Trinasolar

THE TRINA SOLAR VERTEX MODULE WHITE PAPER

Vertex

TABLE OF CONTENTS

1. Birth of the Vertex Module

The International Renewable Energy Agency (IRENA) has expected renewable energy to contribute to 86% of global electricity generating capacity by 2050, which shall include a 25% share derived from solar photovoltaic (PV) capacity and expected to reach a more than 10-fold growth from 2016. It is also expected by IRENA that accumulated solar PV capacity will presumably attain to 8,519 GW worldwide by 2050. As highly renewable energy represents an irreversible shift in global energy policy, solar PV power shall rise as one of the most important sources of electric power in the future.

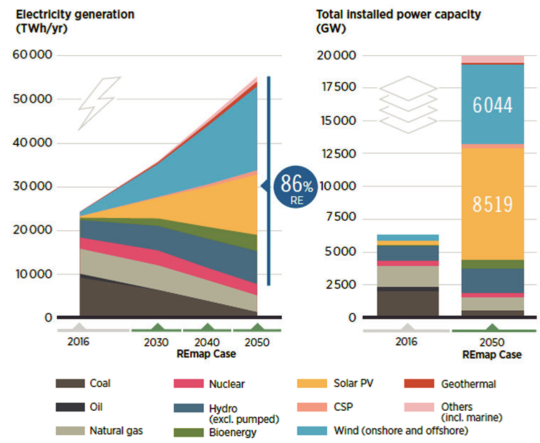


Figure 1 - IRENA forecasts of the future renewable energy structure

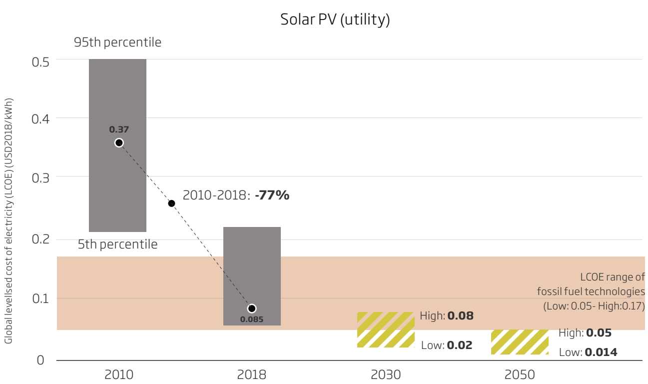


Figure 2 - LCOE development trend of the solar PV industry

The encouraging prospects of solar PV power can be attributed to the continuing reduction in energy costs. The IRENA data indicates that levelized cost of energy (LCOE) plummeted by around 77% from 2010 to 2018 in large utility solar PV projects around the world, as shown in Figure 2, Solar PV power has risen as a formidable rival of fossil fuel-derived traditional electric power and will likely continue with energy cost reduction to reach grid parity worldwide.

Currently all solar power companies are aware of the importance of continuous LCOE reduction and are working towards this goal. As indicated by the LCOE formula in Figure 3, for a solar PV system, lower initial investment and higher total energy generation over the lifespan are two effective means of LCOE reduction. For one thing, lower initial investment involves lower module cost which depends on higher power and conversion efficiency; for another, higher total energy generation means higher energy yield (kWh/kW) and requires longer module service life.

Therefore, the development of a type of high-power, high conversion efficiency ,high reliability and high energy generation solar PV module holds the key of reaching grid parity.

$$LCOE = \frac{\text{Initial Investment} - \text{Residual Value of Equipment} + \text{Operating Expense} + \text{Interest}}{\text{Total Energy Generation over the Lifespan}}$$

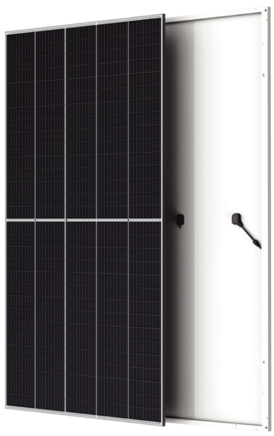
Initial Investment
- Module Cost
- Module Power and Efficiency

Total Energy Generation
- Energy Yield (kWh/kW)
- Module Lifespan

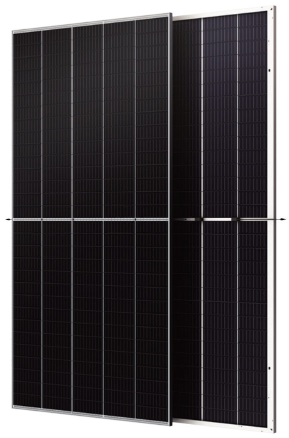
Figure 3 - LCOE Formula

2. Launch of the Vertex Module

As the leading 500W module series, the Vertex family can exceed 500 W maximum power and 21% module efficiency. The Vertex family includes bifacial double-glass modules with the product code DEG18MC.20(II) and backsheet modules DE18M(II), as indicated in Figure 4a,4b. At the same time, the two modules can prove high reliability with a 25 to 30-year power warranty and a lower first year & annual power degradation. In addition, they generate more energy thanks to their excellent low irradiation performance. These factors contribute to the introduction of a new benchmark in module performance in the era of grid parity.



4a. Vertex backsheet module



4b. Vertex double-glass module

Figure 4 - Vertex backheet module and double-glass modules

On February 27, 2020 ,Trina Solar launched the Vertex family which includes a monofacial glass-backsheet and a bifacial double-glass product, both of which can apply to large scale utility and commercial PV projects. The bifacial double-glass module can contribute to further LCOE reduction by achieving an additional energy gain of 5%-30% from its back side, depending on ground albedo.

Considering the impact of high current output on the junction box and inverter, module size on the installation, handling, transportation and logistics, Trina Solar takes the lead in proposing a 1/3-cut solar cell, 5*30 cell layout based on 210mm oversized wafers, with the perfect combination of Multi-Bus Bar(MBB), non-destructive cutting(NDC) and high-density cell interconnection technology. The design also takes into account the compatibility of downstream systems, paving the way for 500W high power modules in system integration and application, which will be the preferred PV module solutions for the next three to five years.

3. Technological Innovations of the Vertex Module

3.1 Oversized wafer

Solar wafer size has long been keeping up with the change in semiconductor wafer size. Driven by the Moore's Law, semiconductor wafers size are continually growing. As indicated in Figure 5, the 5 inch, 6 inch and 8 inch semiconductor wafers correspond with the sizes of the 100mm, 125mm and 156mm solar wafers respectively. Since 2015, due to pressure to improve efficiency and reduce costs, solar wafer manufacturers have enlarged wafer sizes many times, which explains why multiple wafer sizes, e.g. M2 (156mm), M4 (161mm), G1 (158mm) and M6 (166mm), appeared on the market one after another.

