Study: Operating Temperatures of the 210mm Ultra-high Power Module

Trina's 210mm ultra-high power modules have huge potential to reduce Balance of System (BOS) costs and the Levelised Cost of Electricity (LCOE) of new PV project due to their high power and low voltage design. However, the high working temperature of such PV modules due to high current design has long been a concern. Based on comprehensive research and outdoor testing by Trina's engineering team, under the same installation and cooling conditions, the working temperature of 210mm and 182mm modules are nearly the same, as the cells only change the area with the same PERC structure and efficiency.

Operating temperature is worth studying as it affects the performance of a photovoltaic module. As the temperature rises, the open-circuit voltage (V_{OC}) will decrease, while the short-circuit current (I_{SC}) increases slightly. As the fill factor (FF) drops, the photovoltaic conversion efficiency and power of the solar cell decreases. In an energy yield simulation by the PVsyst software in Changzhou, Trina found that there is an energy loss of 0.20% for every 1℃ of increase in operating temperature.

Two factors that indicate the operating temperature is not negatively affected by the high-current output in a 210mm module

Firstly, a cell's current density is determined by its structure and efficiency. 210mm and 182mm cells have the same PERC structure and the efficiency is almost the same. With similar packing materials and under the same optical environment, there is almost no difference in the current density of such modules. The increase in current in the 210mm ultra-high-power module is driven by a larger cell (current = current density x cell area). Despite this larger current, efficiency remains the same with a steady current density and larger cell area.

Furthermore, for the same module efficiency, the amount of unutilised heat – the solar energy which cannot be converted into electric energy – is the same in terms of unit area. With the same installation and heat dissipation conditions, the operating temperatures for 210mm ultra-high power modules and 182mm modules are roughly the same. That means there is no risk of rising operating temperatures.

What is the actual operating temperature of an ultra-high-power module in Trina Solar's Vertex Series? Let us explore that from different perspectives, such as outdoor testing, heat transfer modelling, the empirical formula of module operating temperature calculations and finite element modelling analysis.

Outdoor testing results

An outdoor experiment was conducted in Trina's test field, which is located at the east side of the State Key Laboratory of Photovoltaic Science and Technology in Changzhou. The samples were mounted horizontally on a fixed rack with a tilt angle of 25°, and 0.5m above ground. Temperature data was collected using the HIOKI temperature sensor, which was attached to the same position on the backplanes of different modules. Figure 1 shows the setup of the experiment:

Figure 1：The setup of experiment

The tests were conducted between 3 September and 8 October 2020. Figure 2 demonstrates the weighted average operating temperatures of three different sizes of module（166*72, 182*72, 210*55):

