Trina Solar

210 Vertex White Paper 2.0

Instructing Institution

State key Laboratory of PV Science and Technology

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1. Conception of the 210 Vertex Modules

To combat climate change, many governments have set carbon neutral targets. According to the International Renewable Energy Agency (IRENA), renewable energy will account for 86% of global electricity generation by 2050. The amount of photovoltaic power generation will experience a 10-fold increase compared to the amount generated in 2016, accounting for 25% of the total global power generation, and the total cumulative global photovoltaic capacity is expected to reach 8,519 GW in 2050. Shifting to a high percentage of renewable energy will be the transition direction of the world's energy structure, and photovoltaic power generation will become one of the world's most dominant sources of electric power in the future, as shown in Figure 1.

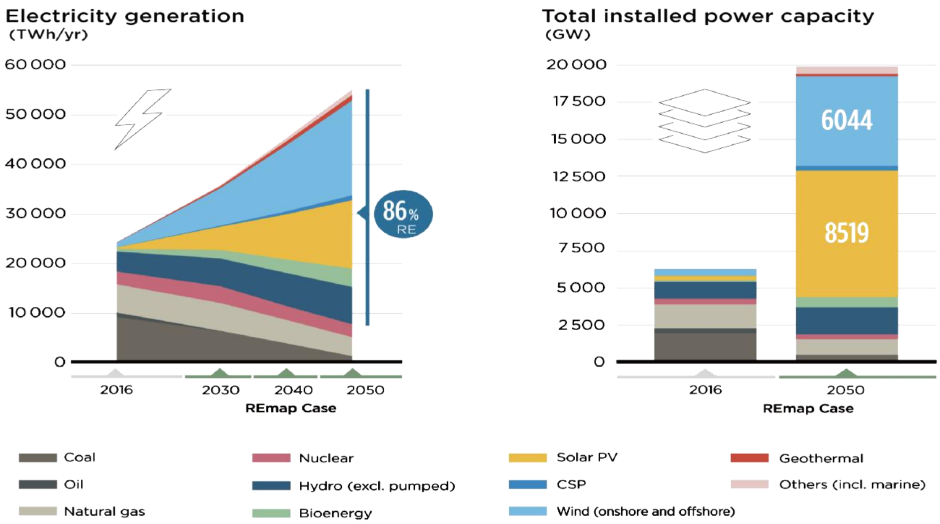


Figure 1 International Renewable Energy Agency (IRENA) forecast of future renewable energy structure

The future of photovoltaic (PV) power is promising due to the decreased cost of electricity generation. According to the Bloomberg New Energy Finance Limited (BNEF), the average levelized cost of energy (LCOE) of large ground-mounted PV plants worldwide has decreased by about 87% from 2009 to 2020, as shown in Figure 2.

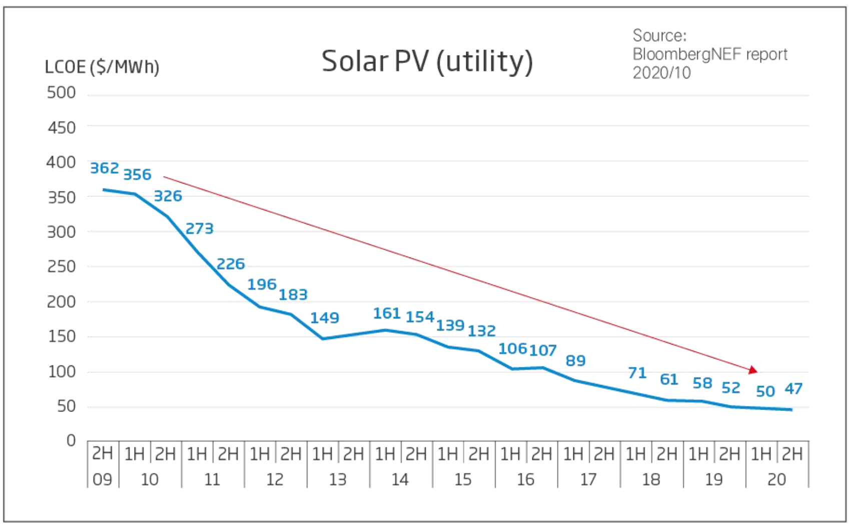


Figure 2. Development of levelized cost of energy (LCOE) in the photovoltaic (PV) industry

Compared to traditional fossil fuel power generation, the cost of PV power generation is now quite competitive and will continue to decrease in the coming years, leading to an era of fully affordable power.

The continuous reduction of the LCOE is the consensus and research direction of all PV companies. The LCOE formula presented in Figure 3 shows that reducing the initial investment and increasing the total life-cycle power generation of PV systems are effective means to reduce the LCOE. First, a lower initial investment means a lower module cost, which depends on module power and efficiency improvements. Second, increasing the total amount of power generated means increasing the module's power generation capacity per watt and requires the module to have a long power generation life.

$$LCOE = \frac{\text{Initial investment - Residual value of equipment + Operating cost + Interest}}{\text{Total power generation over the life cycle}}$$

Initial investment: Cost of module; Module power/efficiency

Total power generation: Power generation capacity per watt of the module; Service life of module

Figure 3. LCOE formula

Therefore, the development of a module with high power, efficiency, and reliability is the key to price parity.

2. Birth of 210 Vertex Modules

As the pinnacle of Trina Solar's high-power era, the Vertex series module has a maximum power of 670 W, with an average module efficiency of at least 21.5%. Moreover, it has both a high reliability e.g., 30-year linear power warranty and lower first-year and annual attenuation and a high power generation capacity with excellent low irradiance performance and low-light response. It has set a benchmark for module performance in the PV power generation era.

Figure 4. Vertex module series

Vertex modules are available in two types: the monofacial module and the bifacial module. With a power range of 410 to 670W+, they can be widely used in residential, commercial, and industrial rooftops and large-scale ground-mounted power plant, as shown in Figure 4. In various application scenarios, the power of Vertex modules is 40 to 90W above the industry average, creating more value to customers.

Trina Solar has taken into account the impact of electrical performance parameters on downstream terminals, the impact of larger size of module on installation and handling, and transportation logistics. The company is the first to propose a diversified layout design based on large 210mm wafers and a perfect combination of advanced technologies, such as multi-busbar (MBB), non-destructive cutting (NDC), and high-density encapsulation. The design solution is compatible with all types of downstream systems, paving the way for high-power modules in system integration applications, and will be the most preferred PV module solution for the next three to five years.

3. Technical Innovations of 210 Vertex Modules

3.1 Large Silicon Wafers

The wafer size in the PV industry has been changing following the development of the semiconductor industry. Along with the development driven by Moore's Law, the wafer size in the semiconductor industry continues to grow, resulting in a similar trend in the wafer size of the PV industry. As shown in Figure 5, the 5-inch, 6-inch and 8-inch wafers correspond to 100mm, 125mm, and 156mm wafer edge lengths, respectively. Since 2015, due to the need to improve efficiency and reduce costs, PV wafer manufacturers have fine-tuned the wafer size several times based on 8-inch wafer technology. As a result, various sizes of silicon wafers, such as M2 (156.75mm), M4 (161.75mm), G1 (158.75mm), and M6 (166mm), have appeared in the market.

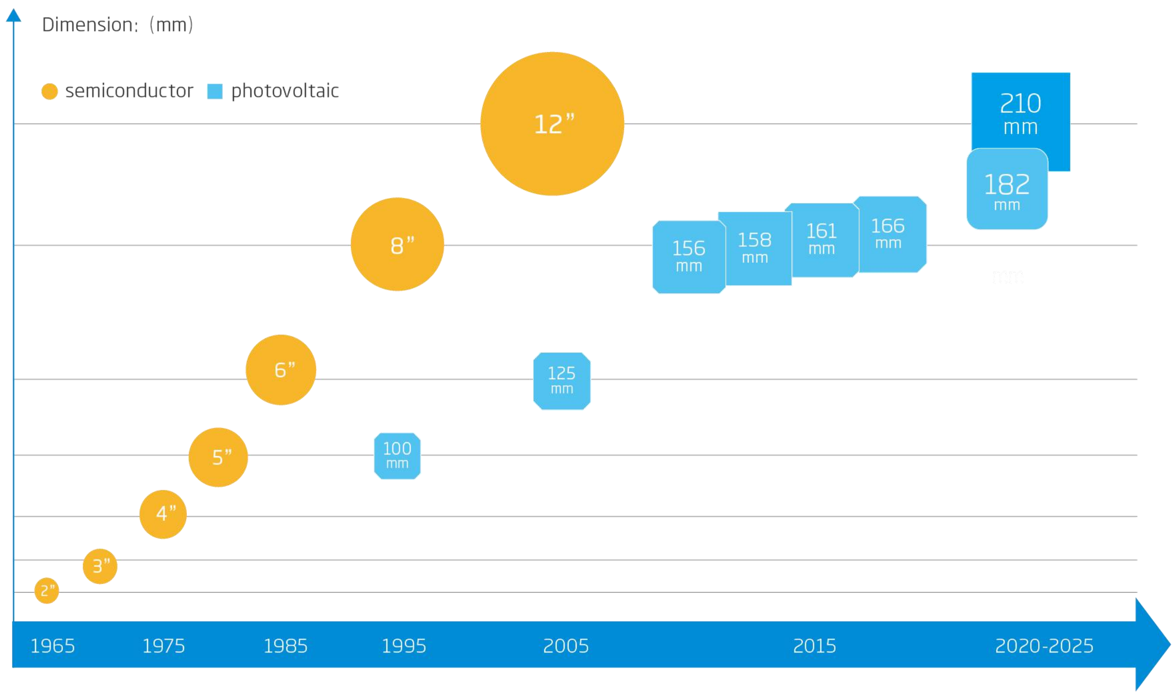


Figure 5. Development of silicon wafer size in the semiconductor and PV industry

The variety of wafer sizes leads to a wide range of module powers and sizes, causing many challenges for downstream system design and applications. For example, due to differences in module power, size, and mounting hole, PV system design needs to be adjusted accordingly. On August 16, 2019, Tianjin Zhonghuan Semiconductor Co. Ltd announced that 12-inch Cz-Si technology would be applied to the solar industry and launched the 210mm PV monocrystalline silicon wafer, which has been completely dominating the semiconductor industry since 2005. The next-generation 18-inch wafers, however, have not been able to replace the 12-inch wafers for mainstream size due to factors such as the hot-field size, crystal pulling process, breakage rate, and high cost.

Therefore, 210mm is almost the upper limit of silicon wafers in the PV industry, and it is expected that this roadmap will persist for at least 5 to 10 years. This helps to standardize not only the sizes of PV modules but also the design of downstream PV systems. Thus, Trina Solar chose 210mm as the wafer size for the new generation of PV modules.

3.2 MULTI-BUSBAR (MBB)

MBB technology is a technical solution to achieve the best balance between reducing electrical losses and improving optical utilization. Currently, MBB has become the mainstream technology in the industry.

In terms of the electrical aspects, if a five-busbar (5BB) design is used in the 210mm cells, the current lateral collection path will increase by more than 30% compared with the 158mm cells. The application of MBB technology can significantly shorten the path of current flowing through the finger to the busbar by more than 50%, effectively reducing the power loss and improving the current collection capability. Moreover, the sensitivity of the module power to micro-cracks is significantly reduced, and the improvement in the comprehensive electrical performance increases the module power by 1 to 1.5% relative to the 5BB design, as shown in Figure 6a and 6c.

Another advantage of MBB technology is its increased optical utilization. The use of round wire enables the incident light to obtain about a 75% utilization in the wire area at any incidence angle. In comparison, flat ribbon is applied in traditional 5BB technology, and the utilization of incident light is only 5% or less. The improved optical utilization of the module leads to a 1 to 1.5% power increase, as shown in Figure 6b.

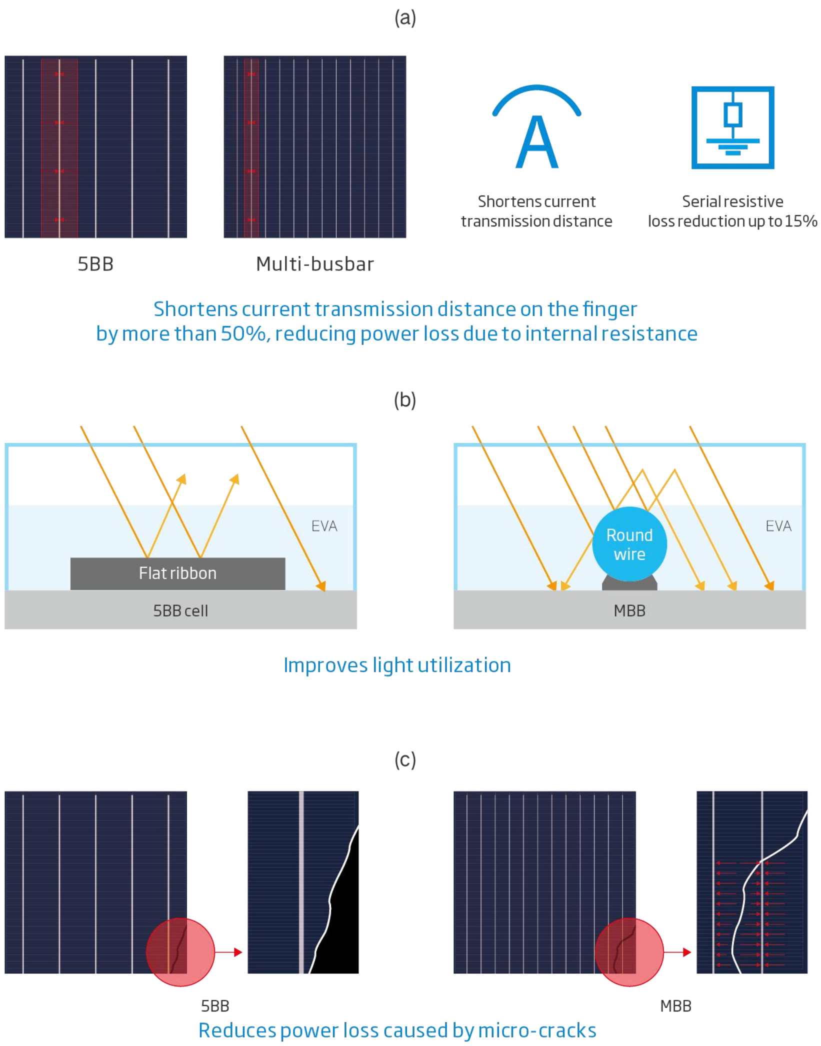
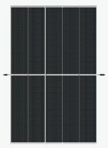
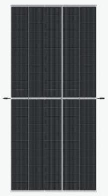
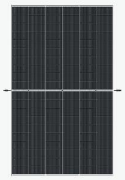
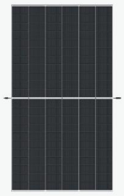


Figure 6. Comparison of multi busbar (MBB) and 5BB cells in terms of (a) current transfer path, (b) light utilization, and (c) resistance to micro-cracks

3.3 Diversified Layout Design

Traditional PV modules generally use a 6 × 10 or a 6 × 12 layout, where 6 represents cell column of a PV module and 10/12 represents full cell number within each cell column. The Vertex modules, however, based on the characteristics of 210mm wafers, introduce various layout designs, e.g., 5 × 8, 5 × 10, 5 × 11, 6 × 10, and 6 × 11, to provide customers more options in different applications. These layouts are designed to balance the electrical performances of the modules, to optimize the area, weight, and other properties, and to improve the installation compatibility while avoiding additional costs. The complete list of Vertex module layouts currently available is shown in Table 1, which are suitable for a variety of applications.

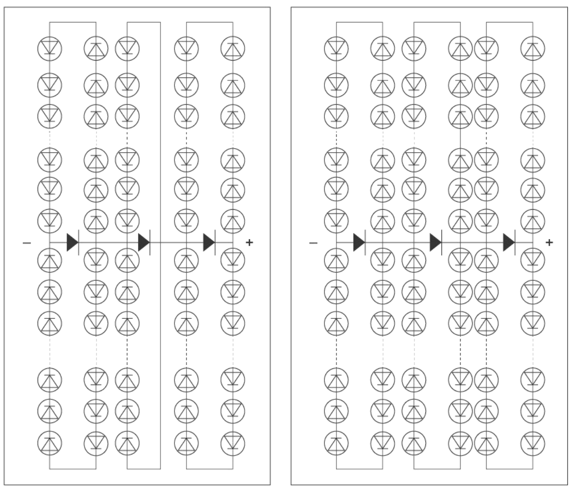
Table 1. Layout design of Vertex series modules

	Vertex S 09 series	Vertex 18 series	Vertex 19 series	Vertex 20 series	Vertex 21 series
Layout design	210-40	210-50	210-55	210-60	210-66
Module dimensions(mm)	1754*1096*30	2187*1102*35	2384*1096*35	2172*1303*35	2384*1303*35
Power range	380~410W	480~510W	525~555W	580~610W	635~670W
Applicable scenarios	Residential rooftops 	Residential and industrial rooftops 	Ground mounted power plant 	Ground-mounted power plant; fishing-photovoltaic and agricultural-photovoltaic complementation 	Large scale ground-mounted power plant; large scale industrial 

Compared with traditional 158mm cells, the area of the 210mm cell is increased by about 75%, and the output current is mainly determined by the minimum cell area and the module circuit. The Vertex DE19/20/21 series follows the half-cut design of traditional modules, and the short-circuit current at STC is increased to about 18A. In addition, the open-circuit voltage of the modules is determined by the number of cells and the layout, and the open-circuit voltage of the Vertex DE19/20/21 series is 37V to 46V, which is lower than that of traditional 158, 166, and 182 modules. The Balance of System (BOS) can be further reduced by increasing the string length in the system.