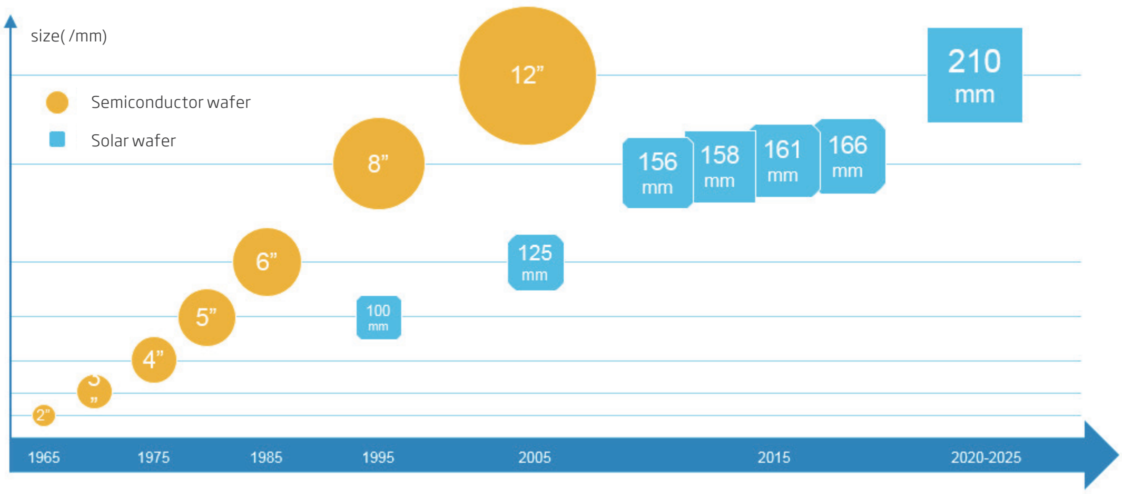


Figure 5 - Development in the semiconductor and the solar wafer sizes

A wide variety of wafer sizes has led to a variety of module power and sizes, which has caused many problems to the downstream system design and application. E.g different module power, module size and mounting hole location force PV system design to be adjusted accordingly. On August 16, 2019, Tianjin Zhonghuan Semiconductor Co., Ltd. announced that the semiconductor 12-inch mono-crystalline wafer technology will be applied in the solar industry, and launched a 210mm large-size solar monocrystalline wafer. The 12-inch wafer has been dominant in the semiconductor industry since 2005. The next generation of 18-inch wafers is not able to replace 12-inch wafers as the mainstream due to the constraints of graphite heater size, wafer pulling process, breakage rate and higher overall cost.

Therefore, the 210mm size is almost the maximum size of the current silicon wafer in the PV industry, which is expected to stabilize for at least 5-10 years from now. Not only does it help the standardization of PV module sizes but it also facilitates the standardization of downstream PV system design. Based on these factors, Trina Solar has chosen 210mm as the wafer size for the 500W PV module era.

3. Technological Innovations of the Vertex Module

3.2 MBB Technology

Multi-busbar (MBB) is an optimized technical solution ,which not only reduces the electrical losses, but also improves the optical utilization(as shown in Figure 6).

From the perspective of electricity loss, if conventional 5 busbar(5BB) design was used for 210mm, the current collection transverse path stabilize would lengthen by 30% or more. In comparison, MBB can shorten the current collection transverse path current collection by 50% and reduce cell internal resistance. Besides, uniformity of resistance distribution will improve current collection by MBB. The state-of-the-art MBB cell metallization technology can strengthen the cell passivation effect and improve electrical properties, with a 1%-1.5% increase in module power compared with 5BB.

Another remarkable advantage of MBB is the improved solar energy utilization factor. With the round ribbon, the utilization factor of incident light in the ribbon area from whichever angle can achieve around 75%. In comparison, with the traditional flat ribbon of 5BB, the utilization factor would be less than 5%. The improved optical utilization increases module power by 1%-1.5%.

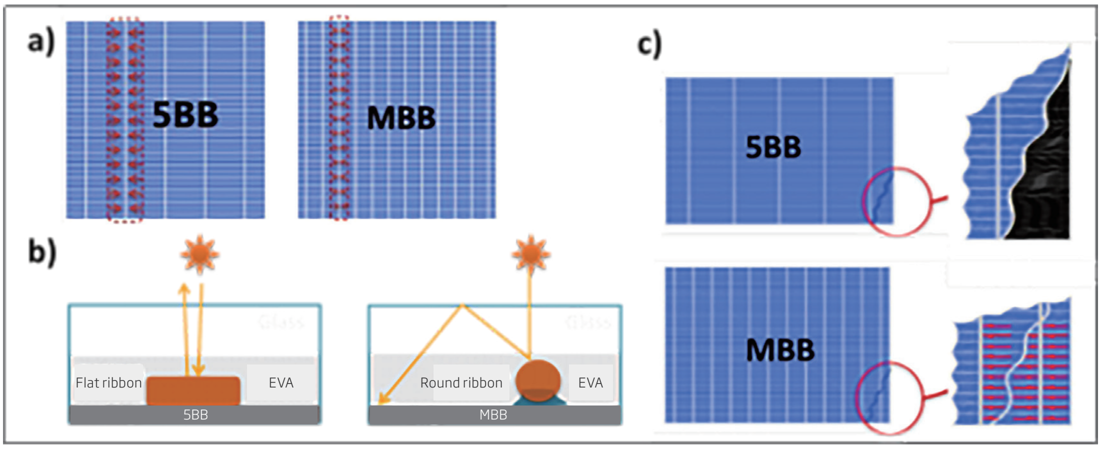


Figure 6 - MBB vs. 5BB: (a) Current transmission path, (b) Solar energy utilization factor (c) Anti-microcrack performance

3. Technological Innovations of the Vertex Module

3.3 “5*30” Cell Layout

If a similar conventional 6*20 or 6*24 Cell layout was adopted for a 210 module, the size and weight of the Vertex module would increase by approximately 40% or more, which might result in extra system installation costs. In addition, the glass width would be limited by the current glass manufacture’s capability. Considering the actual upstream and downstream situation, the optimized "5*30" cell layout is applied for the Vertex module. Integrated with technologies, such as high-density cell interconnection, the actual Vertex module size is similar to a regular 166 series module (see Table 1).

Module type	Trina Solar 158mm DEG15MC.20 (II)	Trina Solar 166mm DEG17MC.20 (II)	Vertex 210mm DEG18MC.20 (II)
Size (L*W) (mm)	2024 x 1002	2111 x 1046	2187 x 1102

Table 1 - 158mm vs. 166mm vs. Vertex: Sizes of Trina Solar bifacial double-glass modules

3. Technological Innovations of the Vertex Module

3.4 1/3-Cut Design

Compared to conventional 158mm cells, the 210mm cell area is increased by about 75%, and the module current is determined by the single cell area. At this point, if the Vertex module would feature the standard half-cut design, the final output current would be significantly higher, which would increase the potential system safety risks. Therefore, based on the MBB technology, Trina Solar’s engineering team calculated the theoretical module power based on the different busbar numbers in combination with the different options to cut the cells in smaller pieces(see Figure 7).

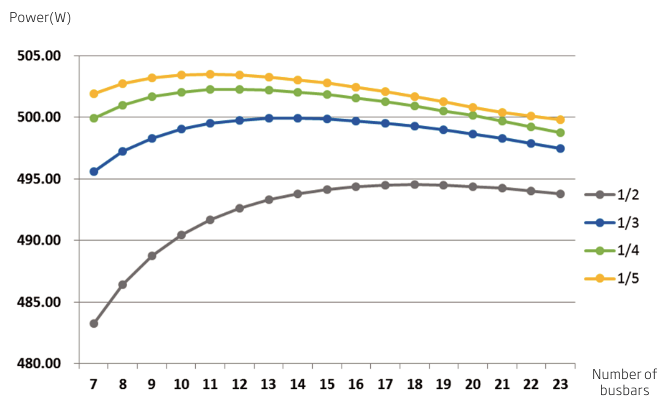


Figure 7 - Power simulation concerning different cutting options and busbar numbers

In terms of power, the half-cut option has a larger resistance compared to the multi-cut technology, and the typical peak power of the module is less than 495W; the power difference between the module with 1/3 cut, 1/4 cut, and 1/5 cut is smaller, and the overall power fluctuates in the range of 500W ± 5W. Meanwhile, when increasing the number of slices, the power would be slightly improved, and the theoretical power of the 1/5-cut is close to 505W.