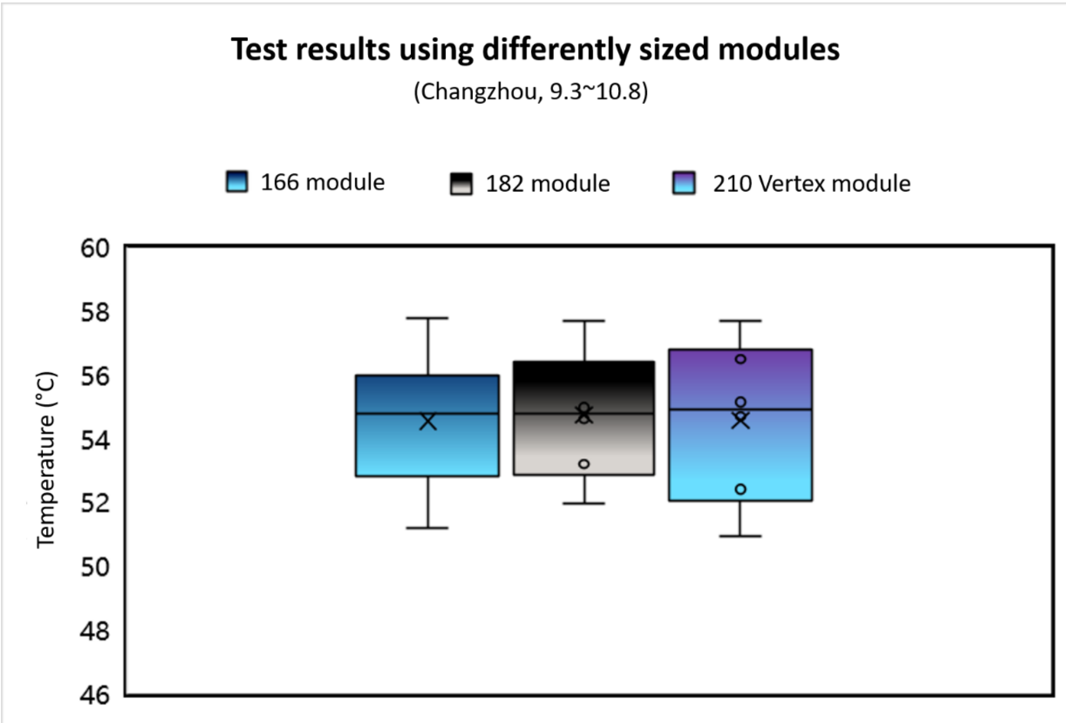

Figure 2：Test results using differently sized modules

The outdoor test results show that the difference in the average operating temperature of the three modules is insignificant.

Heat balance model

For photovoltaic modules, heat is transferred in three ways: conduction, convection and radiation. Conduction is how heat transfers across components within the modules. For a monofacial module, the heat energy transfer at a steady state is demonstrated in Figure 3.

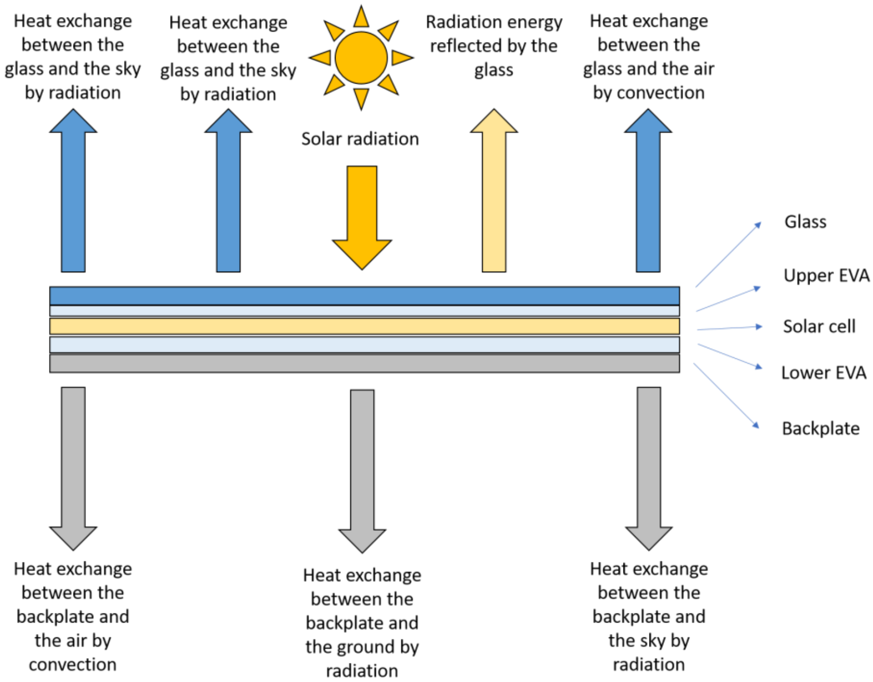

Figure 3： Demonstration of energy exchange in a monofacial module at steady state

When the operating temperature is at steady state, part of the solar energy is reflected into the atmosphere, with the rest converted into electric energy and heat. Taking the monofacial module as an example, according to the law of energy conservation, plus the energy exchange between the module and the surroundings, without considering the heat dissipation on the frame, the energy balancing can be described as the equation below:

$$I_{rec} = P/A + I_{rec}\rho_{PV} + h_{g,air}(T_{PV} - T_a) + \sigma F_{g,sky}(\varepsilon_g T_{PV}{}^4 - \varepsilon_{sky} T_{sky}{}^4) + \sigma F_{g,gro}(\varepsilon_g T_{PV}{}^4 - \varepsilon_{gro} T_{gro}{}^4)$$
$$+ h_{b,air}(T_{PV} - T_a) + \sigma F_{b,sky}(\varepsilon_b T_{PV}{}^4 - \varepsilon_{sky} T_{sky}{}^4) + \sigma F_{b,gro}(\varepsilon_b T_{PV}{}^4 - \varepsilon_{gro} T_{gro}{}^4)$$

Where,

I_{rec} is the solar irradiance on a PV panel in the unit area (W/m^2).