Since the current can be greatly influenced by the inverter, to balance the current and voltage values of the modules, Trina Solar has adopted an innovative 1/3-cut design for the DE09/18 series modules. In the 1/3-cut design, as the name implies, a whole cell is cut into three parts, which are arranged in arrays. The short-circuit current of the module is about 12A, and the open-circuit voltage is about 41V/51V, both of which are within the acceptable range for residential/distributed projects, making it a mass-producible solution with both practicality and safety.

The circuit layout and diode distribution are shown in Figure 7. In addition, the non-destructive cutting technology reduces the potential risk of micro-cracks caused by large wafer sizes.



09/18/19 series   20/21series

Figure 7. Circuit layout and internal diode distribution of the Vertex series

3.4 Non-Destructive Cutting Technology (NDC)

Traditional cell cutting is divided into two steps. First, the cell surface is melted by a laser at a high temperature of over 1500°C, and then after reaching a certain depth, the cell is separated along the laser line under mechanical stress. The technique will generally produce micro-cracks on the cutting edge, as shown in Figure 8b, which eventually affect the mechanical strength of the cell.

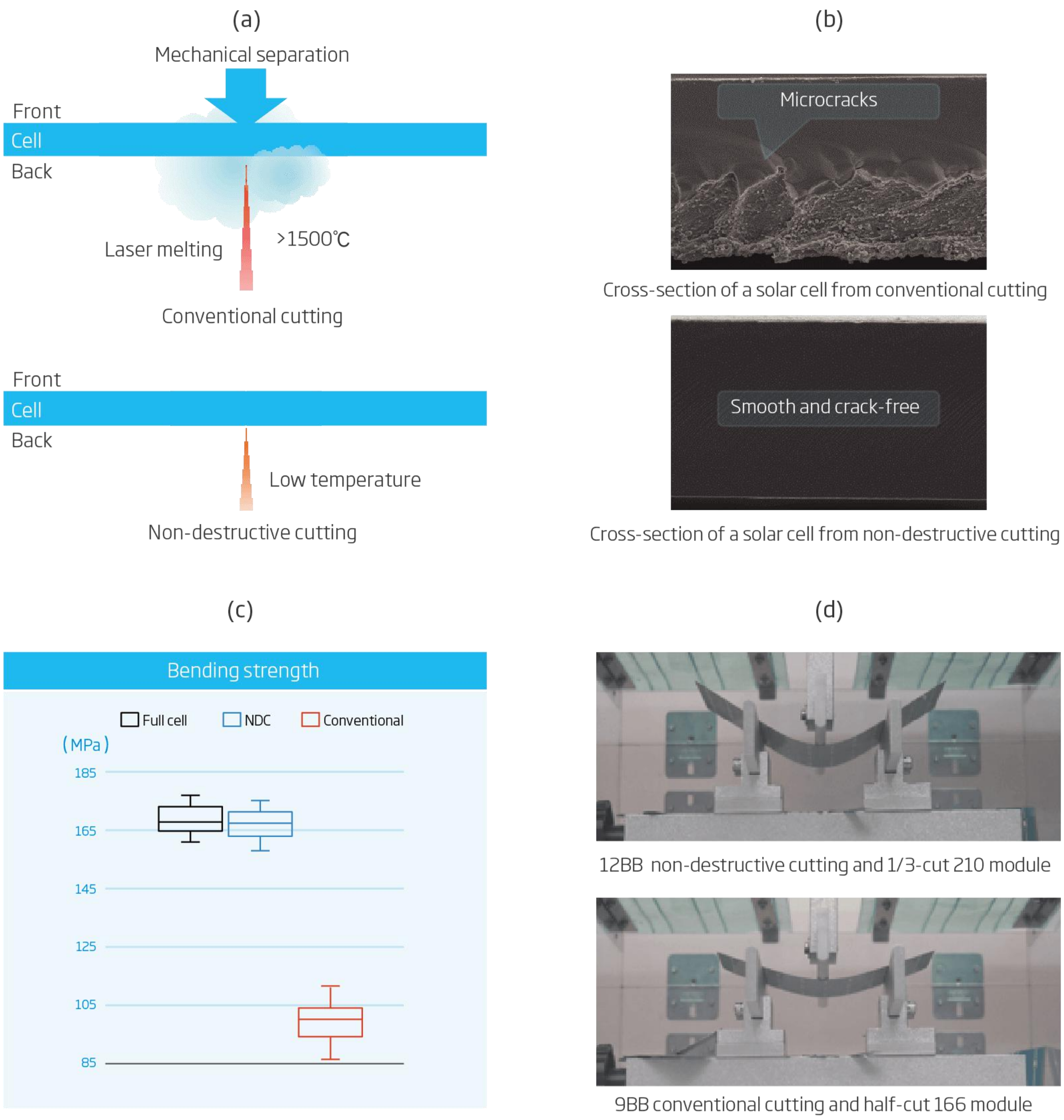


Figure 8. Comparison of traditional and non-destructive cutting techniques: (a) schematic diagram, (b) cross section, (c) three-point bending test, and (d) 210mm non-destructive cutting vs. 166mm traditional cutting

To address this problem, Trina Solar has adopted non-destructive cutting technology. Using low-temperature laser technology, based on the principle of thermal expansion and contraction, the cells are naturally separated due to thermal stress. As shown, the cutting edge is very smooth, without any micro-cracks. The mechanical strength of the cell after non-destructive cutting is comparable to that of the full cell and is much higher than that produced using the traditional cutting techniques, as shown in Figure 8c.

Mechanical tests show that the 210mm non-destructive cut cells have a bending strength of about 1.5 times that of traditional cut cells, and the cell deformation limit is 1.5 to 2.5 times higher than that of 166mm half cells with traditional cutting, as shown in Figure 8d.

3.5 High-Density Encapsulation

As shown in Figure 9a, the adjacent cell gap within one string is generally around 2mm. To increase module efficiency, more cells need to be placed in the limited light receiving area. With breakthroughs in technologies related to ribbon treatment and soldering processes, high-density encapsulation technology has been developed.

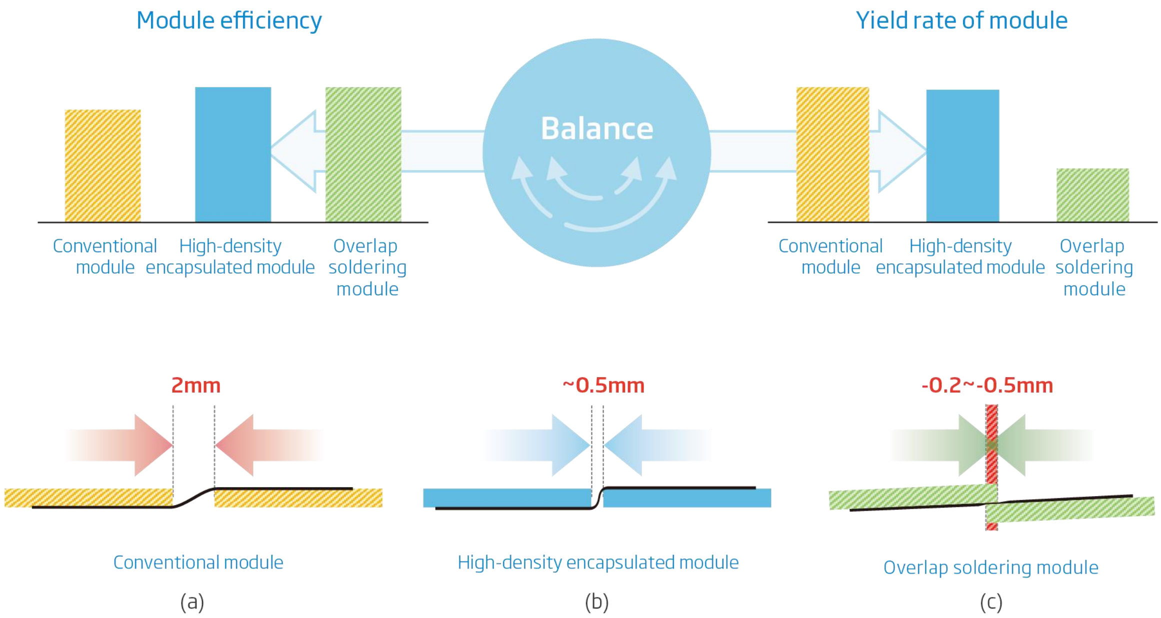


Figure. 9 Schematic diagram of the soldering structure of traditional, high-density encapsulated and overlap soldering modules and comparison of their efficiencies and yields

The current high-density encapsulation techniques can be divided into two types:

(1) By flattening the wire (i.e., the area connecting the adjacent cells), the cell distance is reduced to around 0.5mm, which reduces the module size and effectively improves the module efficiency. In this method, there is still a small gap between cells. However, the yield risk in the production process and the risk of micro-cracks forming during use are reduced.

(2) By overlapping a small part (0.2 to 0.5mm) of one cell with another cell, the gap is completely eliminated. This method can minimize the module size and increase the module efficiency slightly compared to the above method. Because of the overlapping, the damage rate in the production process is higher, and the deformation of cells during actual use increases the risk of micro-cracks.

After a comprehensive evaluation, Trina Solar selected the more mature and low-risk approach (1) as the high-density encapsulation solution for the Vertex modules. The module efficiency is increased by 0.2% to 0.3% while maintaining the same yield level.

3.6 Innovative Low-Voltage and High-String Power Design

A typical process from solar cells to modules, strings, arrays, and a solar power plant is shown in Figure 10. A certain number (typically 60 or 72) of solar cells are encapsulated in series and parallel to form PV modules, which are connected in series to form strings. The strings are then connected in parallel to form an array, and the arrays then form a PV power plant of a certain scale.

In general, two strings of modules are mounted on a support racking, which is fixed to the ground. For tracker, the modules can have up to 3 to 4 strings. For a certain capacity, the higher the string power is, the fewer the number of strings, which reduces the cost per-watt of the various components, such as the mounting system, piles, cables, and cable tray, thus reducing the whole system cost.

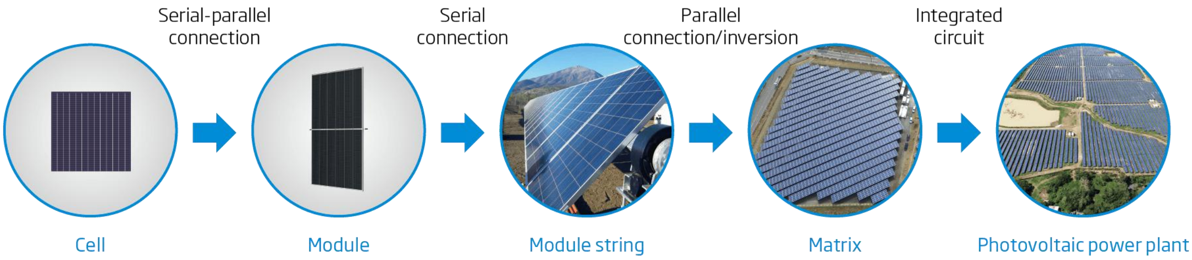


Figure 10. Connection between solar cells, modules, strings, arrays, and PV system

Typically, the power of a single module is about 400 to 600W+ and the voltage is 40 to 50V, which cannot turn on the inverter. Therefore, a certain number of modules must be connected in series to form a string to reach the starting voltage of the inverter and generate AC power. The string can be considered to be the basic circuit unit of the PV system. To understand the string power (string capacity), an analogy in terms of different elevator capacities is provided. To accomplish the target of lifting 36 people upstairs, different elevators can be used. Elevator A has a capacity of 18 people, so the task requires two elevators, while Elevator B has a capacity of 12 people, so the task will require three elevators. The greater the capacity of a single elevator is, the fewer elevators are needed, resulting in a smaller initial investment. Here, the capacity of a single elevator is equivalent to the string capacity, and the number of people carried in the elevator is equivalent to the number of modules that can be connected in a string.

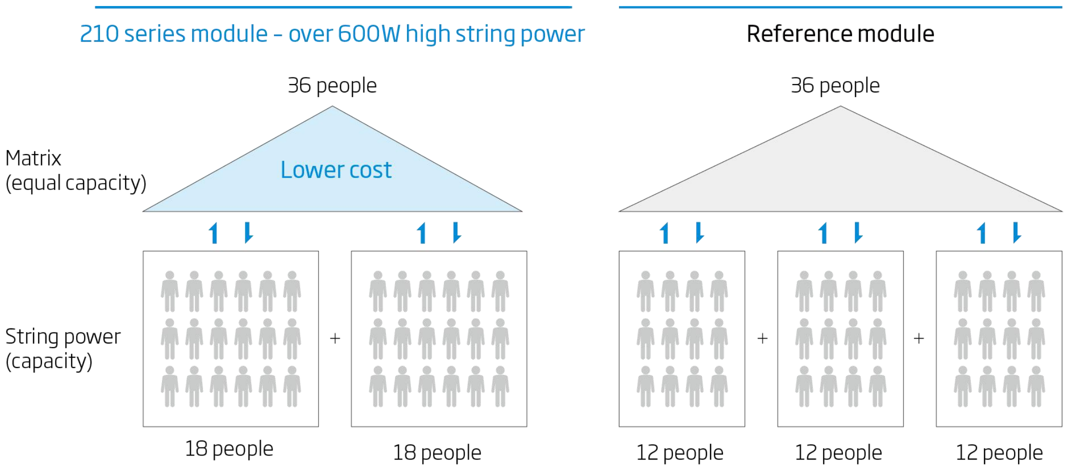


Figure 11. Example of elevators with different capacities

Similarly, the larger the string capacity is, the smaller the number of strings required becomes, which is equivalent to a reduction in the number of elevators required. As a result, the related initial investment and cost sharing of the system will be reduced given a certain installed capacity of the PV plant.

The above example demonstrates the concept of string power enhancement. An analysis of the low-voltage and high-string power design of the 210 series module is further provided below.

String power is equal to the number of modules that can be connected to the string multiplied by the power of a single module: $P_{\text{string}} = N \times P_{\text{module}}$

The number of modules that can be connected in a string, according to the PV system design specifications, needs to satisfy the following equation:

$$N \leq \frac{1500V}{V_{OC} \times [1 + (t - 25) \times K_v]}$$

where K_v is the open-circuit voltage temperature coefficient of the PV module, and t is the ultimate low temperature of the PV module under the operating conditions.

To increase the number of modules that can be connected, the smaller the value of V_{OC} is, the greater the number of modules that can be connected at a given system voltage becomes.

The power of an individual module is equal to the open-circuit voltage V_{OC} multiplied by the short-circuit current I_{SC}, i.e., $P_{\text{module}} = V_{OC} \times I_{SC} \times FF$.

To increase the number of connected modules, V_{OC} needs to be reduced. However, by increasing the current I_{SC}, it is possible to simultaneously increase both the number of connected modules and the module power, thereby achieving the goal of increasing the string power.

As shown in Figure 12, the power of the PV modules has increased from just about 290W to 670W in the last 10 years. Furthermore, the PV system voltage has also increased from 600V to 800V, to 1000 V, and to the current value of 1500 V. The number of modules that can be connected in the string has increased from 10 to more than 30. From a system point of view, both the system voltage and the module power increase are manifested in the increase in the string power, from 2900 W in the past to 19,430W now. This is ultimately reflected in the BOS cost reduction, including mounting system, piles, direct current (DC) cables, labor, and other costs.