From the perspective of the module layout, the number of bypass diodes to protect the modules effectively will vary significantly, as shown in Table 2. The 1/2 cut and the 1/4 cut require the placement of five diodes, which not only increases the difficulty of the process and the width of the module pattern but also increases the number of junction boxes, resulting in higher production costs. The 1/5 cut cell design uses two bypass diodes, but the manufacturing yield would be challenged as the number of cutting increases. Both traditional series-parallel-connected 1/2 cut and 1/3 cut use three bypass diodes, a number already established in the industry for a long time.

Cut type	1/2 cut		1/3 cut	1/4 cut	1/5 cut
Connection type	Series connection	Parallel-and-series connection (similar to the mainstream 1/2 cut)			Parallel-and-series connection (similar to shingled module)
module value power forecast (W)	495.5	494	500	502	503
Cell number of a single string	20	20/10	30/15	20	25
Typical I_{SC} (A)	9	18	12	9	13
Typical V_{OC} (V)	68	34	51	68	34
Number of Bypass diodes	5	3	3	5	2

Table 2 - Module performance of cutting options and the number of bypass diodes

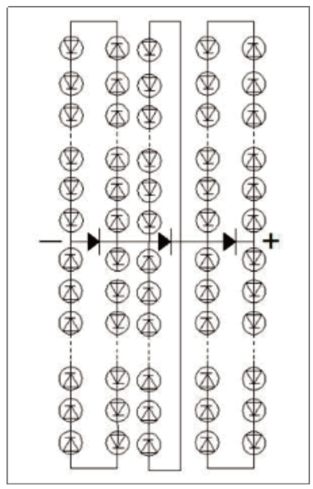


Figure 8 - Circuit configuration of the Vertex module and distribution of the bypass diodes

From the perspective of the product characteristics, if short circuit current (I_{sc}) is increased, this will obviously involve high system safety risk and higher system compatibility difficulties. If open circuit voltage (V_{oc}) is too high, maximum module number of one-string within each string in a PV system will be decreased. That will result in higher system costs. So it is significant to evaluate the values of I_{sc} and V_{oc}. For 1/3 cut, the output current is around 12A and the voltage is around 51V. The above electrical parameters of the Vertex module are a perfect fit with respect to compatibility and safety.

Therefore, considering the simulation results of the electrical performance and the technical difficulties of different solutions, the Vertex module series applies the advanced and optimized 1/3 cut design. The specific circuit layout and bypass diode distribution are shown in Figure 8.

3. Technological Innovations of the Vertex Module

3.5 Non-Destructive Cutting (NDC)

Traditional cell cutting technology involves two steps. Firstly, the wafer surface is laser-melted under temperatures higher than 1500℃ and cut to a specified depth. Secondly, the cell is broken along the cutting line by an external force. Therefore, traditional cutting can't avoid micro-cracks (see Figure 9b) which will ultimately reduce the mechanical strength of the cell. A greater concern is that if traditional cutting is used for 1/3 sized cell, the two cutting edges of the middle 1/3 cell will involve an even higher risk of mirco-cracks.

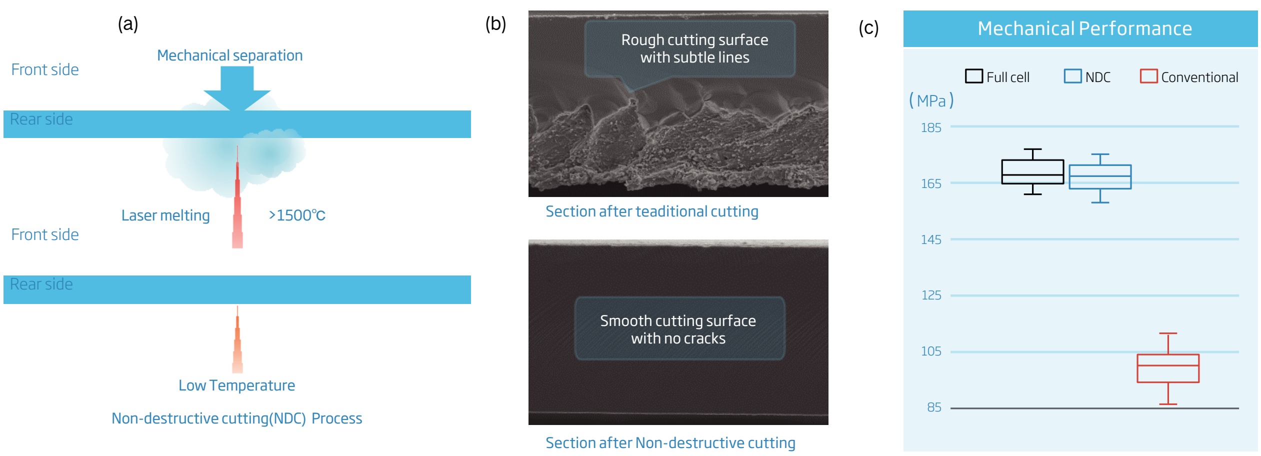


Figure 9 - Traditional Cutting vs. Non-destructive Cutting: (a) Cutting process;
(b) Cross section microscope picture of cutting edge and
(c) Comparison of mechanical properties

In order to overcome the risk, Trina Solar has adopted a non-destructive low-temperature cutting technology based on the principle of thermal expansion and contraction. Under the heat stress the wafer separates by itself. The cutting surface is very smooth without any micro-cracks. A NDC cell has a similar strength and mechanical robustness as a full cell and greatly surpasses that of the traditionally cut ones (see Figure 9c).

3. Technological Innovations of the Vertex Module

3.6 High-Density Cell Interconnect Technology

As shown in Figure 10a, the conventional cell gap is around 2mm. To increase module power and module efficiency, an increase in active area is required within a module. With this background, the breakthroughs in the soldering process resulted in the invention of the high-density cell interconnect technology.