P/A is the power of the module per unit area;

$h_{g,air}$ is the convective heat transfer coefficient between the glass cover and the air;

$h_{b,air}$ is the convective heat transfer coefficient between air and backsheet ($W/m^2 \cdot K$);

σ is Stefan-Boltzmann constant σ = 5.67×10^-8 $W/m^2 \cdot K^4$;

ε_g is emission rate of glass;

ε_{sky} is emission rate of the sky;

ε_b is emission rate of the backsheet;

ε_{gro} is emission rate of the ground;

$F_{g,sky}$ is view factor between the glass and the sky;

$F_{b,sky}$ is view factor between the backsheet and the sky;

T_{sky} is sky temperature

Assuming that two commercial 182mm and 210 mm PV modules were mounted on a fixed rack with a tilt angle of 25 degrees; the boundary conditions and calculated results are summarized in Table 1, below:

Table 1：Boundary conditions and calculated results:

	182-535W module	210-545W module
Ambient temperature Ta(K)	298.15 (25°C)	
POA I_{rec} (W/m^2)	1000	
Average ground temperature T_{gro} (K)	302.55 (29.4°C)	
Sky temperature T_{sky} (K)	284.18 (11.03°C)	
Wind speed WS (m/s)	1.18	
Reflection index of module ρ_{PV}	0.10	
Installation angle (deg)	25	
Module size (m^2)	2.587	2.613
Result Tc (K)	323.32 (50.17°C)	323.26 (50.11°C)

According to the steady-state heat balance PV model, our analysis shows that a typical 182mm, 535W module and a 210mm, 535W module have virtually the same operating temperature.

Furthermore, the outdoor measured data in sunny weather conditions on 5 September was selected. The comparison of real tested results and results calculated via the steady-state heat balance model are shown in Figure 4 below:

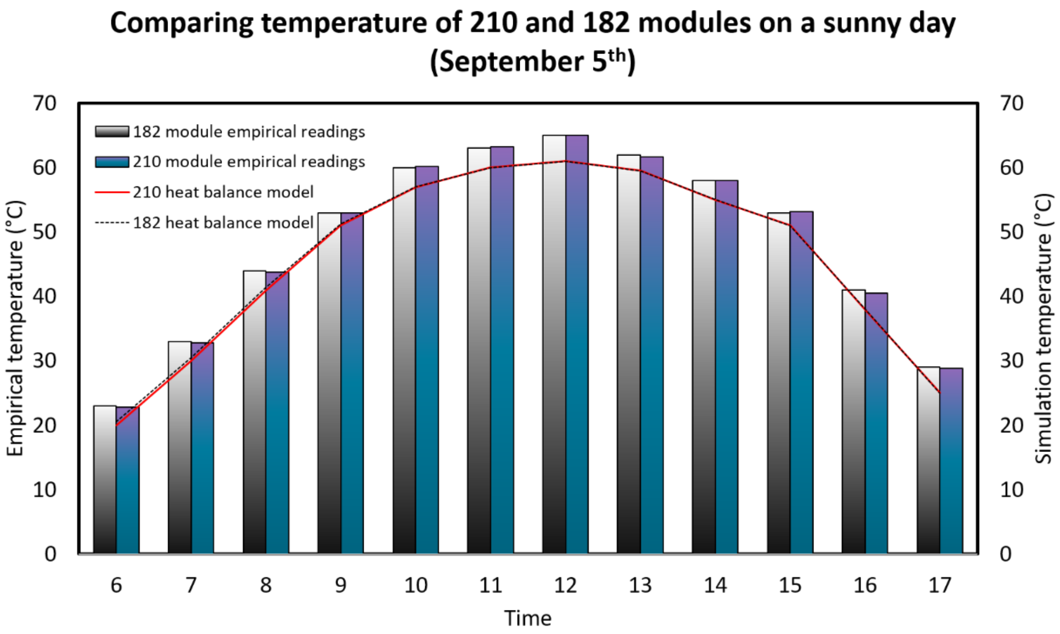

Figure 4：Comparing temperature of 210 and 182 modules on sunny day

The results shown in Figure 4 further prove there is no significant temperature increase for the low-voltage, high-current 210mm module. During the morning and evening, with lower irradiance and lower temperatures, the high-current 210mm module has a slightly lower operating temperature. A lower operating temperature can reduce power loss and thus enhance power generation performance.

Empirical formula

Many papers have proposed different operating temperature models. The most widely used models are those by Sandia, Faiman, PVsyst, Ross, and J. Kurnik. The J. Kurnik model indicates the operating temperature of a photovoltaic module: $T_{PV} = T_{amb} + K*G$ (K is a coefficient determined by conversion efficiency, the tilt angle of installation and wind speed, etc).