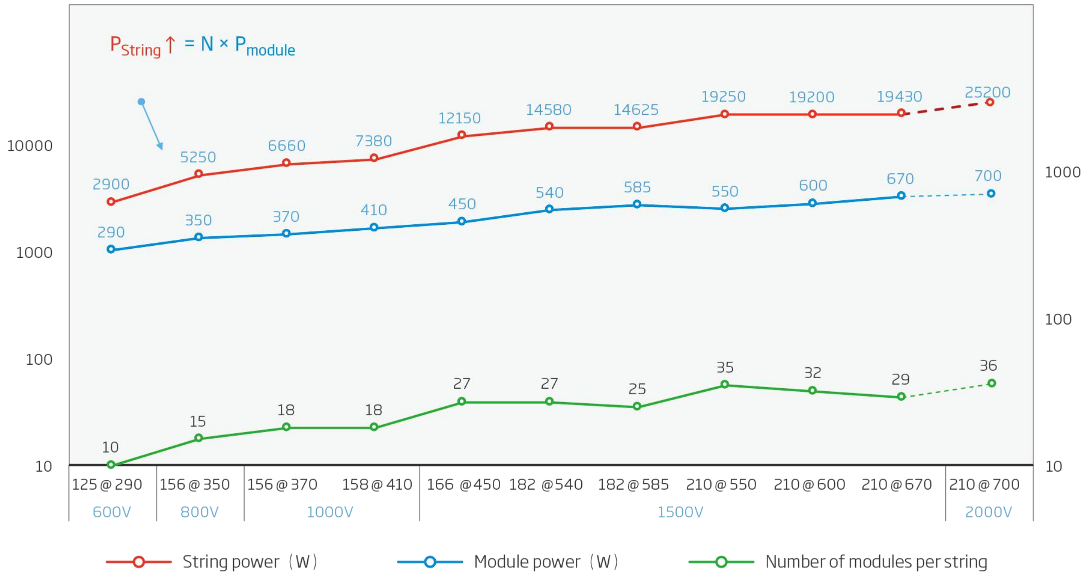


Figure 12. Development trend of string power

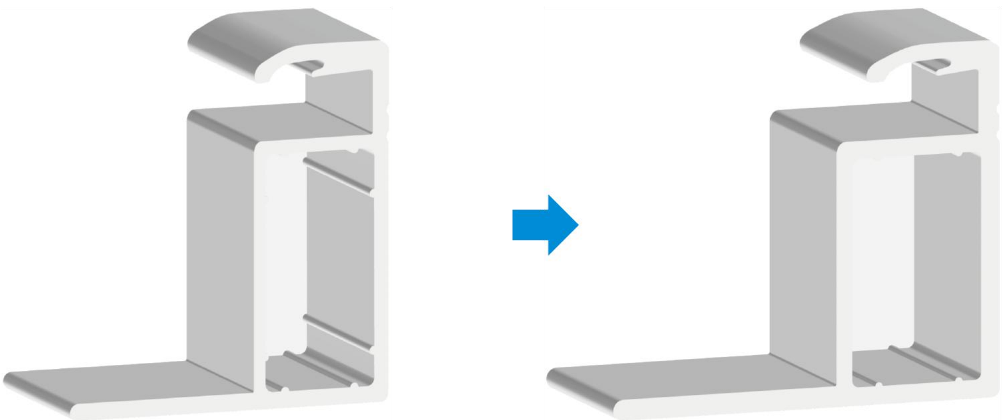
The design of the 210 Vertex module not only involves a larger wafer or module size, but there is an essential design concept innovation to achieve a low voltage and a high current. Such a design concept extends beyond the framework of the module level to the whole system. The low-voltage, high-current design concept is consistent with both the industry development trend and the end customers' target of value maximization.

4. Reliability Assurance of Vertex 210 Modules

4.1 Optimization of Mechanical Load Performance

The deformation and stress distribution inside the module mainly depend on the structural strength of the module itself. For this reason, Trina Solar has optimized its Vertex module. Compared with the conventional structure, the 600W+ module has the following optimizations, which ensure excellent mechanical load performance.

1. Frame thickness reinforced
2. Frame chamber enlarged
3. Large washer installed, clamping enlarged
4. Truss design and connector optimized



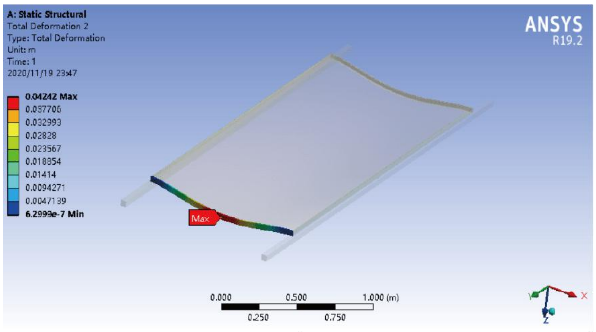
Conventional structure

600W+ structure

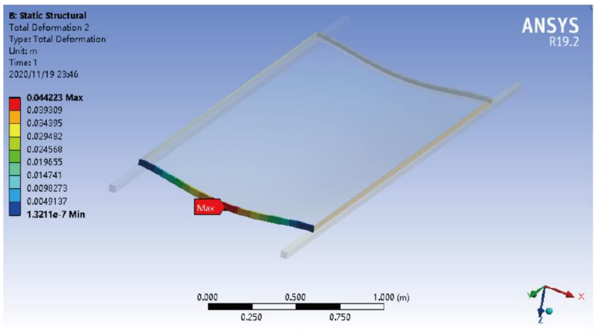
Figure 13 Optimized 600W+ module frame

To compare the load performance of the Vertex module with those of other modules, Trina Solar conducted simulation experiments on the load performances of Vertex modules by combining different module designs and using finite element analysis. Using the 210-55 module as an example, Figure 14 shows the shared-beam installation scheme for bifacial modules and the multi-point installation along the long side for mono-facial modules employing a single-axis tracking system. Compared to the competitor module with 72 series (sized 2256mm*1133mm), the load performance of the Vertex module is slightly better.

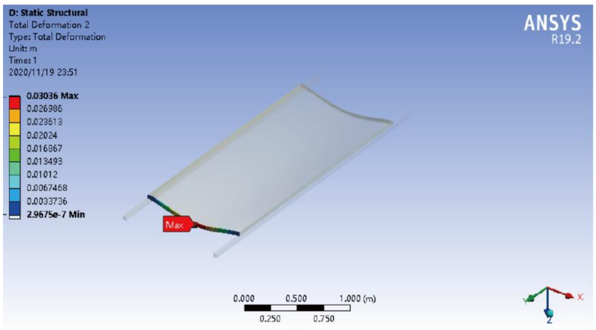
Power degradation after mechanical load test depends not only on the deformation of the module but also on the deformation resistance of the cells themselves. Using non-destructive cutting technology, each small segment of cell is guaranteed to have a bending strength close to that of the whole cell. Since the cutting produces no micro-cracks on the cutting edge, the cells have a significantly greater deformation resistance compared to laser-cut cells. Load tests were conducted according to the specifications in IEC61215 for modules installed in the conventional cross-beam configuration, as shown in Figure 15, and the Vertex single-glass module demonstrated a 1% to 2% decrease in the power attenuation rate (absolute value) compared to that of a typical laser-cut single-glass module.



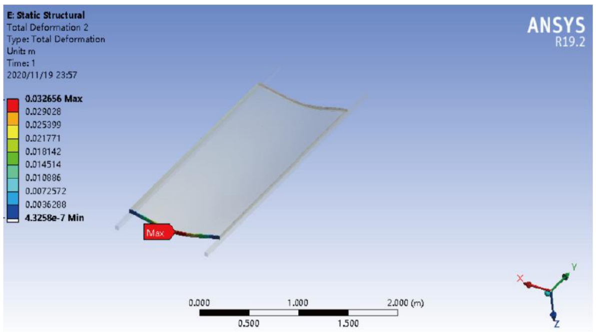
210-55 single glass



Reference module -72 single glass



210-55 double glass



Reference module - 72 double glass

Figure 14 Load simulation comparison of Vertex 210 module and reference module

Table 2 Deformation comparison of 210 Vertex module and reference module with 5400 Pa of load on the front surface and shared beam on the long side

Type	210mm-55 monofacial	Reference module -72 monofacial	210mm-55 double glass	Reference module -72 double glass
Module dimensions (mm)	2384*1096	2279*1134	2384*1096	2256*1133
Maximum deformation(mm)	42.4	44.2	30.4	32.7

Measured power attenuation after loading tests of Vertex module vs. conventional laser-cut module

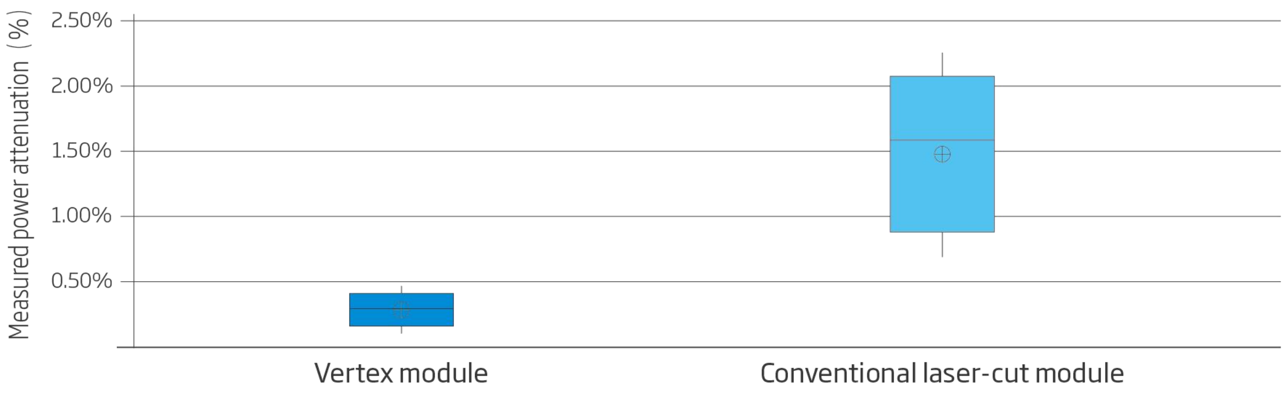


Figure 15 Comparison of power attenuation rates of Vertex single-glass module and conventional laser-cut single-glass module

The above results show that optimized Vertex modules have a reduced risk for cracking and less power attenuation during service, and hence, safety is assured. In addition, Trina Vertex double-glass modules with shared beam installed on the long side with clamp have passed ±1000-Pa dynamic load tests at a 20-times enhancement without any changes in their exterior appearances. For single-glass modules with cross-beam screw installation, no exterior appearance change was observed after load testing at a six-times enhancement, and the power attenuation was less than 0.8%.

4.2 Prevention of Hot-Spot Risks

According to the IEC61215 standard, when the working current of a photovoltaic module exceeds the photocurrent of a single cell in the module, the cell will be placed in reverse bias state. This consumes more power and can easily cause hot spots. The power loss generated by a shaded cell can be approximately expressed as $P = V_{rev} \times I_{rev} + V_{rev} \times I_{ph}$;

V_{rev} is the reverse bias voltage at the two terminals of the shaded cell, I_{rev} is the reverse bias leakage current, and I_{ph} is the photocurrent of the shaded cell. Here, $V_{rev} \times I_{ph}$ is determined by the magnitude of the photocurrent of the mismatched cell and the reverse bias voltage at the two terminals, and this causes the cell to heat up uniformly. $V_{rev} \times I_{rev}$ is the non-uniform heating localized at the position of the current leakage of the cell. This portion of heating is due to the non-uniform leakage current that is caused by the manufacturing process and material defects of the cell. This usually heats up the location of the current leakage, and it is the main reason for the local temperature rise of the cell.

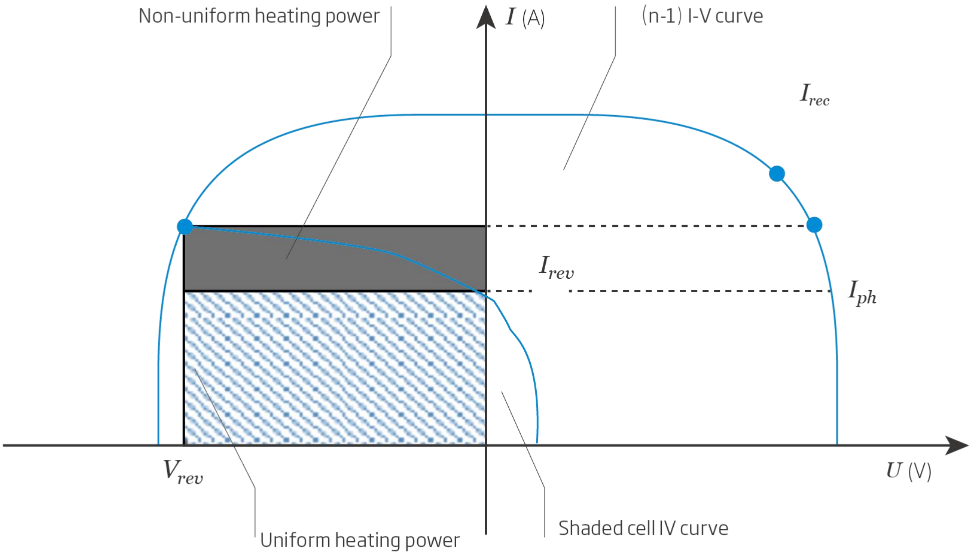


Figure 16 I-V characteristic curve of solar cells with hot spots
Reference: Zhang Z. Photovoltaic System Power Generation Technology [M]. Beijing: Publishing House of Electronic Industry, 2020: 20-21, 126-127.

The most severe case of hot spot occurs just before the diode is about to conduct. All of the voltages generated by the unshaded cells, i.e., the voltage sum of (n−1) cells in the series, are applied across the two terminals of the shaded cell:

$$P = (n-1)V_{cell} \times I_{rev} + (n-1)V_{cell} \times I_{ph}$$

where V_{cell} is the cell voltage.

The temperature of the hot spot is determined by the power dissipated per unit area. When the manufacturing process of the cells is fixed, both the photocurrent density per unit area and the leakage current density are uniform. The greater the number of cells connected in parallel to a bypass diode, the higher the reverse bias voltage, the greater the reverse bias leakage current, and the greater the power consumed by the shaded cells per unit area. As a result, the higher the corresponding temperature and the greater the risk of hot spots. However, this is not related to the size of the silicon wafer. When the number of cells connected in parallel with a bypass diode is fixed, controlling the leakage current level of the cell can also effectively reduce the temperature of the leakage point of the non-uniform heating defect on the unit area, or the temperature of the local hot spot.

The number of cells in a single series protected by a bypass diode is 24 on 210-40 module. On 210-55 and

210-66 module, the number of cells in a series protected by a bypass diode is 22. On 210-60 module, the number of cells in a series protected by a bypass diode is 20. These are all less than the number, 24, of cells on the traditional module with 72 pieces, so in theory, the 210-55/60/66 modules should be better than the 166/182-72 modules.

Table 3 Number of cells protected by a single diode

	210-40	210-50	210-55	210-60	210-66	166-72	182-72	182-78
Number of cells (*n*) protected by a single diode	24	30	22	20	22	24	24	26

To reduce the risk of hot spots, Trina Solar has adopted a hierarchical control of the leakage currents of solar cells. For the 210-50 module with a relatively high reverse bias voltage, a more stringent standard for the leakage current was adopted. Compared with traditional standards, the acceptable range is significantly narrowed. This product design scheme with a relatively high reverse bias voltage can still effectively control the risk of hot spots.

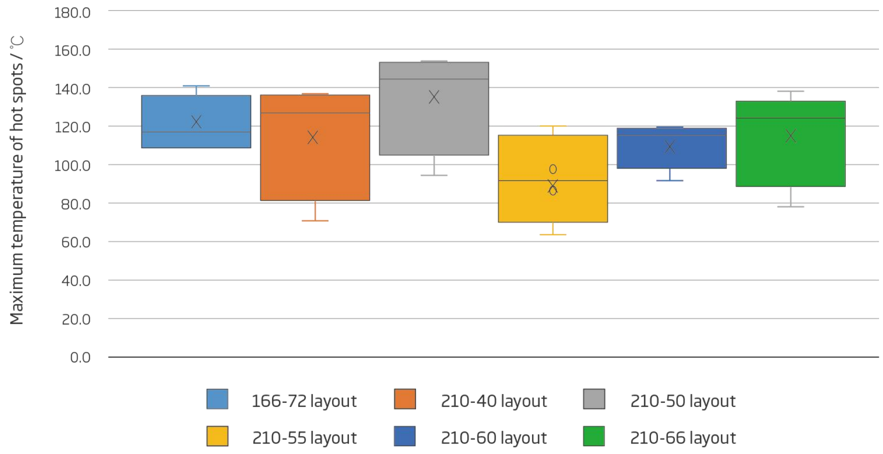


Figure 17 Comparison of indoor hot-spot temperatures of 166 and 210 modules

Based on the IEC61215 standard, a hot-spot test was carried out on the Vertex module and it passed the test. Figure 17 shows a comparison of the maximum hot-spot temperatures of 166 and 210 single-glass modules. The hot-spot temperature of the 210-50 single-glass module is safe and controllable. The maximum hot-spot temperatures of 210-40, 210-55, and 210-60 modules are all lower than that of the 166 single-glass module. Outdoor measurements have also indicated that the Vertex module has excellent resistance to hot spots. According to outdoor measurement data (shown in Figure 19), the hot-spot temperature of the 210-55 single-glass module is about 20°C lower than that of the 166 single-glass module. Therefore, the risk of hot spots on the Vertex module is controllable.