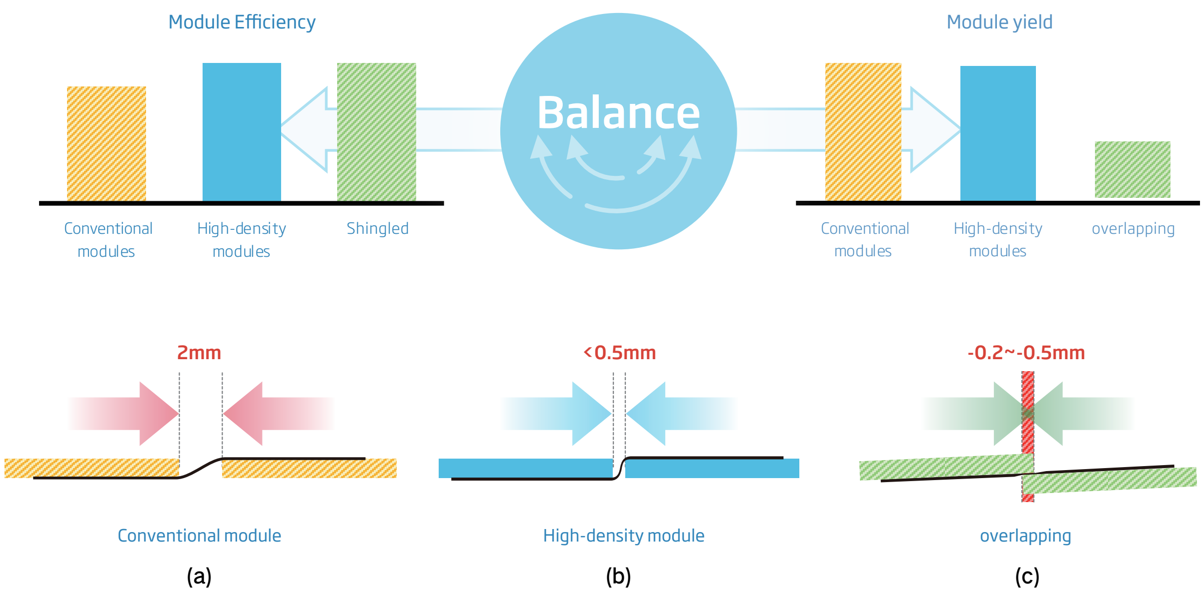


Figure 10 - Conventional Module vs. High-density cell interconnect Module vs. Overlapping Module: Illustrative diagram, efficiency and yield

Currently there are two main high-density interconnect technologies:

(1) Cell spacing is reduced to around 0.5mm by flattening part of the ribbon in between cells. Smaller module size improves overall efficiency effectively. Although there is a small gap, this spacing helps to reduce yield losses in manufacturing as well as the risk of micro-cracks and damage in operation.

(2) Cells overlap each other by a width of around 0.5 mm. The overlapping design minimizes the module size while module efficiency is slightly increased compared to the modules with small cell gap. Besides, the overlap will cause higher risks of micro-cracks in manufacturing and operation.

Trina Solar applies the small cell-gap technology instead of the overlapping technology. The small cell gap technology is a more mature high-density cell interconnect technology for Vertex modules with lower risk. The process improves module efficiency and ensures almost the same module yield.

4. Reliability Assurance of the Vertex Module

4.1 Mechanical Load Performance Optimization

The deformation and stress distribution inside the module depends primarily on the inherent structural strength of the module. Trina Solar's technical team used finite element analysis to simulate load performance of the Vertex module to compare with the traditional 166 series modules.

We take the shared-crossbeam support as an example (see Figure 11), which is a mainstream installation solution for bifacial double-glass modules to avoid backside shading. In this case, the load failure models include primarily irreparable short-side deformation and glass-profile material interfacial rupture. Because the Vertex double-glass module has a total size slightly larger than the 166 series module and unchanged glass thickness, its total deformation is slightly greater than that of the 166 series double-glass module. Nevertheless, the Vertex double-glass module involves an enhanced 35mm frame height structure, so its deformation and stress are smaller than those of the 166 series double-glass module with 30mm frame height. Therefore, the optimized and strengthened design and material used ensures the Vertex Module exceeds load performance standards.

The Vertex double-glass module is equivalent to the 166 series double-glass module with respect to load performance.

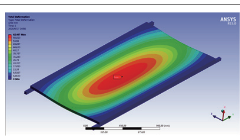
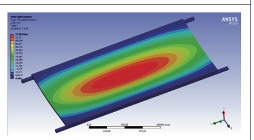
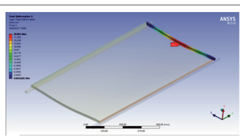
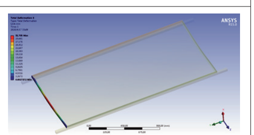
Model	Vertex double-glass	166 series double-glass
	DEG18MC.20	DEG17MC.20
Test Condition	5,400 Pa load on the front side	
Description of installation	Shared - Cross beam support	
Frame-and-glass features	35 mm frame, 2mm glass	30 mm frame, 2 mm glass
Total deformation		
Short-side deformation		
Numerical value of Short-side deformation (mm)	29.3	31.7

Figure 11 - 166 series vs. Vertex: Finite element analysis of mechanical load performance

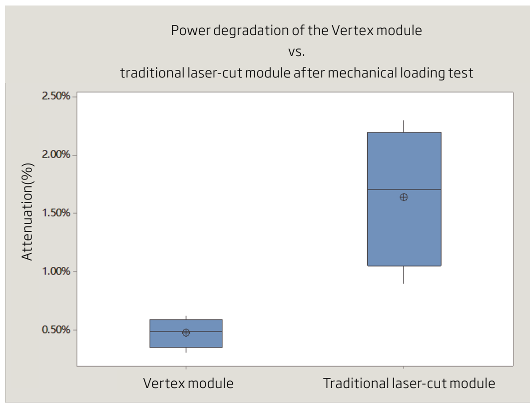


Figure 12 – The Vertex backsheet Module vs. Typical Laser-cut backsheet Module: Power degradation

The Power degradation after the mechanical load test depends both on module deformation and on cell deformation resistance. Since the Vertex module involves the use of non-destructive cutting, every 1/3-cut piece can keep almost the same bending strength as full cells and there is no micro-crack on cutting surface as well. In the load test, the NDC 1/3-cut cell exhibits remarkably higher deformation resistance than the traditionally half-cut cell. Based on typical installation on the crossbeam support, the test is conducted under the load test condition specified in IEC 61215. As shown in Figure 12, compared with the typical half-cut cell backsheet module, the Vertex backsheet module shows a reduced power degradation by an absolute value of 1%-2%. The optimized Vertex module reduces the risk of cracking and power degradation during real-life application, ensuring higher safety.

4. Reliability Assurance of the Vertex Module

4.2 Hot-spot Prevention

As shown in Figure 8, the layout of a Vertex module features "5*30" cell layout with three bypass diodes. The maximum cell number of each string protected by one bypass diode increases from 24 (in a conventional module) to 30. That means each bypass diode has to protect more cells, elevating the risk of hot-spot failures. The Trina Solar technical team primarily utilized the following solutions to prevent hot-spot failure effectively.

Cell Reverse Current Control. Power loss caused by partial shading mainly depends on cell quality, i.e. such factors as parallel resistance, reverse current, center of impurities and lattice defects. In the shading area, the correlation of the temperature variation (ΔT) with the reverse current and the parallel resistance could be expressed as $\Delta T \propto \kappa \cdot I_{rev}^2 \cdot R_{sh}$, where κ、I_{rev}、R_{sh} stands for the constant, reverse current and parallel resistance respectively. Therefore, the reverse current of the cell impacts very significantly on the hot-spot temperature. The smaller the reverse current, the higher the parallel resistance is. Therefore, Trina Solar rooted out the hot-spot risk by strict control on the reverse current.

Current Control of Cell String. The current through a cell is positively correlated with its area. A larger area will result in a larger current which drives up the hot-spot temperature incrementally. Take the common 166 series monofacial module with half-cut cells under the typical STC condition for example. In parallel connection, the maximum current through each string would around 5.4A . If the Vertex module had also been composed of half-cut cells, the current through each path would rise to about 8.7A. It would increase hot-spot risk obviously. In order to overcome the risk, Trina Solar adopted a unique design, which cuts a cell into three pieces to create series-parallel connection. The smallest unit of each piece is only 1/3 of a full cell. In the event of extreme irradiation, the output current of each cell string is only around 5.8A and surpasses that of a traditional 166 series module by around 0.4A. In this manner, the hot-spot risk is effectively under control with 1/3 cut design.