In other models such as the Ross, Nominal Operating Cell Temperature (NOCT) is also considered, where it measures module temperature with an installation angle of 45° on an open tracker, the POA irradiation at 800W/m^2 , the surrounding temperature of 20°C and 1m/s of wind speed. As NOCT is only checked while the module is under open circuit conditions, the measured and actual temperatures may differ. This paper takes the PVsyst cell model as the prototype, and the model described in the equation below:

$$T_c = T_a + POA\,\frac{\alpha(1 - eta_m)}{U_0 + U_1 \times WS}$$

- Tc = Cell temperature (°C)
- Ta = Ambient temperature (°C)
- α = Module adoption coefficient
- POA = Solar irradiance on a PV panel in the Plane of Array (W/m2)
- Etam = Module efficiency
- U0 = Conduction coefficient (Wm2K)
- U1 = Convection coefficient (Wm2K)
- WS = Wind speed (m/s)

Assuming modules are installed on an open fixed rack with excellent air circulation. The POA irradiance is 1000 W/m^2 , and the wind speed is 1m/s. Given U_0=29, U_1=0. The difference in efficiency between a 182mm, 535W module and a 210mm, 545W module is 0.18%. The boundary conditions and calculated results are listed as in Table 2 below:

Table 2： Boundary conditions and calculated results:

	182-535W module	210-545W module
Ta (°C)	25	
POA (W/m^2)	1000	
α	0.9	
eta_m	20.68%	20.86%
U_0 (Wm^{2}K)	29	
U_1 (Wm^{2}K)	0	
WS (m/s)	1	
Result Tc (°C)	49.617	49.560

The results in Table 2 show that the 210mm high-current module has virtually the same operating temperature as the 182mm module, giving it a slight edge.

Finite element analysis

A finite element modelling was carried out, the models including glass, EVA on upper and lower layers, cell, ribbons and backsheet. As there is no difference on the frame, the heat dissipation has been neglected to simplify the model. The boundary conditions for the simulations are set as follows: ambient temperature at 20℃, irradiance at 800W/ m^2, wind speed at 1m/s. Figure 5 shows the result: the temperatures of the 210mm and the 182mm modules are basically the same.

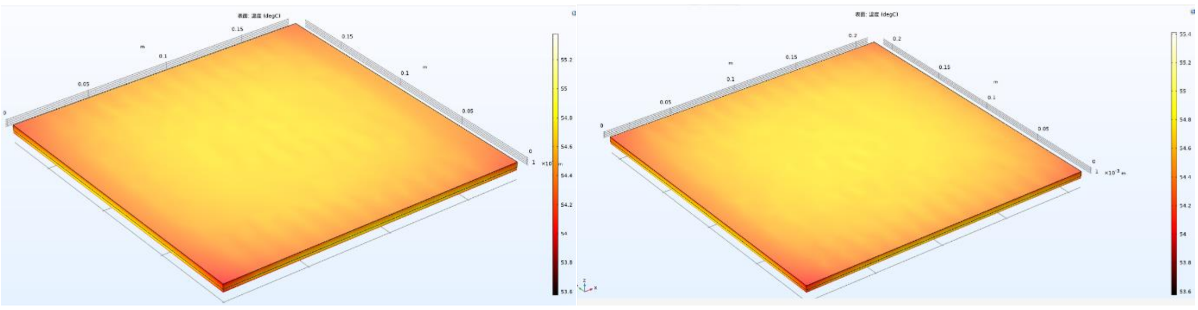

Figure 5：Finite element analysis results（Left: 182mm module, Right: 210mm module）

Conclusion

Trina Solar’s Vertex series ultra-high power modules are designed with lower voltage and high current characteristics, which increases the length of single strings. It helps lower the BOS cost and LCOE while driving grid parity. Research and simulations in the National Laboratory have proven the reliability of Vertex series modules with their ideal operating temperature, which can ultimately drive down the energy cost of photovoltaic modules.

About the Vertex Series 600W+/550W+

Trina Solar’s superior multi-busbar technology, along with its unique low-voltage, high-current design, combined with non-destructive cutting and high-density cell interconnect technology, helps enhance anti-cracking and lower hot-spot temperature properties. Low voltage, meanwhile, can effectively increase the length of a single string and boost power, which can ultimately reduce system and per-watt electricity costs.

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