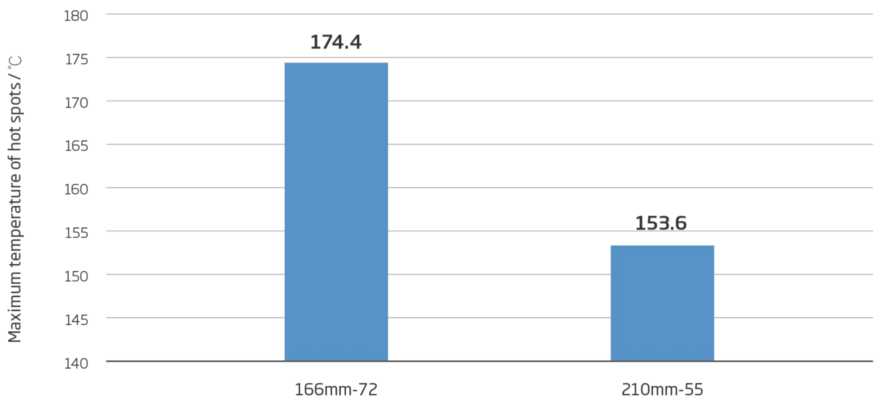


Figure 18 Comparison of maximum outdoor hot-spot temperatures of 166 and 210 single-glass modules

4.3 Safety of Junction Box on High-Power Modules

4.3.1 Working principle of junction box

The main function of the junction box is to transfer the power generated by the PV module to external circuits, including the chassis, diode, connector, cable, and other components, with the diode being the core device. When the module is working normally, the diode in the junction box is in a reverse cut-off state. When the cells of the module are blocked or damaged, the bypass diode is turned on to protect the entire PV module. The key indicators of the junction box include the rated current of the junction box, the rated current of the diode, and the maximum reverse voltage, which depend on the structural design of the junction box and the selection of the diode specifications.

4.3.2 Rated current of junction box

According to IEC and UL standards, the rated current of the junction box needs to be greater than or equal to 1.25 times the short-circuit current I_{SC}. For 210 high-current monofacial module, $1.25 \times I_{SC} = 1.25 \times 18.6A = 23.2A$; the present rated current of the junction boxes in this type of Trina Vertex module is 25A. The junction boxes currently on the market can meet this current requirement and ensure a long-term safe working environment.

4.3.3 Diode temperature

The function of the junction box diode is to isolate the affected cell string from the module circuit in case the cell fails or when the module cannot properly generate electric power due to the obstruction of external objects to protect the module. When the module is working normally, the bypass diode in the junction box is in a reverse cut-off state. When the solar cell is shaded, the bypass diode is in a forward conducting state, and power is dissipated in the diode. The heat comes from the current flow in the diode and the connecting wire. If the junction temperature of the diode rises and exceeds the safe temperature, the diode or junction box assembly can be damaged or the operating parameters can change, resulting in a reduced service life of the PV module.

Trina's technical team did tests to compare diode temperature between 210 modules and 166 modules. For the 210 half-cut modules, all the monofacial and bifacial modules used 25A junction boxes. In the case of the 210 monofacial module, the diode temperature for a short-circuit current of Isc = 18.6A was 160°C. The temperature was far below the upper diode temperature limit of 200°C specified in the IEC standard. For bifacial 210 half-cut modules, even considering Bifacial Stress Irradiance (BSI) in new IEC draft standard, the diode temperature could meet the requirement of the IEC standard. In addition, for the 166 series, all the monofacial and bifacial modules used 18A junction boxes.

As shown in Figure 19, for both the monofacial and bifacial modules, the heat generated by the 210 and 166 modules were similar, and the junction temperatures were all below 200°C. Thus, the junction boxes can be operating in a safe temperature range, and there is no reliability risk for 210mm Vertex
modules.

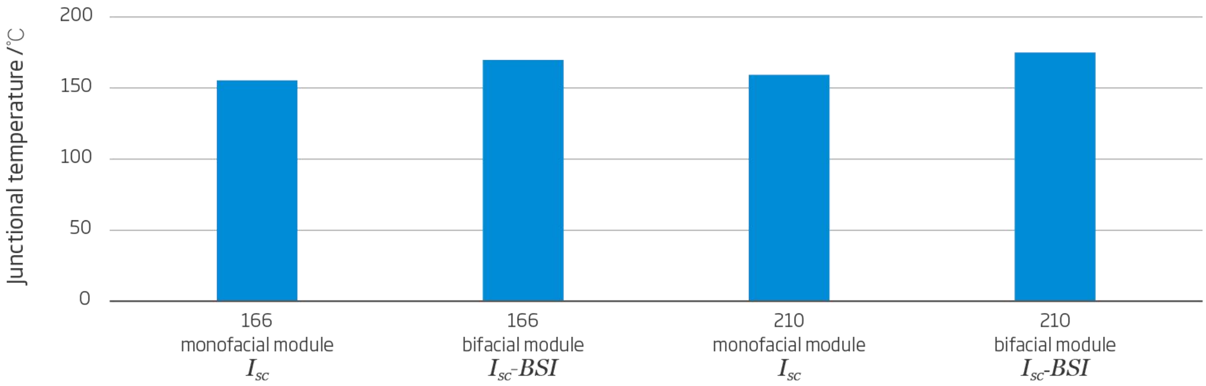
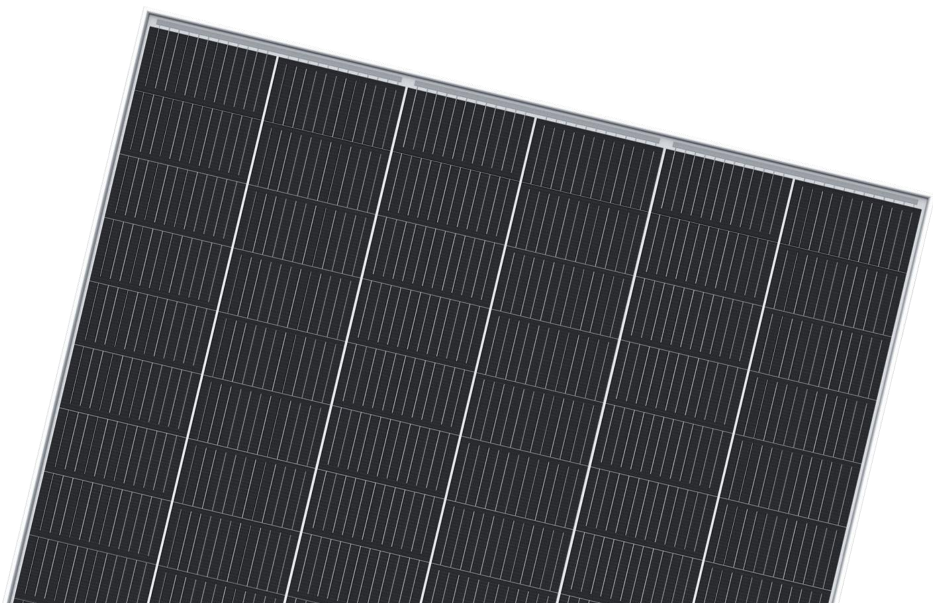


Figure 19 Comparison of diode temperatures

4.3.4 Connectors and cables

As one of the power transmission components, the connector is responsible for the successful connection of the power plant. At present, the rated currents of mainstream connectors commonly available on the market are all greater than 30A, with the maximum reaching 55A. They can all adequately satisfy the power transmission requirements of existing high-power module. As for cables, the 4mm^2 cables that conform to EN or IEC standards have rated currents of 44A when the surfaces are adjacent. This is much higher than the rated current of the junction box, so there is no concern about the reliability of the cables.

In addition to improving the manufacturing capabilities of the junction box manufacturers themselves, the testing, evaluation, and quality control capabilities of module manufacturers and third-party organizations for junction boxes and components have also been continually improved to further elevate the quality assurance and the research and development capabilities of junction box manufacturers. With the steady improvement of the manufacturing standards and quality control capabilities of junction boxes, the performances and reliability of junction boxes are guaranteed and can fully meet the requirements for the use of large-size silicon wafers and high-power modules.

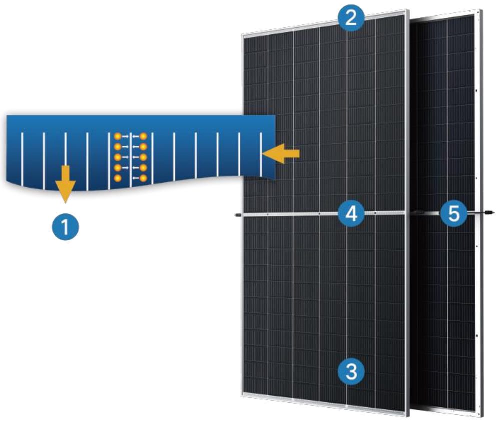


4.4 Operating Temperature Management for High-Power Modules

The operating temperature of a PV module has an important influence on its performance. As the operating temperature increases, the open-circuit voltage V_{OC} of the module decreases, and the short-circuit current I_{SC} increases slightly. This decreases the fill factor (FF) and lowers the PV conversion efficiency of the solar cell, resulting in a decrease in the overall output electrical performance of the module. For this reason, effective management of the operating temperature is important.

Where are the large currents in 210 Vertex module?

Type of module	210	Reference
Multiple busbar	12	9 to 11
⑤I_{SC} (A)- Junction box	18.4	13.8
④Middle string connector (A)	18.4	13.8
②③Side string connector (A)	9.2	6.9
①Current density (mA/cm^2)	41.7271	41.7992



Based on the same Passivated Emitter and Rear Cell (PERC) structure, the cell efficiencies are similar for difference wafer sizes. When the cells are exposed to the same irradiation, there is no difference in the current density ① of the modules per unit area. The thickness and width of string connector③ and ④ are optimized, and the cross-sectional area is enlarged to lower the local heating.

Trina's technical team relies on the testing and simulation projects of the State Key Laboratory of Photovoltaic Science and Technology, including verification tests of the operating temperature of the Vertex module and multi-dimensional research results, such as heat transfer and heat balance models. This collaboration has effectively verified the outstanding reliability and superior operating temperature of the Vertex modules.

The heat transfer of a PV module include heat conduction, heat convection, and heat radiation. The internal components of the module transfer energy through heat conduction, and the energy is transferred to the environment through heat radiation and heat convection. When the operating temperature of the module reaches a steady state, the solar energy is irradiated on the top surface of the module, part of the solar radiation energy is reflected back into the atmosphere by the module, and the remaining solar radiation energy is converted into electrical and thermal energy. As an example, the energy exchange in the steady state of a monofacial module is shown in Figure 20.

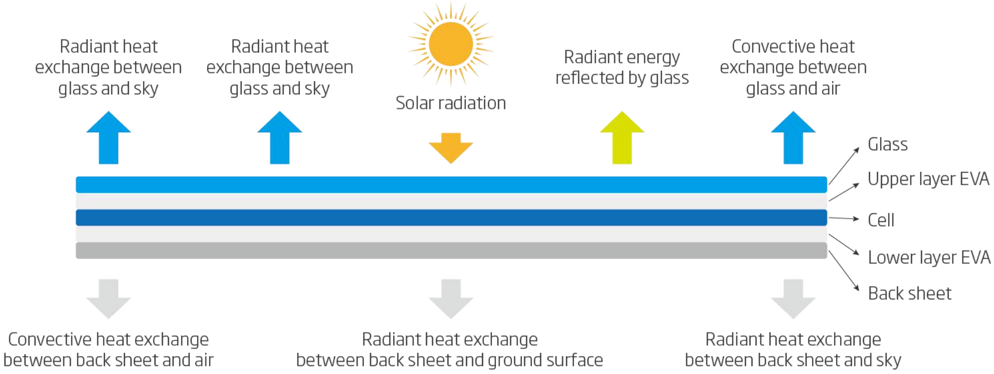


Figure 20 Schematic diagram of energy exchange

Based on the principle of energy conservation and the energy exchange between the module and the surrounding environment, the steady-state energy equilibrium equation of the module may be written in the following form without considering heat dissipation at the edge of the frame:

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

where I_{rec} represents the solar radiation energy obtained per unit area on the surface of the module (W/m^2), P/A represents the output power of the module per unit area, $h_{g,air}$ is the convective heat transfer coefficient between the glass and the air, $h_{b,air}$ is the convective heat transfer coefficient between the backsheet and the air (W/m^2K), the Stefan-Boltzmann constant is $\sigma = 5.67 \times 10^{-8} W/m^2K^4$, ε_g is the emissivity of the glass, ε_{sky} is the emissivity of the sky, ε_b is the emissivity of the backsheet, ε_{gro} is the emissivity of the ground, $F_{g,sky}$ is the viewing angle coefficient between the glass and the sky, $F_{b,sky}$ is the viewing angle coefficient between the backsheet and the sky, and T_{sky} is the temperature of the sky.

A cement ground surface is considered as an example, with an installation angle of 25°, an ambient temperature of 25°C, a plane of array irradiance of $1000W/m^2$, and a wind speed of $1.18 m/s$. The input boundary conditions and calculation results for reference module (72pieces) and 210-55 modules are shown in Table 4. The calculation results show that the operating temperatures of the two are basically equivalent.

Table 4 Comparison of temperature tests

	Reference Module	210-55 Module
Ambient temperature Ta(K)	298.15（25℃）	
Slanted irradiance Irec(W/m2)	1000	
Mean ground temperature Tgro(K)	302.55（29.4℃）	
Sky temperature Tsky(K)	284.18（11.03℃）	
Surface wind velocity on module WS(m/s)	1.18	
Module reflectance PPV	0.10	
Inclination angle (deg)	25	
Module size (m2)	2.587	2.613
Result Tc(K)	**323.32（50.17℃）**	**323.26（50.11℃）**

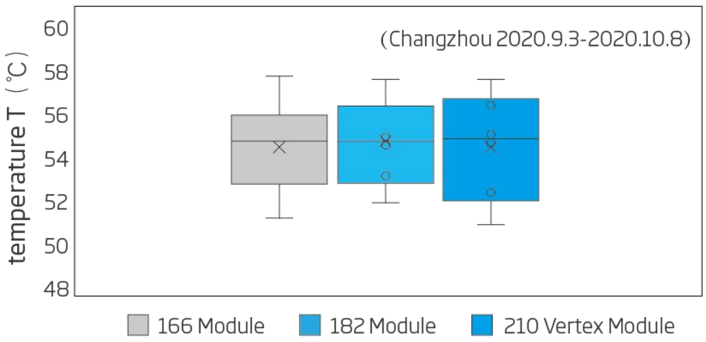


Figure 21 Temperature test results for modules of different sizes

In the hot summer months, outdoor temperature measurements were made for modules with three different silicon wafer sizes (166-72, 182-72, and 210-55). The test location was in Changzhou, the ground surface was grasslands, and the test samples were installed horizontally on fixed-tilt racking at a tilt angle of 25° and a height of 0.5 m. The operating temperature of the module was acquired using a HIOKI thermocouple, and all thermocouples were attached to the same position on the backsheets of different modules. The weighted average temperatures of the three different-sized modules are shown in Figure 21. The results showed that there was almost no difference in the average operating temperatures of the three types of test samples.

Figure 22 shows the hourly temperature data for a typical sunny day during the test period. The meteorological conditions of that day were fed into the simulation model and good agreement was obtained between the measured and calculated results. Compared with the 182 series modules, the 210 modules had similar temperatures, but they had slightly better operating temperatures during morning and evening when the irradiation was lower.