Reduction of Cell Mismatching Risk. Cell mismatching is another important factor contributing to hot-spot formation. The risk of cell mismatching increases with the growth of the number of cuts. To avoid the hot-spot risk, Trina Solar adopts a cut-and-sort technology to sort out the 1/3 cutting pieces based on electrical properties and eliminate the mismatch of the smallest cell units effectively. The hot-spot risk is therefore effectively removed and the high power output is ensured.

The Vertex modules have successfully passed the hot-spot durability test in accordance with IEC 61215 standards. As shown in Figure 13, the maximum hot spot temperature was tested on 158 series,166 series and Vertex modules. The Vertex module was found to be only 7% higher than 166 series with respect to hot-spot maximum temperature. Therefore, the Vertex module can operate safely under the worst shading conditions and guarantee a high power output.

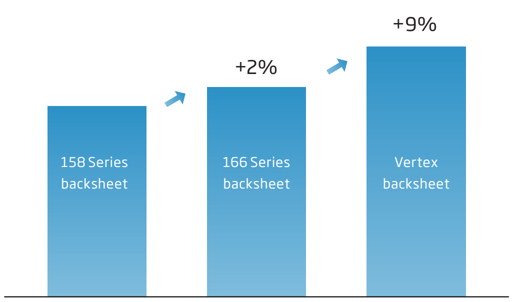


Figure 13 - 158 series backsheet vs. 166 series backsheet vs. Vertex backsheet: Maximum hot-spot temperature

5. Optimized Logistics and Transport of the Vertex Module

The Vertex module is designed for global market. Normally domestic delivery is primarily by flatbed trucking, while international shipping is by containerization. Considering logistic costs, transport safety, module security and ease of handling, the Vertex module is designed for vertical packaging and 2 pallets stacking in containers which is most popular and a mainstream packaging and transportation solution.

In this way, the most impacting factor of container load capacity is module's width, because the width of the module determines the height of stacking when modules are packed vertically. Normal stowage will be impossible if the total height of any two stacks surpasses the height of the container's door. A common 40HC container's (high cube) inside dimension: 12 m×2.35 m×2.69 m; height of door: 2.58 m (see Figure 14).

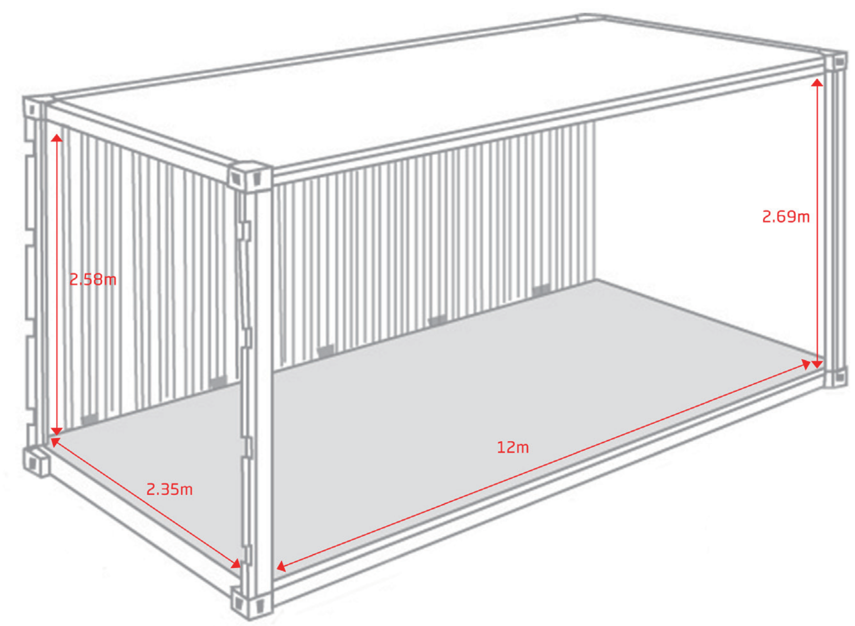


Figure 14 - Common 40 HC container dimension

Figure 15 illustrates the total height of each Vertex module stack. The total height is about 1.242 meters which can be broken down into the pallet height, the module height, the cartoon box thickness and the cushion plate thickness. Besides, considering the operation space of forklifts such as the manual and electrical hydraulic forklifts, the height of the pallet must be not lower than 8.5 centimeter.

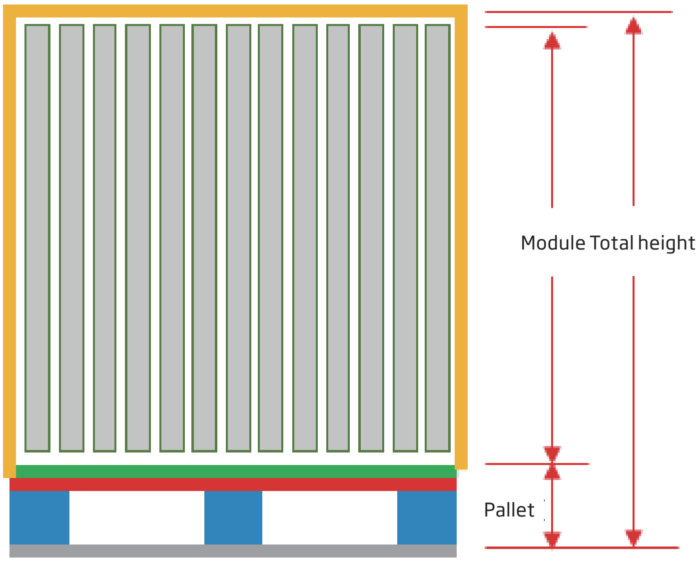


Figure 15 - Total height per pallet of Vertex modules (packaging material included)

The two packages are stacked up to a total height of approximately 2.484 meters, less than the height of the container door of 2.58 meters, and can be handled by regular trained workers, allowing normal loading and unloading. With approximately 10 centimeter of operating space between the top of the stack and the upper frame of the container door, it can also be affirmed that the width of the Vertex module makes for the best use of loading and containing.

Figure 16 - Loading height of Vertex double-glass modules in a container

Certainly, stacking or loading/unloading solutions other than generic standards may also be employed to load modules which are designed with a greater width. Nevertheless, the risk of micro-cracks during transportation has to be addressed and new handling equipment and means have to be developed.

6. System Compatibility Design for the Vertex Module

6.1 Inverter Electrical Compatibility

Vertex modules incorporate a number of innovative highlights. More than that, Trina Solar took advantage of its own total solution at the beginning of the design of the Vertex module family to make a comprehensive assessment of the compatibility of the current/voltage output with mainstream inverter products. That explains why the Vertex family has been adapted to fairly match the downstream system design.

As observable inverter product trend, the single inverter capacity increases with module power, be it a string inverter or a central inverter. Besides, the rated current is being regulated together with the regulation of the output current of the module.

6.1.1 Central Inverter

The change of the electrical parameters of the Vertex family requests the current rating of the DC fuse and the DC switch of the central inverter to be sufficient for use. It is very easy to improve by using larger-capacity fuses and switches (see Figure 17).

