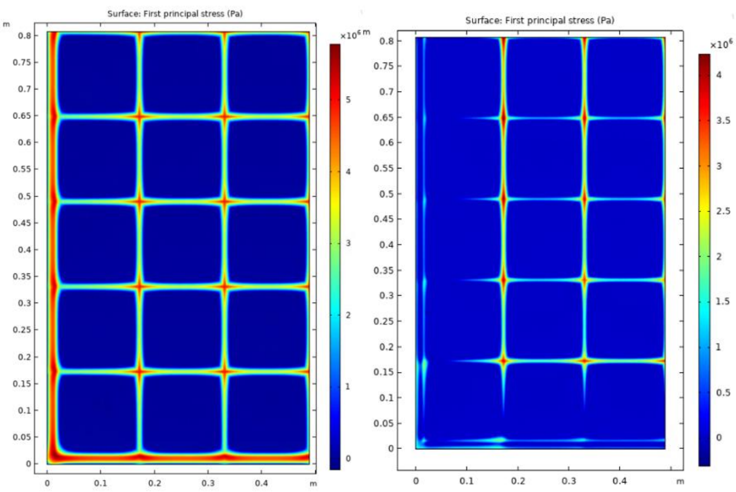

Figure 3: Tensile stress (Pa) on the front surface of the glass before (left) and after (left) thermally conductive strip, showing reduced stress with thermal conductive strip added.

Reduction in Moisture Ingress Rate and DC Leakage Current due to Module Cooling

Reducing the rate at which moisture enters the silicon solar cells (moisture ingress rate) and the leakage current between silicon solar cells is important as water vapour (relative humidity) can cause mechanical and electrical failures in PV modules.

Moisture is constantly being absorbed and diffused through the silicon edge sealant and the back sheet of the module. This process is thermally activated meaning that the diffusion coefficient of water vapour exponentially depends on the temperature.

A simulation was used to evaluate how thermally conductive strips also have the ability to reduce moisture ingress. When the module temperature is reduced, the rate at which water vapour is diffused into module reduces exponentially. Slowing down the moisture accumulation can therefore have a positive impact on the lifespan of a module.

Cost Analysis Report

A levelised cost of electricity analysis was used to consider the cost of implementation, the impact of cooling and any impact on module as-produced efficiency for two of the technologies outlined above.

The Vortex Generator technology could reduce the levelised cost of energy by 5-8% if implemented as an add-on during module manufacturing. A 2-3°C cooling benefit outweighs the estimated cost of USD 3-5/m^2. However, to add the technology to existing PV installations, the cost must be kept low (with a limit of around 15 minutes per m^2).

The Glass Texturing technology could reduce the levelised cost of electricity by 3-15 %. This technology can only be implemented when manufacturing PV modules. This benefit varies depending on the actual cooling effect, which has a wide estimate range of 1-5 °C. The cost of this technology is expected to be very low, at less than USD 0.4 /m^2.

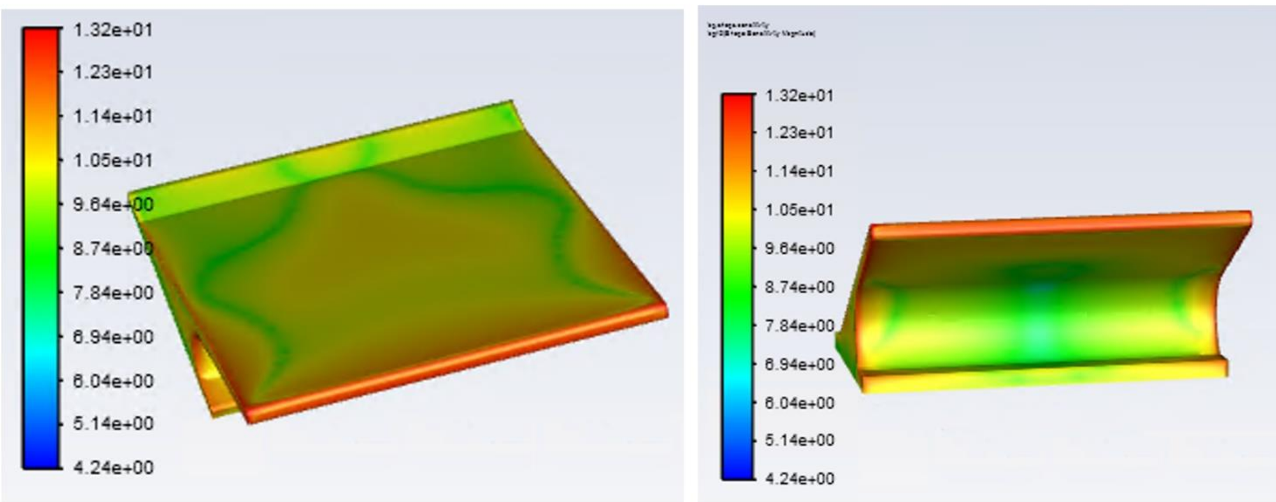

Figure 4: Fin/Vortex Generator shape mapping in FLUENT.

Lessons Learnt Report: Desktop Study an Effective way to Progress Early Stage Research and Industry Engagement.

Project Name: *Module Design for Lowering Field Operating Temperature and Improved Yield Study*

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Solar PV
State/Territory:	NSW

Key learning

- Desk top studies are an effective way to support innovation and to attract industry interest.
- This program of work started with initial models discussions at an industry forum. Cross sector interest motivated a greater investment in early stage modelling. Could have accelerated the effort and outcomes by acting sooner on the interest generated.
- The desktop study has identified opportunities as well as limitations on some approaches. It has been valuable to model technologies before field test to focus the scope. The next stage is to test the opportunities identified in real-world tests.

Implications for future projects

Consider initiating programs of work with desktop study to establish an understanding and to better engage with ARENA and with industry in framing the research questions.

Knowledge gap

None that are not already the subject of further study.

Background

Objectives or project requirements

The project aimed to use a desktop study to establish the potential for improving module lifetime and performance by including passive cooling in the module design