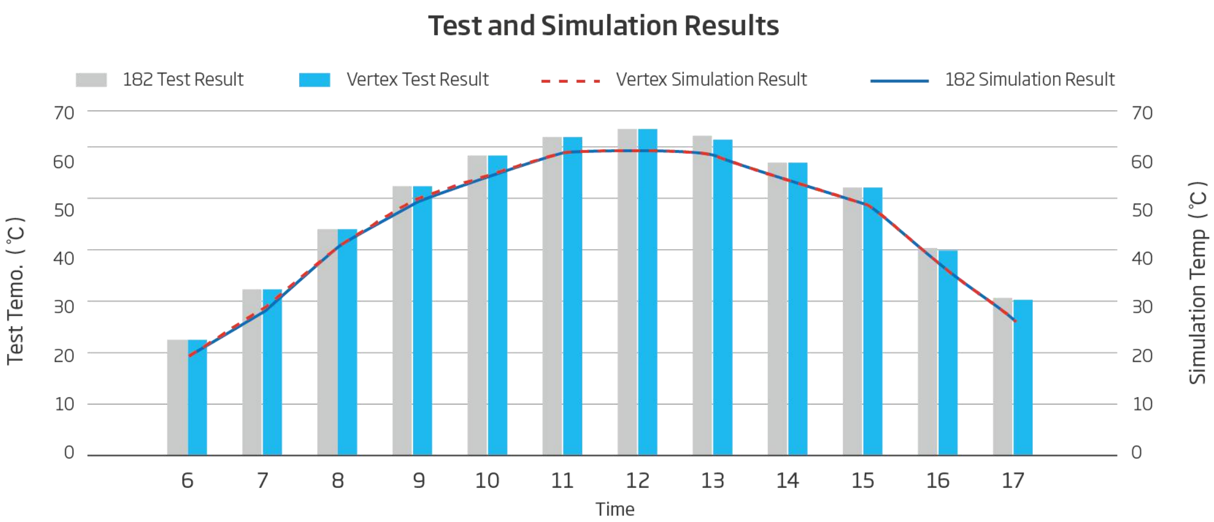


Figure 22 Temperature comparison for a typical clear day

5. Logistic and Transportation Optimization for 210 Vertex Modules

With the globally oriented application of Vertex modules, the main mode of domestic transportation is pallet trucks, while overseas shipments mainly use container transportation. Based on considerations such as logistics costs, transportation safety, module safety, and ease of operation, Vertex modules are shipped with two packaging transportation methods: the mainstream traditional packaging transportation method and the innovative vertically portrait packaging transportation method.

Under conventional packaging solution

Under the conventional method of packaging, the effect of the module size on the container is mainly the width of the module, because the stacking height is determined by the width of the module. If the stacked height of two modules exceeds the door height of the container, it will prevent normal loading. The inner dimensions of commonly used 40HC (high cabinet) containers are 12m × 2.35m × 2.69m, and the door height is 2.58m, as shown in Figure 23.

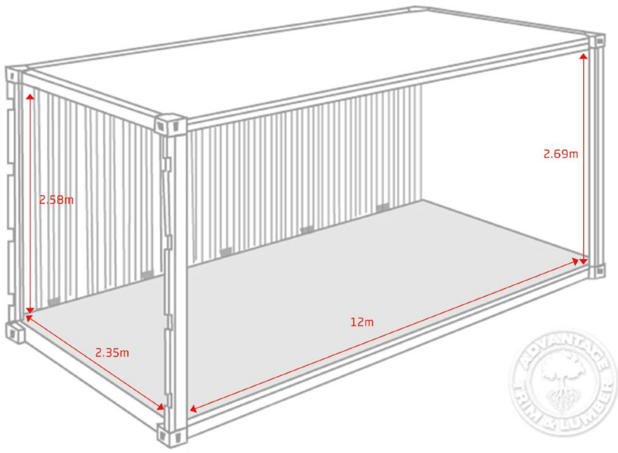


Figure 23 Commonly used 40 HC container

As shown in Figure 24, the total height of each pallet package of the Vertex module is approximately 1.24m, which includes the height of the pallet, the height of the module, the thickness of the carton, and the thickness of the pad. Considering the height of the forks of forklift equipment commonly used in shops and warehouses, such as manual hydraulic vehicles, electric pallets and others, the height of the pallet corner pier plus the face height should generally be no less than 0.085m.

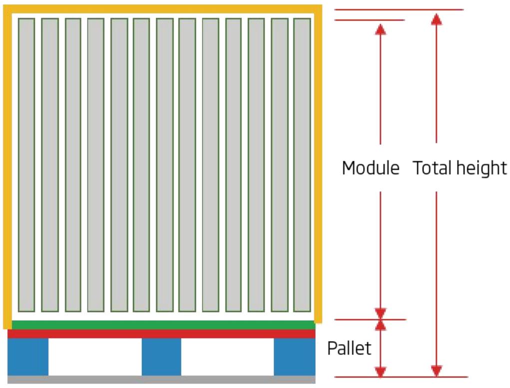


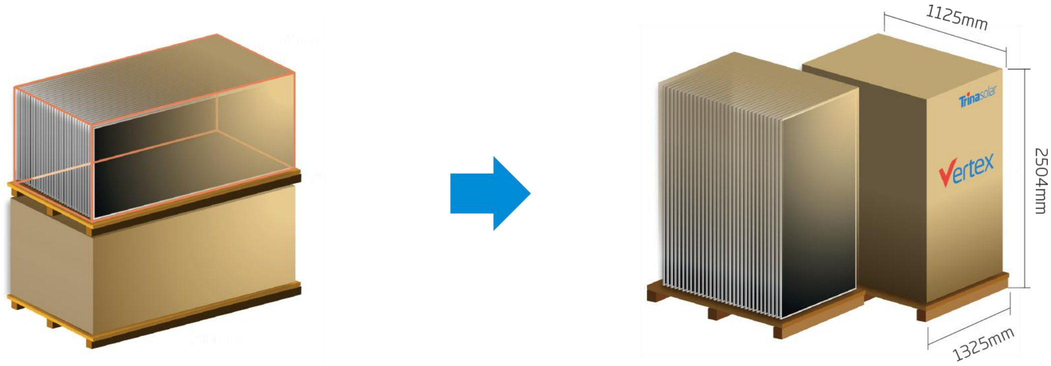
Figure 24 Schematic diagram of single-pallet packaging height

After the two loaded pallets are stacked, the total height is about 2.48m, which is less than the height of the container door of 2.58m and leaves about 0.1m of operating space between the stacking height and the container door height. Operated by trained and regular workers, pallets and containers can be used for the normal loading and unloading of cargo. Thus, it can also be calculated that the width of the Vertex series module has reached the maximum level suitable for loading and placement.

With innovative vertically portrait packaging solution

For the 600W+ series products, Trina Solar has innovated the container transportation and packaging method using an upright orientation, so that the placement is no longer restricted by the conflict between the module width and the container height, as shown in Figure 25. This mode of packaging can make maximum utilization of the internal capacity of the container. Compared with the traditional method, the loading power of the 600W+ vertically portrait packaging method has been increased by up to 12%, and the transportation cost has been reduced by 11%, as shown in Table 5. In terms of safety, the packaging is performed by automated equipment to ensure safety and efficiency. Moreover, the module pallets are tightly packed inside the container to avoid shaking during transportation, which prevents swaying, tilting, and collision. In addition, the optimized frame design and material selection can prevent deformation even when the module area has increased, thereby reducing the risk of micro-cracks caused by handling and transportation. Finally, stable and reliable unloading and transfer are realized at the project site to ensure safe delivery to the customers.

Innovative vertically portrait packaging for transportation



Transportation cost of each container is reduced by 11%

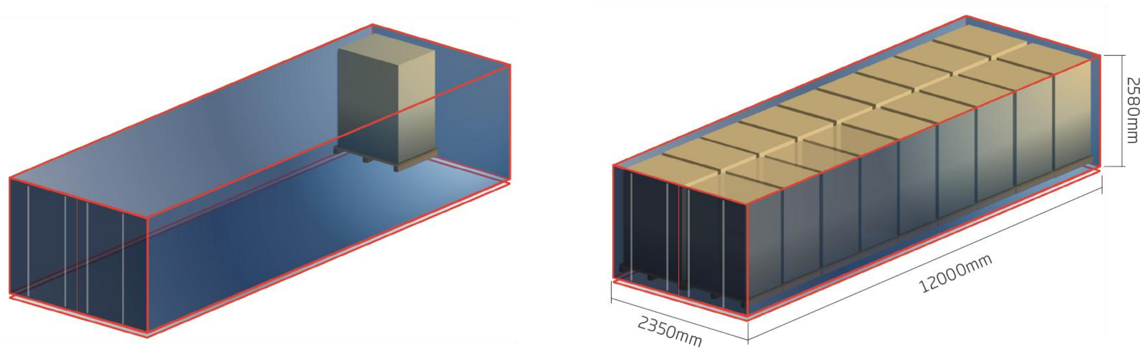


Figure 25 Transportation solution

Table 5 Comparison of module transportation solutions

Classification	Module power	Number of modules per pellet	Number of modules per 40HC container	Total module power per container
Other modules	540 W	31	620	334,800 W
Vertex modules	670 W	31	558 MAX	**373,860 W** +12% ↑

The auxiliary unpacking method adopted by Trina, as shown in Figure 26, has the following advantages:

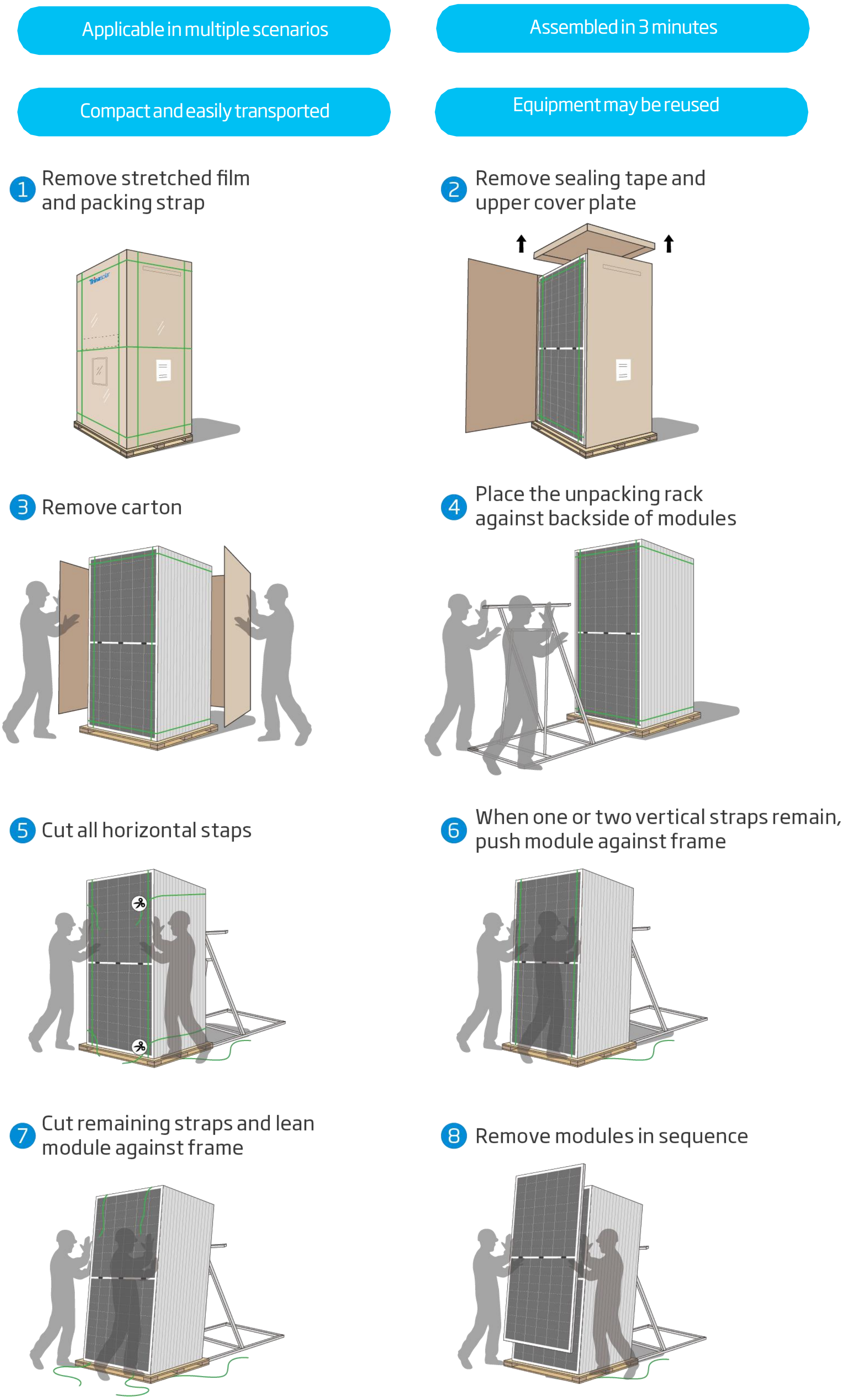


Figure 26 Auxiliary unpacking tool and unpacking process

6. System Compatibility Design for 210 Vertex Modules

6.1 Electrical Compatibility of Inverter

In addition to the innovative new products, Trina Solar has also leveraged its problem-solving capabilities and conducted a comprehensive evaluation of the modules output current and voltage compatibility with mainstream inverters during the initial design phase of the Vertex modules. As a result, Vertex modules enjoy a high degree of compatibility in the downstream market.

The capacities of inverters have been increasing along with the power ratings of the other components of solar power plants, regardless of whether they are in the string or centralized configuration. In the meantime, the rated current is also adjusted according to the output current of the module.

6.1.1 Centralized inverter

The electrical parameters of the Vertex module must provide an adequate rated current through the DC fuse and load switch on the DC side of the centralized inverter. The capacity may be easily expanded by switching the type of inverter, as shown in Figure 27.

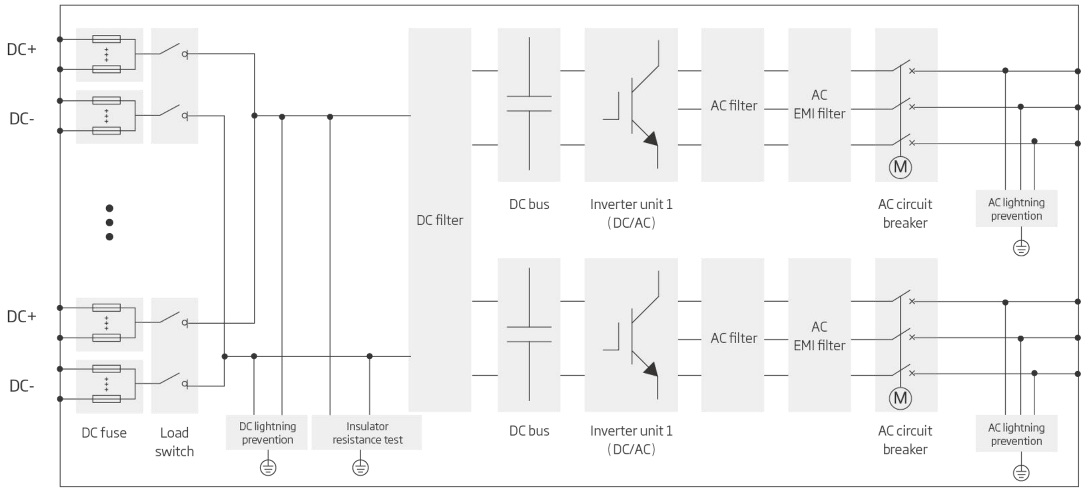


Figure 27 Block diagram of centralized inverter from manufacturer S

The current limit of the DC fuse and the DC load may be expanded by changing the inverter.

6.1.2 String inverter

When string inverters are intended to be used, the currents provided by Vertex modules must be suitable to the inverters maximum short-circuit current and to the maximum power point. The difficulty of its expansion is mainly in the heat dissipation of the BOOST voltage-boosting circuit and the heat dissipation of the expanded IGBT. The single-channel MPPT of current mainstream string inverters has reached 30A, which is compatible with the Vertex series modules of Trina Solar and can cover most of the application scenarios. At the same time, for string inverters with higher DC/AC ratio requirements, the current mainstream inverter manufacturers' have developed and certified new products which will be officially launched in 2021 to match the Vertex series modules for all application scenarios.

Solution from manufacturer H: A high-power string inverter adapted to the Vertex module, with three channels of MPPT, each with a maximum input current of 100A, which can be connected to 4 or 5 strings. The inverter supports a 14-channel string input, which allows for the flexible selection of the DC/AC ratio.

Solution from manufacturer S: A high-power string inverter with 12 channels of MPPT. To better adapt to the Vertex module, the maximum PV input current of the MPPT is upgraded from 30A to 40A+. The inverter supports 24 channels of the string input, with a flexibly selectable DC/AC ratio.