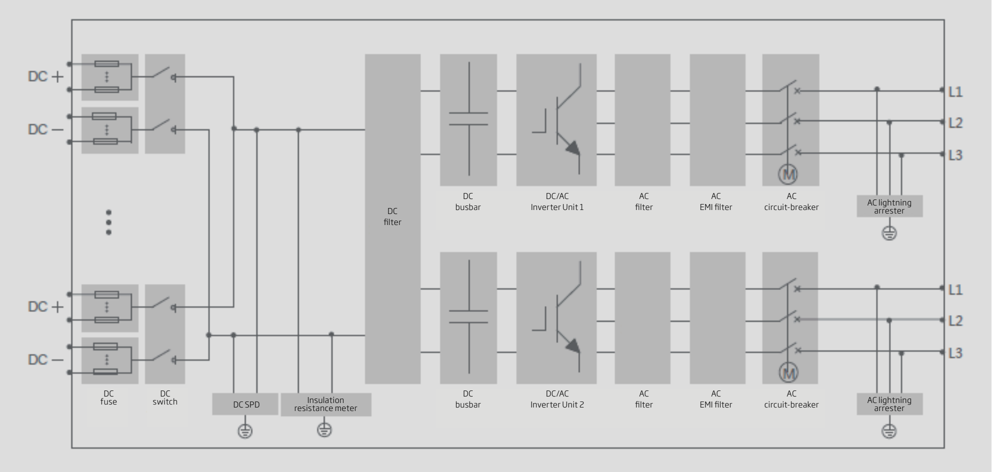


Figure 17 - Schematic of the central inverter supplied by Manufacturer S

- A larger-capacity DC fuse can be used to increase the limit.
- A larger-capacity DC switch can be used to increase the limit.

6.1.2 String Inverter

The change of the electrical parameters of the Vertex family requires corresponding matching of the maximum power point of a string inverter.

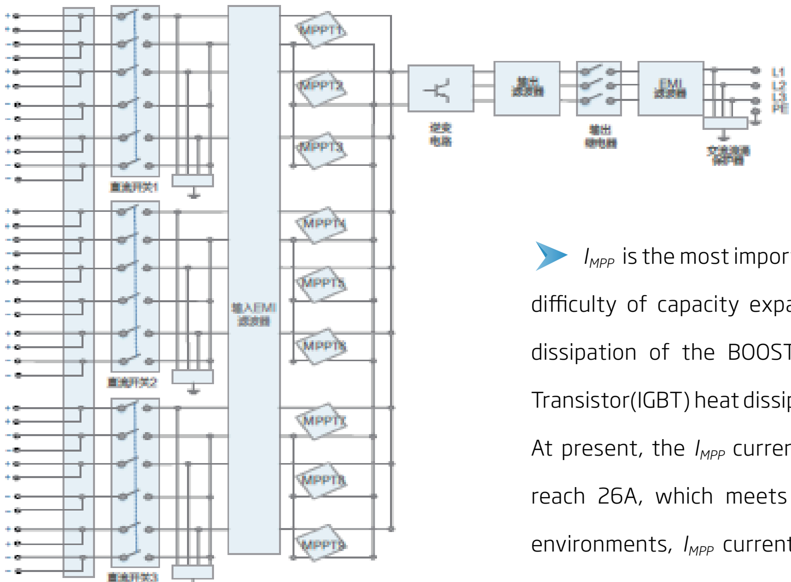


Figure 18 - The electric circuit of the string inverter of H manufacturer

I_{MPP} is the most important limitation of string inverters. The difficulty of capacity expansion is mainly related to the heat dissipation of the BOOST circuit and Insulated Gate Bipolar Transistor(IGBT) heat dissipation after the expansion (Figure 18). At present, the I_{MPP} current of mainstream manufacturers can reach 26A, which meets most applications. In some special environments, I_{MPP} current needs to be extended to 30A; for example when the back side gain of the bifacial module exceeds 30% and the temperature is very low. The actual possibility of such scenario is very rare. Mainstream inverter manufactures have completed R&D and upgrading, and there are already corresponding products available.

6.1.3 Maximum Module Number of One-String

Under the same V_{oc} temperature coefficient, the maximum module number of one-string of the Vertex module is less than that of Trina 158 series modules.

Analysis according to the most extreme conditions: Take Hainan, Qinghai as an example, consider -20 °C

(1) With a 410W module, open circuit voltage is 49.3V, $\boldsymbol{V_{oc}}$ temperature coefficient is -0.25% / ℃

Maximum module number of one-string: N * 49.3 + N * 49.3 * 45 * 0.25% <1500

N <= 27.3 and the maximum module number of one-string

(2) With the Vertex 500 W module, open circuit voltage is 51.5 V, $\boldsymbol{V_{oc}}$ temperature coefficient is -0.25% / ℃

Maximum module number of one-string: N * 51.5 + N * 51.5 * 45 * 0.25% <1500

N <= 26.2 and the maximum module number of one-string is 26 pieces

6. System Compatibility Design for the Vertex Module

6.2 DC Cable Loss Analysis

According to $R = P * L / S$

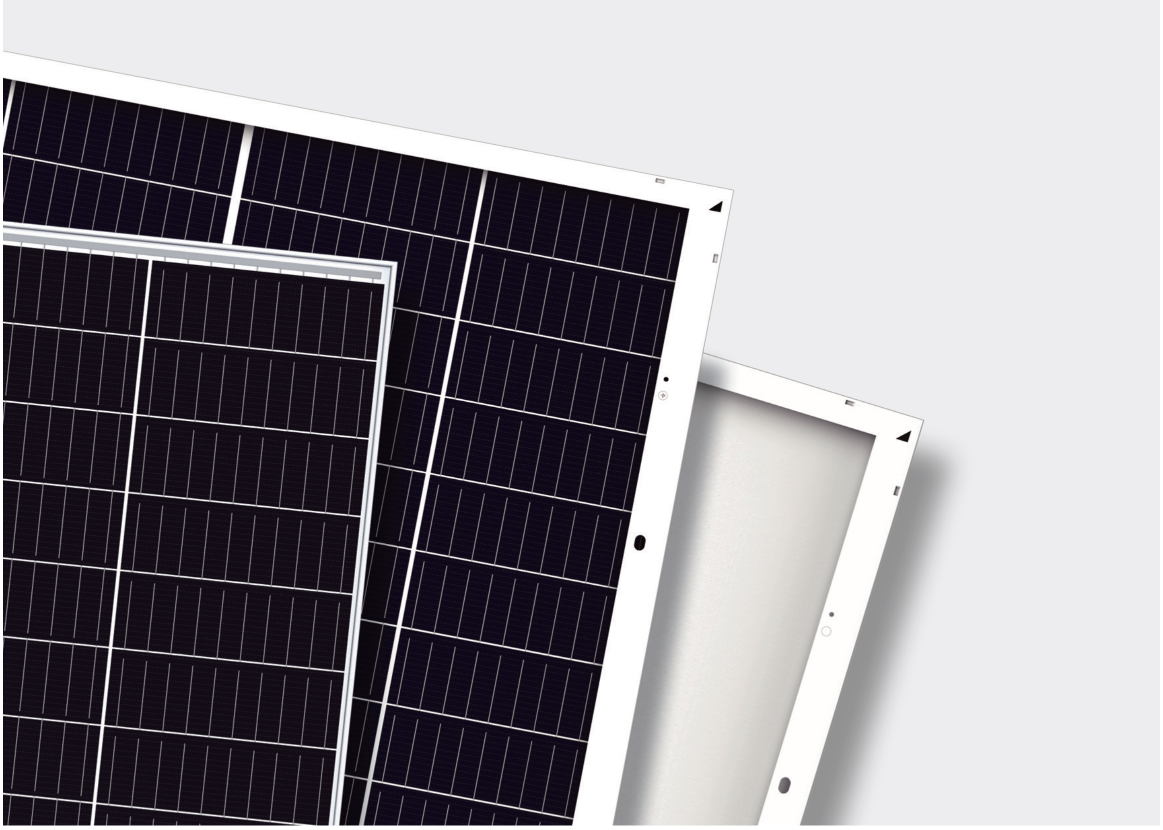
(R=resistivity, P=specific electrical resistance, L=length in meters, S=section in square mm)

410W Module DC cable length: 16,662.24m (taking 3.15MW square array layout as an example, I_{MPP} = 9.91A

500W Module DC cable length: 13,384.00m (taking 3.15MW square array layout as an example) I_{MPP} = 11.53A

Formula: $P_{loss} = R * I^2$ ↓

The DC power loss of the 500 W module is only 8.7% higher than the 158 series modules. According to the previous DC cable loss of 1.21% of the annual power generation of the module, the DC line loss of the Vertex module is 1.32% (B% = 1.21 % * 108.7%), Compared with the traditional 410 W module, it is only increased by 0.11%, which can be ignored.



6. System Compatibility Design for the Vertex Module

6.3 Mounting Compatibility Design

The Vertex module is compatible with a wide range of mounting options, from fixed-tilt mounting (landscape and portrait) to tracker mounting.

6.3.1 Fixed-tilt mounting

Thanks to the 5*30 cell layout, as shown in Table 3, there is not much difference in size and weight (5%-6%) between the Vertex module and 166 series modules, Whether the beam is mounted perpendicular to the long side or parallel to the long side, the mechanical load can reach 2400 Pa (negative) and 5400 Pa (Positive), which meets the certification requirements and is compatible with the fixed-tilt mounting (Figure 19).

Product type	Trina158 series module DEG15MC.20(II)	Trina 166 series module DEG17MC.20(II)	Vertex module DEG18MC.20(II)
Weight (kg)	26.0	28.6	30.1
Load capacity (Pa)	+5400/-2400	+5400/-2400	+5400/-2400

Table 3 - The weight and mechanical load parameters of Trina 158, 166 and Vertex bifacial double-glass modules

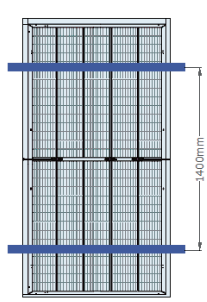
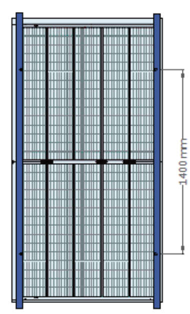
Installation method of fixed-tilt mounting		
	Static load+5400Pa/-2400Pa Bolt connection	Static load+5400Pa/-2400Pa Bolt connection

Figure-19 Matching the installation positions for fixed-tilt mounting

6.3.2 Tracker mounting

(1) Size changes for main parts of the tracker

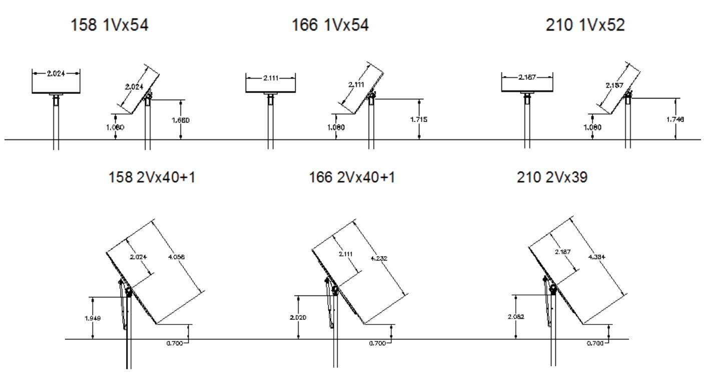
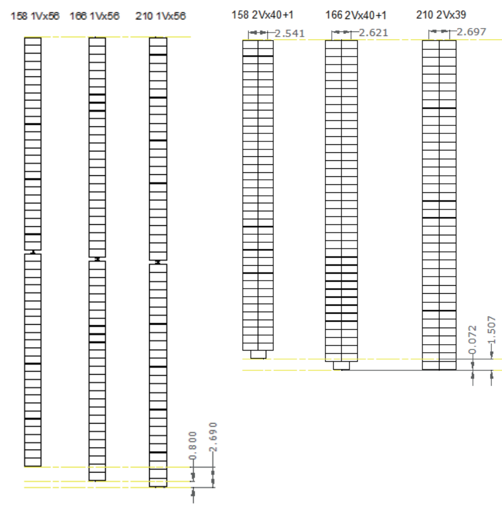
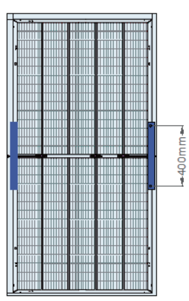
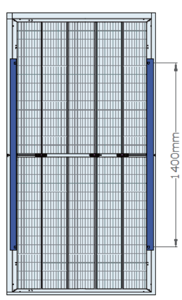


Figure-20 The different designs of trackers to match different module sizes



Refer to the calculation results of string length in 6.1.3, we compare the sizes of different trackers with three series of modules. The length of the torque tube of the 1V tracker with Vertex modules is 2.690 meters longer than that with 158 series modules. While the width is increased by 0.091m. For 2V tracker, the length of torque tube with Vertex modules is 1.507 meters longer than that with 158 series modules, and the width is increased by 0.182m. The length of purlins and the height of posts have increased also to varying degrees, as shown in Figure 20.

(2) Installation method of the tracker mounting to match the dimensions of the Vertex modules (1V / 2V) as shown in Figure 21

The installation method of tracker mounting 1V (One module in vertical)		
	Static load+2400Pa/-2400Pa Bolt connection	Static load+3600Pa/-2400Pa(TBD) Bolt connection

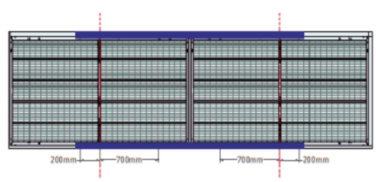
The installation method of tracker mounting 2V (Two modules in vertical)	
	Static load+2000Pa/-2000Pa Bolt connection

Figure-21 Matching the installation postilions for tracker mounting

(3) The matching of tracking system driving force

The Vertex module surface area is 2.41m^2 (length * width 2187mm * 1102mm), compared with 158 series surface area 2.03m^2 (length * width 2024mm * 1002mm), with an increase of 17.5%; module weight increased from 26.0kg in 158 series to 30.1kg in Vertex series, with an increase of 14.6%. The value of the driving torque is based on the capacity of the tracker to drive the rotating unit, which is usually determined by the wind torque and wind eccentric load generated under the maximum wind load, the eccentricity generated by the integrated center of mass of the rotating parts, and the panel rotation to overcome friction torque tracker. For this reason, for the two mainstream installation methods of tracking tracker 1V and 2V, through mechanical calculations, the driving force parameters of the existing products of 1V meet the requirements for increasing driving force parameters due to the increase in module size and weight, and no adjustment is required. The 2V scheme needs to be newly developed. Currently, mainstream tracker manufacturers all already new driving force schemes (Figure 22).