Solution H

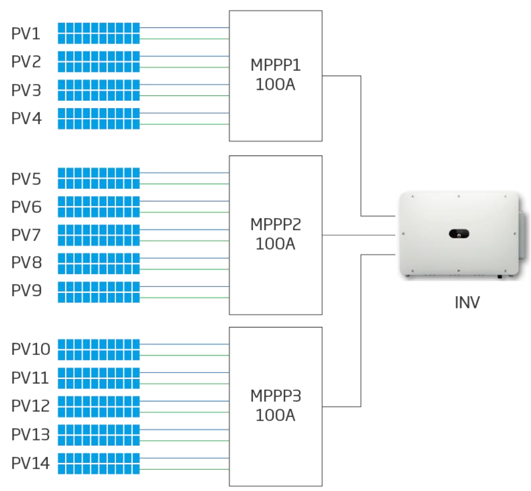


Figure 28 Block diagram of H manufacturer string inverter

Solution S

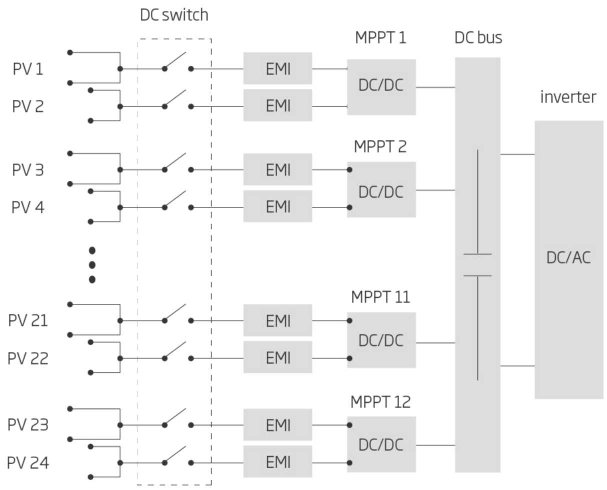


Figure 29 Block diagram of S manufacturer string inverter

6.1.3 Number of modules in one string

One of the key drivers for reducing the BOS cost of a solar project is to increase the power of a single string. Thanks to the low-voltage characteristics of the Vertex module, the power of a single string may be increased by 35% compared to other modules in the industry under the same design conditions. This can significantly reduce the construction cost of the system.

Table 6 Comparing number of modules per string

Type of module	Modules per string	Power per module	Power per string
Comparison module	27	540 W	14580 W
Trina Vertex module	36	550 W	19800 W

Note: String calculation for a specific region with temperatures of −10°C.

The voltage of the string must not exceed the highest voltage the system can withstand, nor the maximum input voltage of the inverter and other electrical equipment installed in the system. To ensure this, the open-circuit voltage of the array should be calculated for the most restrictive voltage conditions that occur when the ambient temperature is the lowest expected temperature at the installation site. The following formula is recommended for the calculation:

$$\text{Maximum system voltage } \geq N \times \mathrm{V}_{oc} \times [1 \times TC_{voc} \times (T_{min} - 25),$$

where N is the number of modules in the series, V_{oc} is the open-circuit voltage of the module at Standard Test Conditions (STC), TC_{voc} is the temperature coefficient of the open-circuit voltage of the module (see the datasheet), and T_{min} is the lowest operating temperature of the module.

The specific number of modules that can be connected should be determined by a qualified design organization or personnel based on the PV system and electrical design specifications of the installation site. The formula recommended by Trina Solar is for reference only.

6.2 Module mounting system (MMS)

Vertex modules have extremely high installation compatibility and can simultaneously meet various installation requirements with different systems, such as fixed tilt racking system (portrait and landscape) and tracking system.

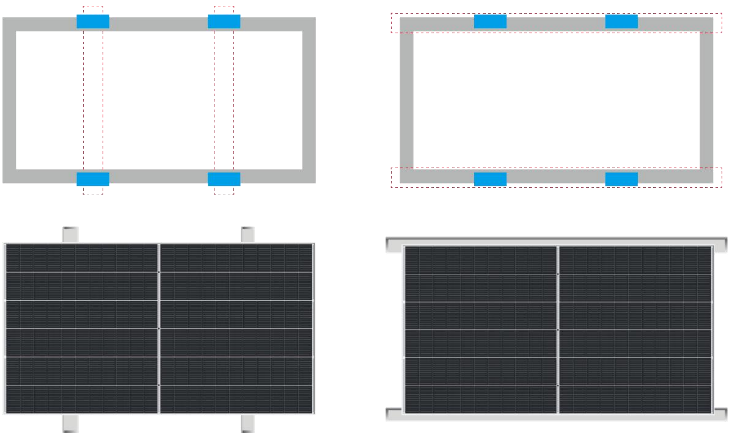
Figure 30 Schematic diagram of mounting system

6.2.1 Fixed tilt racking

With the advantages of the innovative layout design, there are no significant differences between the Vertex S and the 18/19 series modules compared to conventional modules in terms of size and weight. For this reason, the mechanical load capacity requirements of 5400Pa on the front and 2400 Pa on the back can be met whether the mounting style has the cross-beam perpendicular or parallel to the long side. This satisfies the certification requirement and is compatible with a fixed-tilt racking, as shown in Table 7.

Table 7 Comparison of maximum mechanical loads of different modules

Product type		Vertex S		210-50 Vertex	210-55 Vertex	210-60 Vertex	210-66 Vertex
Module Name		DE09	DE09.08	DEG18MC.20(II)	DEG19C.20	DEG20C.20	DEG21C.20
			DE09.05				
Weight (kg)		21.0		30.1	32.6	35.3	38.7
Load capacity (Pa)	Cross-beam	6000/−4000	6000/−4000	5400/−2400	5400/−2400	5400/−2400	5400/−2400
	Shared beam on long side	/		5400/−2400	3600/−2400	3600/−2400	3600/−2400



Cross-beam installation Shared-beam on long side installation

Figure 31 Schematic diagram of installation methods

6.2.2 Tracking system

For the ultra-high-power modules of Vertex series, Trina Solar has worked with downstream partners in the industry to develop tracking system that are more reliable, cost-effective, and compatible with a greater amount of products, including the upgraded Trina tracking system products.

The increased length, width, and weight of the Vertex modules, as well as the longer string length presented greater challenges to the structural design and reliability of the tracker, as shown in Figure 32.

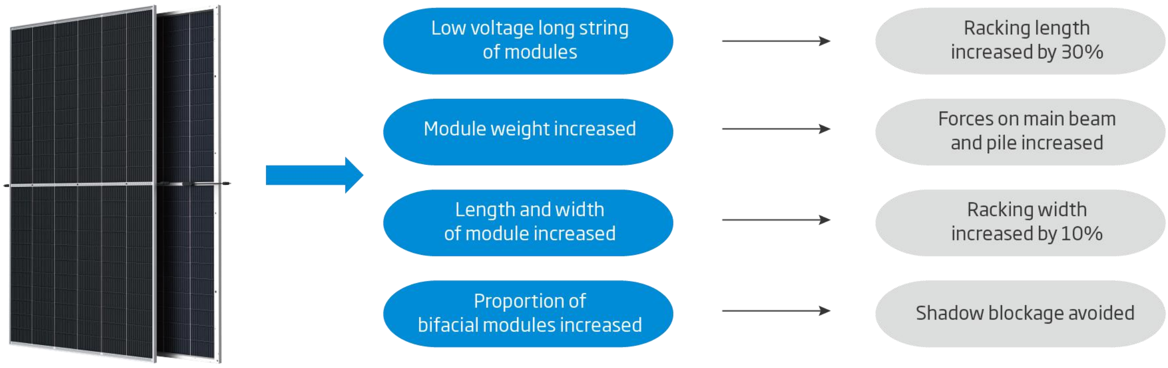


Figure 32 Structural design of Vertex module tracker

To address these challenges, Trina Tracker has integrated a multi-point drive technology into the trackers to make the entire system more stable and balanced in terms of the forces. This has improved the rigidity at key connection points, reduced the risk of bending and torsion tremors caused by the increase in size and weight of the modules, and ensured wind stability, as shown in Figure 33.

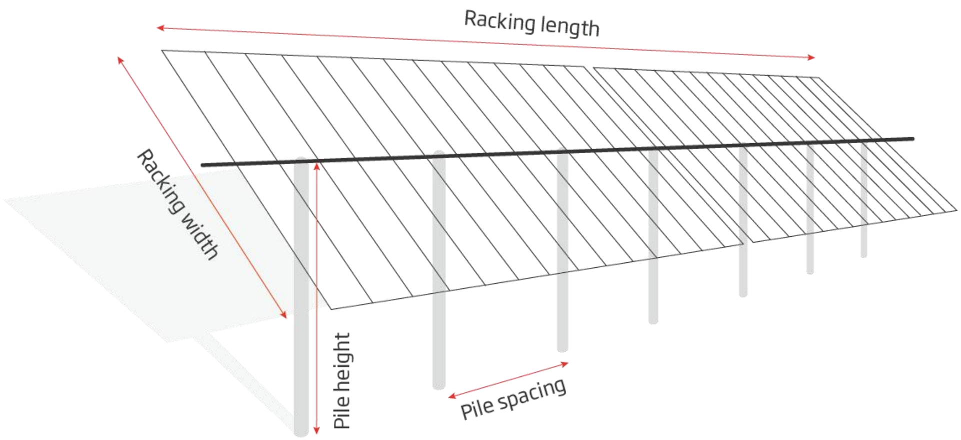


Figure 33 Schematic diagram of the tracker

Although the weight and size of the module have increased, due to the upgrade of the multi-point drive, the driving force and the moment experienced by the tracking system have been greatly reduced. Since the torque T = F × L, the torque experienced by a single drive system is only 30% or less of the original torque, and the force is even more balanced, as shown in Figure 34.

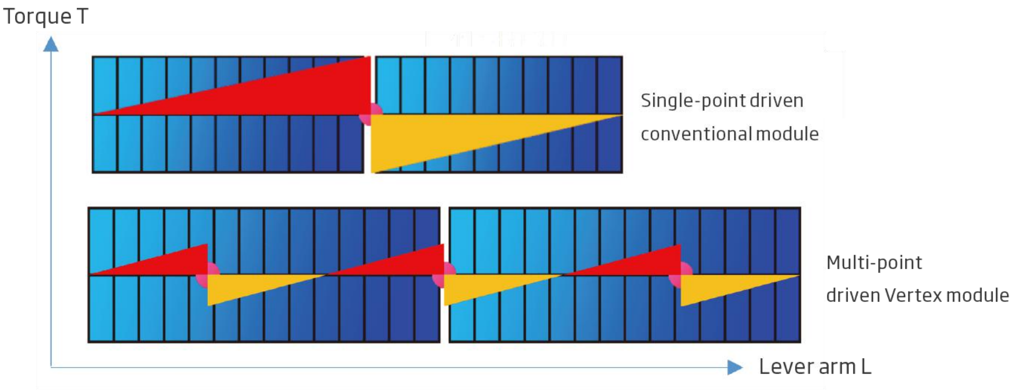


Figure 34 Comparison of torque on a single-point drive and a multi-point drive

6.2.3 Compatibility of tracking system

The new tracking system can achieve greater lengths and increase the installation capacity per tracker, thereby reducing the number of trackers, piles, and electrical systems per unit watt and lowering the total cost of tracking system. The following table compares the component layout of the TrinaTracker tracker with that of the conventional system.

Table 8 Comparison of power per tracker of different modules

	Drive mode	String layout of module	String layout of module	Power per tracker (kW)
Conventional module	Single-point drive	30 × 3 string	90	40.5
Vertex module	Multi-point drive	40 × 3 string	120	66

The world's leading manufacturers of PV tracking systems–TrinaTracker, Arctech Solar, Array Technologies, GameChange Solar, IDEEMATEC, Nextracker, PVH, Soltec, FTC Solar, and Soltigua–have also carried out similar technical upgrades for Vertex modules and can fully match the installation and application of Vertex modules with assured reliability (for more information about the matching of Trina Solar's Vertex modules and tracking systems, see TrinaTracker and other technical white papers on tracking system).

7. Customer Value of 210 Vertex Modules

7.1 Direct Current (DC) Cable Loss

7.1.1 Analysis of DC cable loss

Causes of DC cable loss

Work is produced when an electric current passes through a conductor due to wire resistance. Part of the electric energy is converted into heat, which is the cable loss. The heat generated can be calculated using Joule's law, as follows:

Joule's law

$$Q = I^2 \cdot R \cdot t$$

$$Q = I^2 \cdot \left(\frac{\rho \cdot L}{s}\right) \cdot t$$

Table 9 Units and definitions

Symbol	Definition	Unit
Q	Cable loss heat	J
I	Current	A
ρ	Conductor resistivity ↑	$\Omega \cdot mm^2/m$
R	Conductor resistance	Ω
L	Total cable length ↓	m
s	Cable cross-section area	mm^2
t	Work production duration	s

1) When the cables have identical materials and cross-sectional areas, the cable resistivity remains unchanged. The overall cable loss is determined by the current and cable length.

2) At equal length, the resistance of a cable with a 6mm^2 cross-sectional area is 33% less than that of a cable with a 4mm^2 cross-sectional area.

3) The current of the 210 module is greater than other modules, but the total cable length is shorter.

Location of DC cable loss

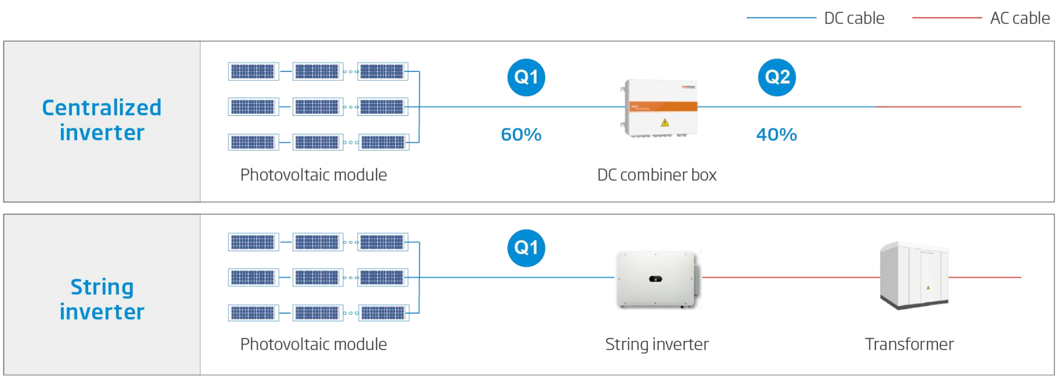


Figure 35 Illustration of direct current (DC) cable loss (centralized inverter and string inverter)

Two scenarios for DC cable loss

When a centralized inverter is used, the DC cable loss equals $Q_1 + Q_2$, which is the sum of the cable loss from the photovoltaic array to the combiner box (Q1) and the cable loss from the combiner box to the centralized inverter (Q2). In general, the ratio of Q_1 to Q_2 is approximately 6:4. When a string inverter is used, the DC cable loss is Q_1, which is the cable loss from the photovoltaic array to the string inverter.

Comparison of Q_1 in DC cable loss between different modules

Table 10 Design of 3.125MW photovoltaic plant

Module type	DC/AC ratio of installation	Module power (W)	Module per string	String power (W)	Number of strings	Total PV cable length L_1 (m)
Reference module	1.2	535	26	13910	270	17083
210-545	1.2	545	34	18530	202	10424 39%

Project location: Inner Mongolia, 45.67°N/120.58°E Inverter: 3.125MW, 1500V

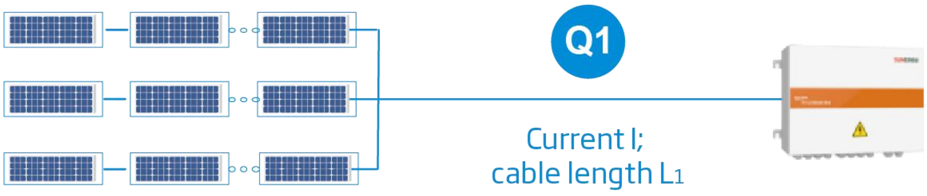


Figure 36 Q1 in DC cable loss

Comparison of calculated Q_1 of DC cable loss

Table 11 Comparison of DC cable loss of centralized inverter

Module type	Cable length (m)	PV cable cross-section area	Current (A)	Cable loss
Reference module	17083 (100%)	$4mm^2$	12.9	100%
210-545	10424 (61%)	$4mm^2$	17.24	109%
210-545	10424 (61%)	$6mm^2$	17.24	72.70%

The overall DC cable loss of the reference module is assumed to be 1.5%, where Q_1 accounts for 60%, i.e., a cable loss of 0.9%.

Table 12 Comparison of DC efficiency

Module type	Q_1 DC cable loss	Q_1 DC efficiency
Reference module: 4 mm^2 cable	0.90%	99.10%
210-545W: 4 mm^2 cable	0.98%	99.02%
210-545W: 6 mm^2 cable	0.65%	99.35%

The DC efficiency of the 210 module is 0.09% lower than that of the reference module if the $4mm^2$ cable is used. The DC efficiency of the 210 module is 0.25% greater than that of the reference module if the $6mm^2$ cable is used.