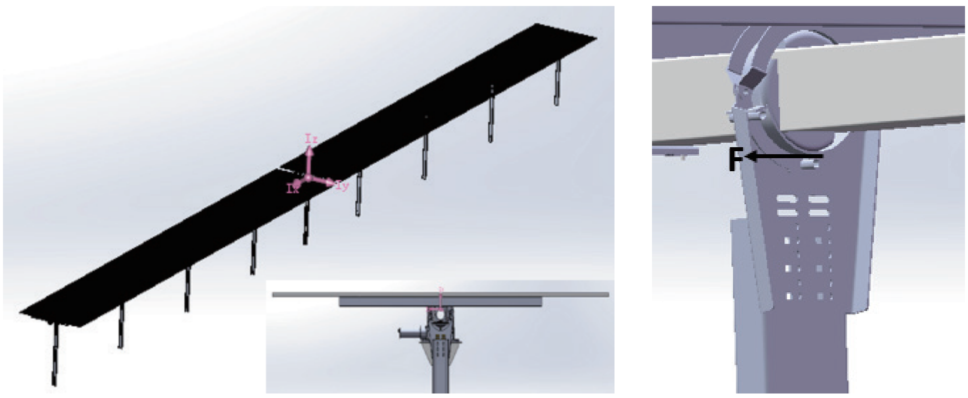


Figure-22 The design of tracking panel driving force matching Vertex module

(4) Tracker resonance and flutter analysis

The slight increase in the weight and size of the Vertex modules has caused the tracker system to undergo resonance fatigue and flutter fatigue under long-term external forces (Figure 23), Therefore, wind tunnel tests are required to conduct relevant research. Trina Solar has cooperated with third-party laboratories and mainstream tracker suppliers to complete relevant tests, and mainstream tracker suppliers already have corresponding solutions.

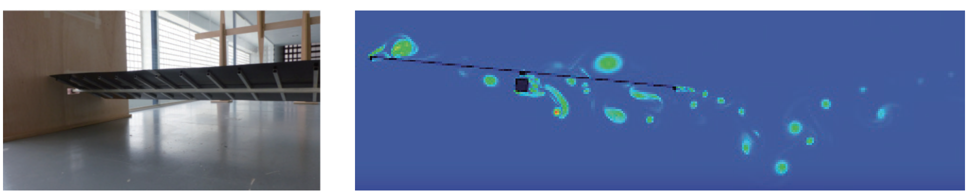


Figure-23 Simulation of resonance and flutter of the tracker matching the Vertex module

7. Customer Value of the Vertex module

The Vertex module not only eliminates the concerns of end-users with downstream compatibility, but also provides additional value to end-users in terms of lower initial investment cost and additional energy generation respectively. In order to maximize the value of the Vertex module, it is highly recommended to apply it in large scale utility and commercial PV projects.

7.1 Reduce Initial Investment Costs

We take Qiqihar City, Heilongjiang Province, China as the reference project site, with a scale of 100 MW, selecting 410 W modules of Trina Solar 158 series, 450 W modules of 166 series and 500 W Vertex modules, using a fixed-tilt mounting to estimate the difference in BOS(Balance of system) cost. The results are as follows:

Module model	Panel	Cable	Panel pile foundation	Panel and module installation	Cable laying	**BOS total**
158 Series(410W)	-	-	-	-	-	**-**
166 Series(450W)	-4.4%	-5.8%	-8%	-8%	-8.3%	**-3%**
Vertex(500W)	-8.4%	-13%	-15.6%	-15.6%	-16.7%	**-6%**

Table 5 - Simulated BOS cost difference of 100MW power station construction in Qiqihar City, Heilongjiang Province.

As shown in Table 5, compared with the traditional 410 W 158 series module, the BOS of the Vertex module can be reduced by about 6%. This considerable cost reduction is mainly due to the large span of nearly 90W module power, which reduces the amount of panels, cables, and pile foundations, also it reduces installation cost accordingly.

7.2 Additional Energy Generation

Vertex modules have excellent low-irradiation performance and temperature coefficient, which can bring additional energy generation benefits to PV systems. We simulated module energy generation according to the installation locations as in Table 6, respectively.

Installation location: The three typical cities are Changzhou, Golmud and Jeddah (Table 6). Among them, Changzhou and Golmud have similar latitudes, but the proportion of scattered light is quite different. The average annual temperature of Jeddah is the highest at 32.5 ℃, while the average annual temperature of Golmud is the lowest at 6.6 ℃.

Location	Latitude	Average annual direct irradiance kWh/m²	Average annual scattered irradiance kWh/m²	Average annual temperature °C	Scattered light ratio
Changzhou, China	31.83°N	1264.7	846.1	16.6	66.9%
Golmud, China	36.4°N	1935.9	600.6	6.6	31.0%
Jeddah, Saudi Arabia	22.3°N	2201.7	735	32.5	33.4%

Table 6 – Latitude, irradiance and temperature conditions of three typical cities

Comparing modules: 410 W (from competitors) 450 W (from competitors), 500 W Trina Solar Vertex modules

Installation method: fixed-tilt mounting, double row vertical installation

City	410W	450W	500W
Changzhou, China	Baseline	+ 2.07%	+ 2.15%
Golmud, China	Baseline	+ 1.51%	+ 1.7%
Jeddah, Saudi Arabia	Baseline	+ 1.4%	+ 1.9%

Table 7. Simulation of energy generation results of Vertex modules in Changzhou, Qinghai, Saudi Arabia

The results of the simulations for three typical cities: Thanks to the lower optical loss and excellent temperature coefficient, Trina Solar's 500W Vertex module overall energy generation is about to 2.15% higher compared to modules from competitors, which shows that Trina Solar 500W Vertex modules will bring additional value to end users.

8. Future Outlook of the Vertex Module

The Vertex Module series has built up a brand new technology platform by integrating and innovating a variety of technologies such as 210mm large size silicon wafers, multi-busbars, 1/3-cell non-destructive cutting, and high-density cell interconnection, demonstrating the vast potential for future development. On April 23, 2020, the Vertex module was certified by the independent 3rd party TÜV Rheinland and the module's power output has achieved 515.8W.(Figure 24).

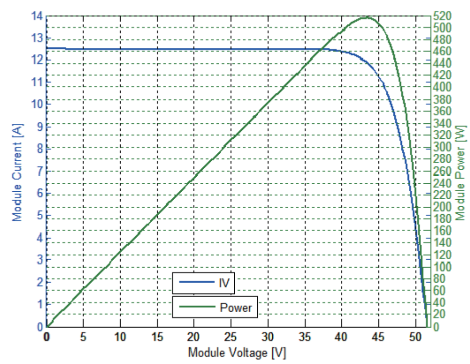


Figure 24. Vertex module power test result by TÜV Reheihland

With the development and improvement of the industrial chain, especially in terms of glass supply capability, adding another column of solar cells to the existing 5 columns design (from the current 5 columns to 6 columns), the Vertex module power can be increased to 600W. Furthermore, with PERC+ cell efficiency anticipated to surpass 24%,combined with other factors such as optimization of module design, improvement in mechanical loading ,and enhancement in downstream installation methods, the Vertex module's power output will continue to increase in the future. This also points to a clear direction and path for the continuing increase of PV module power in the future, it will further drive down the solar PV system cost and LCOE, accelerating the global application of PV power.