Comparison of Q_2: DC cable loss from the combiner box to the centralized inverter

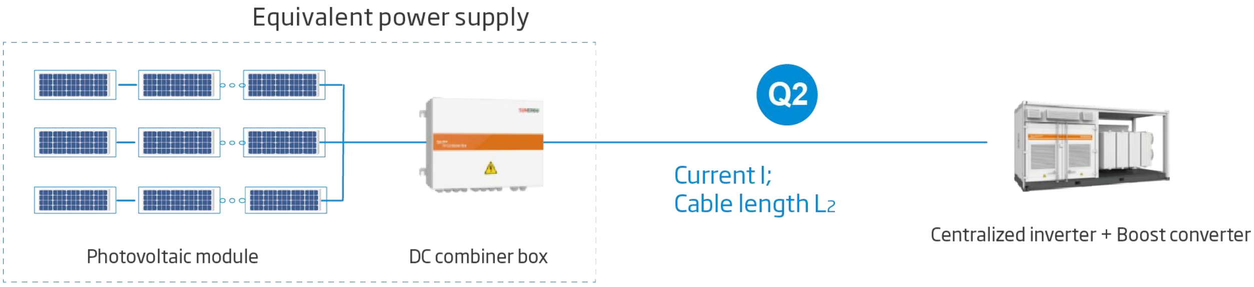


Figure 37 Q_2 in DC cable loss

The module array and the combiner boxes are treated as one large equivalent power supply. The total current is calculated for the circuit from the equivalent power supply to the inverter.

Table 13 Comparison of total current of Q_2

Module type	Number of strings	Impp (A)	Total current (A)
Reference module	270	12.9	3483
210-545	202	17.24	3482.48

Calculation comparison of Q2 in DC cable loss:

$$\frac{Q_{210}}{Q_{\text{Reference module}}} = \frac{(I_{210})^2 \times \rho \times L_{210}}{(I_{\text{Reference module}})^2 \times \rho \times L_{\text{Reference module}}} = \frac{(3482.48)^2}{(3483)^2} = 1$$

The Q2 (DC cable losses between the combiner box and the centralized inverters) values for the reference module and the 210 module are approximately the same.

The overall DC cable loss of the reference module is assumed 1.5%, where Q_2 accounts for 40%, i.e., a cable loss of 0.6%.

Table 14 DC efficiency of Q_2 in DC cable loss

Module type	Q2 DC cable loss	Q2 DC efficiency
Reference module: 4mm² cable	0.6%	99.4%
210-545: 4mm² cable	0.6%	99.4%

Comparison of total DC cable loss of the centralized inverter:

4mm² Cable

$$\frac{Q_{210}}{Q_{\text{Reference module}}} = \frac{Q1+Q2}{Q1+Q2} = \frac{0.981\%+0.6\%}{0.9\%+0.6\%} = 1.054$$

6mm² Cable

$$\frac{Q_{210}}{Q_{\text{Reference module}}} = \frac{Q1+Q2}{Q1+Q2} = \frac{0.654\%+0.6\%}{0.9\%+0.6\%} = 0.836$$

The DC cable loss of the reference module corresponds to a 1.5% system efficiency, serving as a baseline for comparison.

Table 15 Comparison of DC efficiency PR

Module type	Overall DC cable loss	DC system efficiency E1	Remainder overall efficiency except DC system, E2	PR (E1*E2)
Reference module: 4 mm^2 cable	1.5%	98.50%	85%	83.72%
210/545 4mm^2 cable	1.58%	98.42%	85%	83.66%
210/545 6mm^2cable	1.25%	98.75%	85%	83.93%

The performance ratio (PR) of the 210 module is 0.06% less than that of the reference module when the 4mm^2 cable is used, and it is 0.21% greater than that of the reference module when the 6mm^2 cable is used.

Note: The power generation advantages achieved by the low radiation and low-temperature coefficient of the 210 module are not considered in overall efficiency E2.

Comparison of DC cable loss of string inverters:

Table 16 Design of 3.125MW photovoltaic plant

Module type	DC/AC ratio of installation	Module power (W)	Module per string	String power (W)	Number of strings	PV total cable length L_1 (m)
Reference module	1.16	535	27	14445	236	17857
210-545	1.16	545	35	19075	179	10945 39%⬇

Project location: Henan, 35.32°N 113.93°E Inverter: string type, 1500V

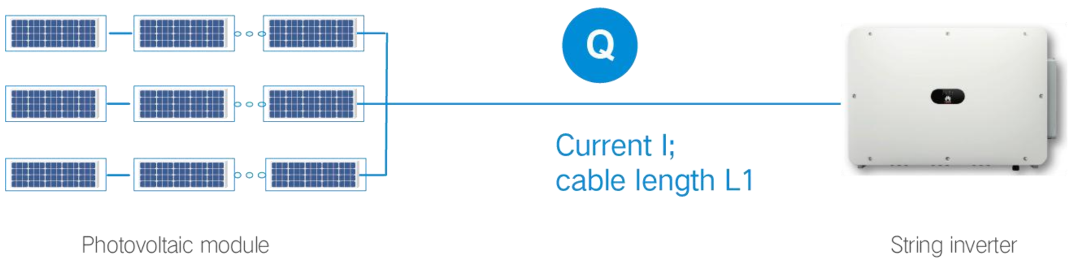


Figure 38 DC cable loss of the string inverter

Calculation comparison of DC cable loss:

Table 17 Comparison of Q1 DC cable loss of string inverters

Module type	Cable length (m)	PV cable cross-section area	Current (A)	cable loss
Reference module	17857 (100%)	4mm^2	12.9	100%
210-545	10945 (61%)	4mm^2	17.24	109%⬆
210-545	10945 (61%)	6mm^2	17.24	73%⬇

Assuming the overall DC cable loss of the reference module is 1% for this type of configuration, the calculation process is the same as above.

Table 18 Comparison of DC efficiency PR

Module type	DC cable loss	DC system efficiency E1	Remainder overall efficiency E2	PR (E1 × E2)
Reference module: 4mm^2	1%	99.0%	84.5%	83.65%
210-545: 4mm^2 cable	1.09%	98.91%	84.5%	83.57%
210-545: 6mm^2 cable	0.73%	99.27%	84.5%	83.88%

The PR of the 210 module is 0.08% less than that of the reference module when the 4mm^2 cable is used, and it is 0.23% greater than that of the reference module when the 6mm^2 cable is used. The power generation advantages achieved by the low radiation and low-temperature coefficient of the 210 module are not considered in the remainder overall efficiency E2.

7.1.2 Summary of DC cable loss comparisons

The DC cable loss caused by the higher current of Vertex modules is negligible compared to that of conventional reference modules. A 6mm^2 DC cable can be used together with Vertex module to further reduce the DC loss of the system and therefore increase the PR of the power plant. Since the amount of DC cable used in the 210 module is much lower than that in the traditional 182 modules, even with the 6mm^2 DC cable, the system BOS is still lower than that of the reference module using the 4mm^2 cable (see the next section for more details).

7.2 210 Vertex Modules BOS Cost and System Value

7.2.1 Engineering workload analysis

(Based on the case study of a 100MW project at a middle latitude with a centralized inverter)

System technical specifications of the 210 modules and reference modules

Table 19 System technical specifications of the 210 modules and reference modules

Module type	Module power (W)	Module quantity per string	String power (W)	Number of strings	Mass of steel used in mounting system(t/MW)	Total number of mounting system	Total number of piles
Reference module	535	26	13910	270	37.15	135	1080
210-545	545	34	18530	202	35.05	101	1010

The 210 Vertex module can greatly reduce the BOS cost of a power plant thanks to its high power, low electrical voltage, and excellent layout design. These features result in higher power per string and a reduction in the number of modules, the number of strings, the cable length, the amount of steel used in mounting systems, and the number of foundation piles.

Amount comparison of system component in power plants

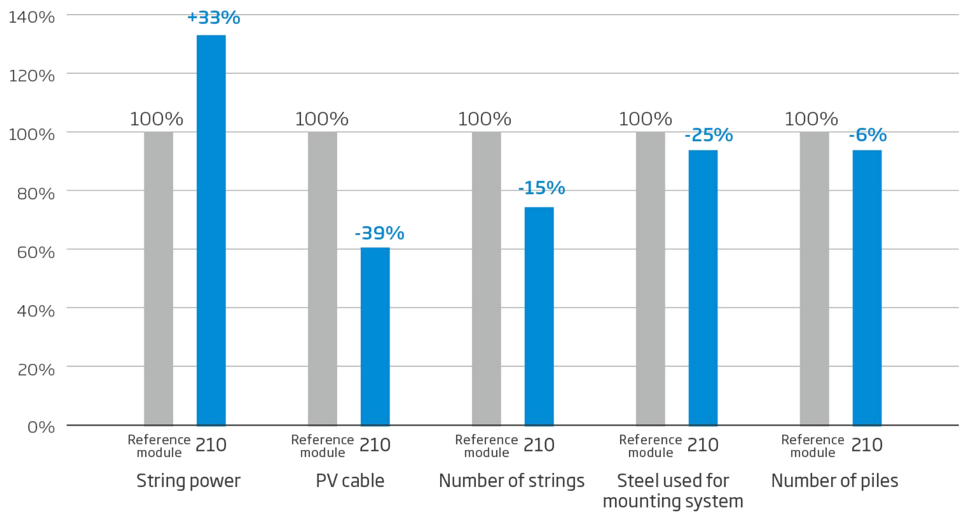


Figure 39 Comparison of power plant technical specifications

Under the same project conditions, the BOS cost of the 210 module is lower:

Table 20 Comparison of BOS cost

PV cable cross-section area	Module type	Module size (mm)	Module efficiency	Module quantity per string	Equipment cost ￥/W	Construction cost ￥/W	Installation cost ￥/W	BOS cost ￥/W	BOS cost difference ￥/W
$4mm^2$	Reference module	2256 × 1133	20.9%	26	0.536	0.197	0.177	0.910	BL
$4mm^2$	210-545	2384 × 1096	21.0%	34	0.517	0.190	0.174	0.881	−0.030
$6mm^2$	210-545	2384 × 1096	21.0%	34	0.522	0.190	0.174	0.886	−0.025

For a 100MW power plant, the 210 module can lower the BOS cost by approximately ￥3 million. If a $4mm^2$ photovoltaic cable is used with the 210 module, the BOS cost can be reduced by ￥0.03/W compared with the reference module; If the 210 modules are installed with $6mm^2$ photovoltaic cable, the BOS cost can be reduced by ￥0.025/W.

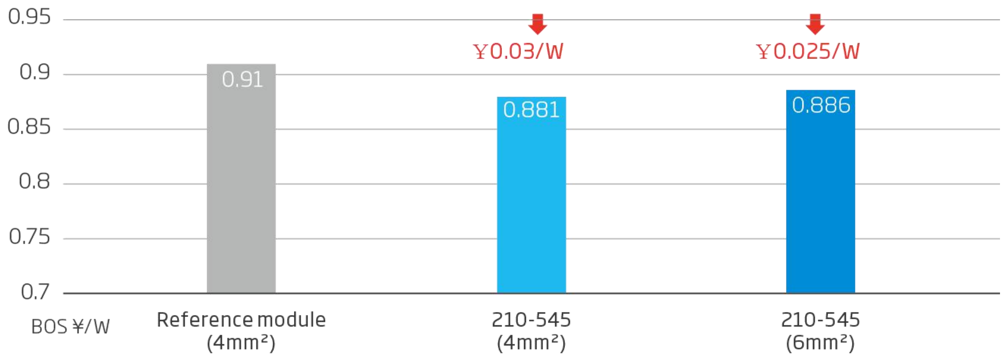


Figure 40 BOS cost comparison

Power generation losses data

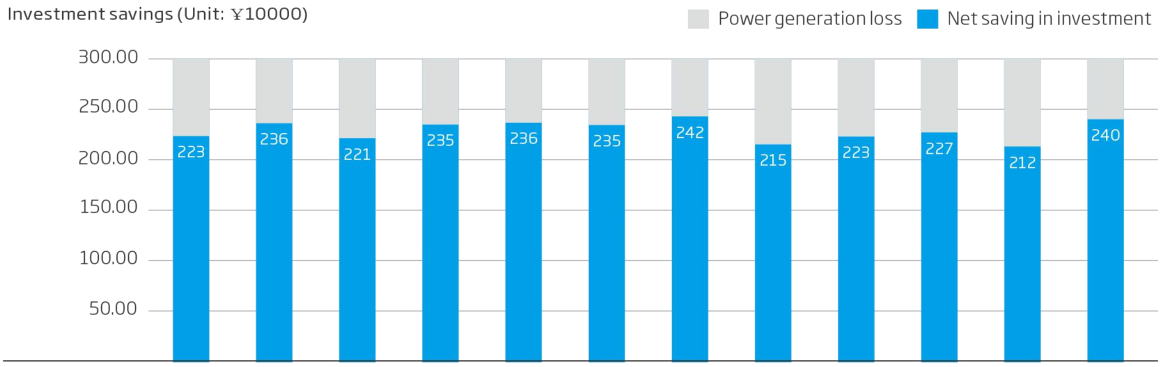
210 module $4mm^2$ **VS** **Reference module $4mm^2$**

Comparison baseline 1:

- The system efficiency is 83.72 % for the reference module.
- The system efficiency is 83.66 % for the 210-545 modules.
- The annual total radiation is assumed to be the maximum of each region.
- 100MW of power is generated, and the operation period is 25 years.
- The electricity grid price is assumed to be the maximum price of 12 provinces. The radiation amount is assumed to be the maximum of each province.

Note: The power generation advantages achieved by the low radiation and low-temperature coefficient of the 210 module are not considered in the calculation of system efficiency.

The BOS savings easily compensate for the loss in power generation



	Hebei	Henan	Heilongjiang	Hubei	Hunan	Jiangsu	Ningxia	Qinghai	Shandong	Inner Mongolia	Guangdong	Xinjiang
Power generation loss of 210 module	77.28	64.29	78.68	64.99	64.08	65.21	58.28	85.28	76.59	72.69	87.73	59.84
BOS savings of 210 module	300	300	300	300	300	300	300	300	300	300	300	300
Net investment savings of 210 module	222.72	235.71	221.32	235.01	235.92	234.79	241.72	214.72	223.41	227.31	212.27	240.16

Savings in investment cost and power generation loss of 210 module is project-dependent

Figure 41 Cost analysis of the 210 module

Even higher efficiency can be achieved by using the $6mm^2$ cable for the 210 modules.

210 module $6mm^2$ **VS** **Reference module $4mm^2$**

Comparison baseline 2:

- The PR is 83.72 % for the reference module.
- The PR is 83.93 % for the 210-545 modules.
- The annual total radiation is assumed to be the maximum of each region.
- 100MW of power is generated, and the operation period is 25 years.
- The electricity grid price is assumed to be the maximum price of 12 provinces. The radiation amount is assumed to be the maximum of each province.

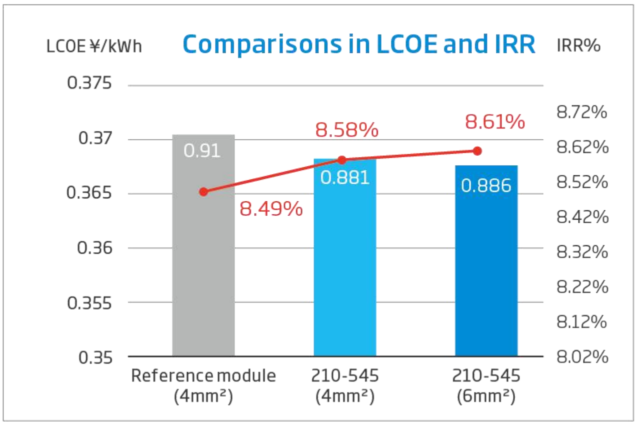
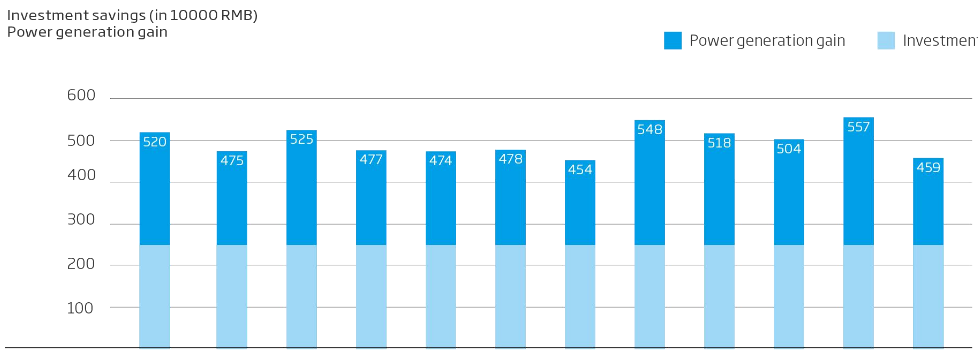


Figure 42 Comparison of LCOE and IRR

Note: The power generation advantages achieved by the low radiation and low-temperature coefficient of the 210 module are not considered in the calculation of system efficiency.

BOS saving and increased power generation income by using 6mm^2 cable



	Hebei	Henan	Heilongjiang	Hubei	Hunan	Jiangsu	Ningxia	Qinghai	Shandong	Inner Mongolia	Guangdong	Xinjiang
Investment savings of 210 module	250	250	250	250	250	250	250	250	250	250	250	250
Power generation gain of 210 module	270.48	225.01	275.4	227.46	224.27	228.23	203.99	298.47	268.06	254.42	307.06	209.45
Total revenue	520.48	475.01	525.4	477.46	474.27	478.23	453.99	548.47	518.06	504.42	557.06	459.45

Savings in investment cost and power generation loss of 210 module is project-dependent

Figure 43 Total benefits of the 210 module

7.2.2 Summary of system values

1) The low-voltage characteristics of the 210 module can significantly reduce the initial cost (CAPEX) of the power plant.

2) The IRR and LCOE of the 210 module are better than those of the other modules, regardless of whether the 4mm^2 or 6mm^2 cable is used.

3) The 210 module with the 6mm^2 cable can increase the system efficiency. Although the cable cost increases slightly, the overall benefit is far more significant. The 4mm^2 and 6mm^2 cables can be integrated in the project design based on the wiring distance to achieve the highest efficiency of the power generation and reduce the investment costs.

4) The calculations are based on the 210- 545 module. If the 210-600 module is used, the advantage of cost saving is greater compared to the reference module

8. Future Outlook of 210 Vertex Modules

8.1 Applications of Trina Solar 210 Vertex Module with Ultra-High-Power Photovoltaic Module

The Vertex series modules is supported by multi-busbar (MBB) and the PERC high-efficiency technologies. It creatively integrates other advanced technologies, such as nondestructive cutting and high-density encapsulation, to successfully establish a highly innovative product technology platform. It provides more feasibility in photovoltaic module design and solutions for customers with great potential. Since the product launch, more than 16GW orders has been singed globally, covering the entire spectrum of large-scale ground-mounted power plant, C&I and distributed generation market.

Comparison between Trina Solar Vertex module and other products in market

Top level in the industry	Top level in the industry	NO.1
Manufacturing Yield of 210 module	Manufacturing Yield of 210mm Cell	210 module has the world's largest production scale
0.03-0.1 RMB/W	**1%-3%**	**Over 16 GW**
BOS cost reduced	LCOE reduction	Vertex modules orders signed

The 210 Vertex module has been widely used in many applications globally due to its great advantages, receiving encouraging compliments from customers. Some projects are shown in Figure 44.

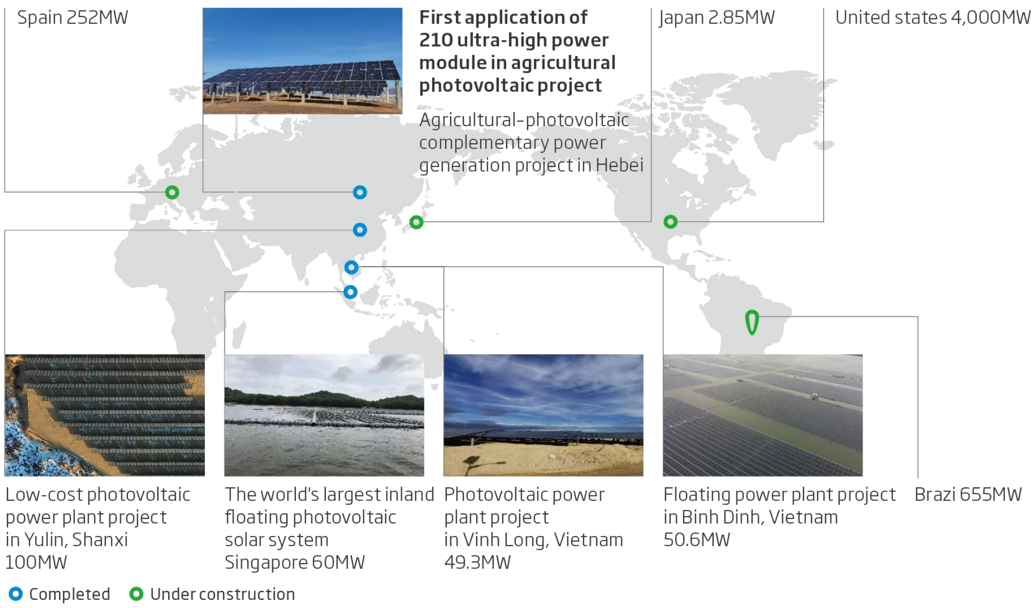


Figure 44 Projects using the 210 module

8.2 Industry Collaboration Driven by 600W+ Photovoltaic Open Innovation Ecological Alliance

In addition to the product innovation of the 210 Vertex series, Trina Solar has solved many problems in product reliability, secured raw materials, and achieved system integration through collaborative innovation and concurrent research and development with suppliers and customers. Therefore, the 210 Vertex series has been optimized and applied rapidly in the market. These efforts benefit all suppliers and customers in the photovoltaic industry and promote technological upgrades. Trina Solar led the establishment of the 600W+ Photovoltaic Open Innovation Ecological Alliance in July 2020. Many enterprises are joining the alliance, helping the entire industry step into the new era of 600W+.

System

Terminal EPC and business owners

Beijing Jidong Energy Development Co., Ltd.
PowerChina Guizhou Engineering Co., Ltd.
Power China Jiangxi Electric Power Construction Co., Ltd.
China Huadian Engineering Co., Ltd.
Huadian New Energy Technology Development Co., Ltd.

Inverters

Huawei Digital Technology (Suzhou) Co., Ltd.
SMA Solar Technology
Sineng Electric Co., Ltd.
Suole Solar Technology (Shanghai) Co., Ltd.
Sungrow Power Co., Ltd.
Kehua Data Co., Ltd.
Ginlong Technologies Co., Ltd.
Jiangsu GoodWe Power Supply Technology Co., Ltd.
Guangdong Growatt New Energy Co., Ltd.

Mounting system

Jiangsu Arctech Solar New Energy Technology Co., Ltd.
Nextracker, Inc.
Ideematec GmbH
Array Technologies FTC Solar
Trina Solar Trina Tracking

Cables

People's Cable Group Co., Ltd.

Low-voltage electrical apparats

Beijing People Electrical Apparatus Factory Co., Ltd.

Photovoltaic combiner box

Wuxi Longmax Tec Co., Ltd.

Design Institutes

Datang Group Future Energy Technology Innovation Center Co., Ltd.
China Power Engineering Consulting Group East China Electric Power Design Institute Co., Ltd.
China Energy Engineering Corporation Limited
Heilongjiang Electric Power Design Institute Co., Ltd.
Shunde Solar Energy Research Institute of Sun Yat-sen University

Cell and Module

Cells

Anhui Yingfa Desheng Technology Co., Ltd.
Changzhou Fusion New Material Co., Ltd.
Suzhou iSilver Materials Co., Ltd.
Lead Thin Film Materials (Guangdong) Co., Ltd.
Shanghai Heraeus Industry Technology Materials Co., Ltd.
Singulus Technologies AG
Tongwei Solar Co., Ltd.

Modules

Risen Energy Co., Ltd.
Huansheng Photovoltaic (Jiangsu) Co., Ltd.
JA Solar Holdings Co., Ltd.
Jiangsu Runergy New Energy Technology Co., Ltd.
Trina Solar Co., Ltd.
Yongzhen Photovoltaic Technology (Changzhou) Co., Ltd.
Suzhou Talesun Solar Technologies Co., Ltd.
Canadian Solar, Inc.

Materials

Flat Glass Group Co., Ltd.
First Applied Material Co., Ltd.
Cybrid Technologies Co., Ltd.
Jolywood (Suzhou) Sunwatt Co., Ltd.
Anhui Triumph Science & Technology Co., Ltd.
Xinyi Photovoltaic Industry (Anhui) Holding Co., Ltd.
China Building Materials (Yixing) New Energy Co., Ltd.
Rainbow (Hefei) Photovoltaic Co., Ltd.
Zhongtian Technology Advanced Materials Co., Ltd.
Zhongtian Photovoltaic Materials Co., Ltd.
Yunnan Wudian Target Materials Technology Co., Ltd.

Equipment

Von Ardenne Vacuum Equipment (Shanghai) Co., Ltd.
Hunan Red Sun Photoelectric Technology Co. Ltd.
Jiejiawei Innovative Energy Equipment Co., Ltd.
Folungwin Automatic Equipment Co., Ltd.
Ideal Energy (Shanghai) Sunflower Thin Film Equipment Ltd.
Suzhou Maxwell Technology Co., Ltd.
Xiangtan Hongda Vacuum Technology Co., Ltd.
Ningxia XN Automation Equipment Co., Ltd.

Logistics

DB Schenker Logistics

Silicon wafers

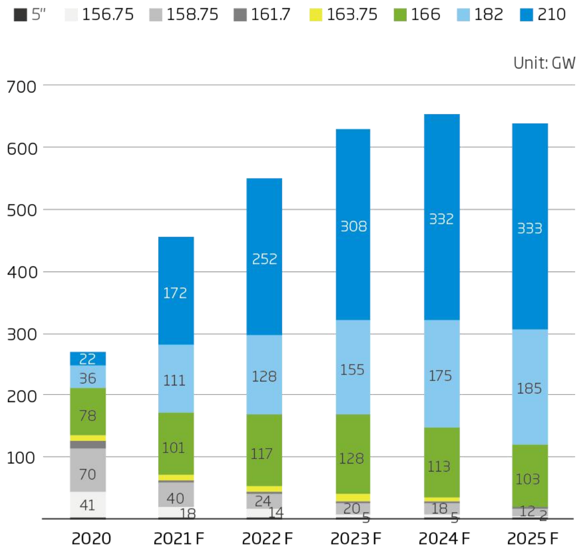
Tianjin Zhonghuan Semiconductor Co., Ltd.
Wuxi Shangji Automation Co., Ltd.
Wuxi Shangji Numerical Control Co., Ltd.
Yuze (Jiangxi) Semiconductor Co., Ltd.
Wuhu Yingri Technology Co., Ltd.
Zhejiang Liniz New Materials Co. Ltd.

3rd party

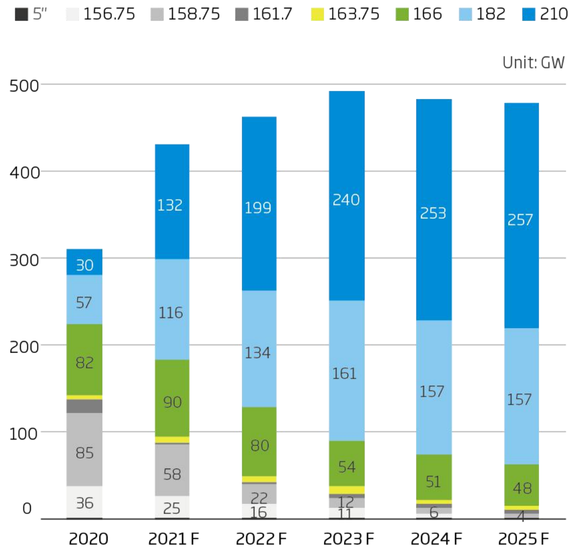
Hangzhou TÜV NORD Quality Certification Service Co., Ltd.
TÜV Rheinland Certification Service (China) Co., Ltd.
TÜV SUD Certification Testing (China) Co., Ltd.
UL CCIC Company Limited-Suzhou
Beijing General Certification Center Co., Ltd.
DNV GL Singapore Pte., Ltd.

8.3 210 Vertex Modules Expected to Enjoy Increased Global Market Share

Trina Solar and many leading enterprises in the industry promote the development of the 210 Ecology. Advanced modules and collaborative innovation have been becoming more popular. The photovoltaic industry will continue to reduce customer electricity cost per kilowatt hour to satisfy customer needs. Ultra-high-power modules will become the mainstream of the market and occupy the majority of the market share. The entire industry will fully enter the era of ultra-high-power modules. As shown in the figures below, the capacities of the 210mm cell and module will gradually increase in the next several years, far exceeding the capacities of other sizes. The annual cell capacity will reach 333GW by 2025, and the annual module capacity will reach 257GW.



Data sources: PV InfoLink 2021. April



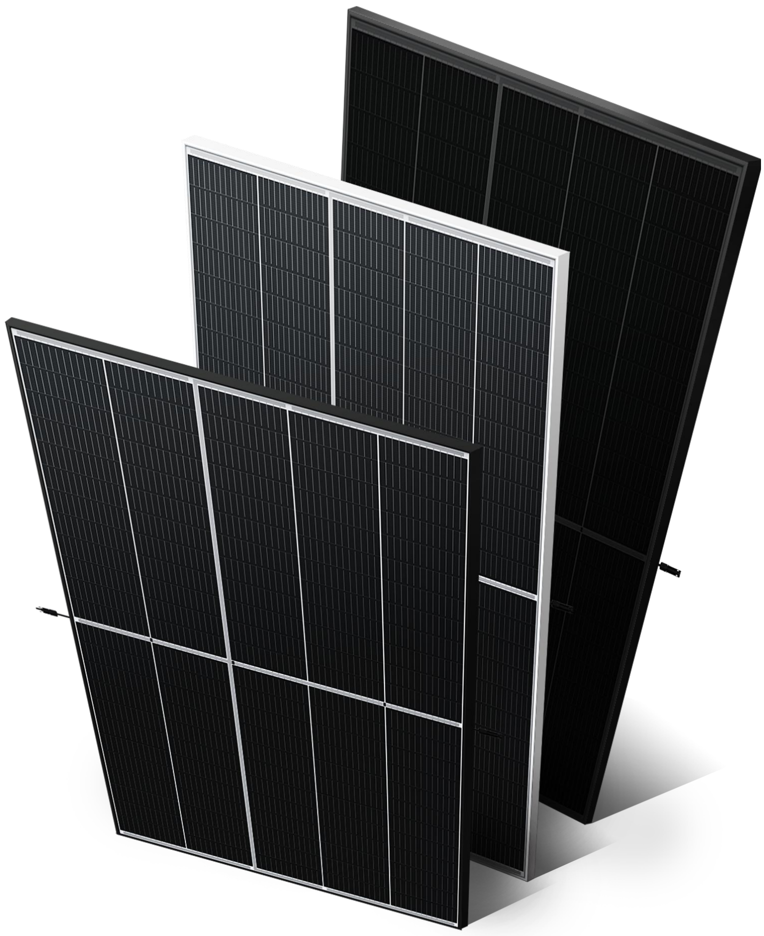
Data sources: PV InfoLink 2021. April

The expanded new capacity will make the 210 module compatible with earlier modules. High-power products will enter the stage of rapid mass production, and the proportion of large silicon wafers, such as the 210 module, will exceed 50%.

8.4 Maximizing End-User Values by Standardization of 210 Vertex Modules

The Chinese Photovoltaic Association organized meetings to reach an agreement on the size and technical details of the 210 module. This means that the component manufacturers, end users, and system integration providers have reached a consensus on the technical path of the 210 module. The standardization of the 210 Vertex module effectively helps the enterprises involved improve the production efficiency, optimize the supply, and achieve the best scale effect. These efforts can also help promote industry-wise technology innovation and reduce the costs of manufacturing, the initial investment of the photovoltaic system, and the photovoltaic power generation per kilowatt hour, further maximizing end-user values and making costs competitive. The entire industry will benefit from this standardization and the reduced costs of collaboration.

As a global leader in intelligent energy, Trina Solar continues making breakthroughs in innovation to achieve the mission of utilizing solar energy to benefit human beings. Trina Solar calls for establishing innovation mechanisms in the photovoltaic industry to build advanced power systems with new energy. Moreover, based on the Vertex product platform, it is expected that the module power will increase to 700W+, and the module conversion efficiency will become greater than 23% with more advanced cell technologies that enable the cell conversion efficiency to become greater than 25%. These specifications provide a clear direction and technical path for the continuous improvement of photovoltaic modules in the future. This development will further reduce photovoltaic system costs and the LCOE of photovoltaic power generation, accelerating global applications of photovoltaic power generation.



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