White Paper on Module Based on 182mm Wafer

Optimal Module Solution for Achieving Lower LCOE of Utility Photovoltaic Power Station

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(In alphabetical order)

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1. Background - Evolution of PV Silicon Wafer Size

Both aspects need to be considered for the evolution of PV silicon wafer size: the influence of silicon wafer size change on the manufacturing cost of the industrial chain, and, the influence of silicon wafer size on module size, electrical parameters and module application at the system side.

In early time, PV cells are similar to semiconductor chips, and the equipment and process costs are relatively high. Thus, increasing the size of silicon wafer can significantly reduce the manufacturing cost of cells. As the PV industry becomes more mature, situation is different now. Today, the solar cell manufacturing cost is about $0.03/Watt, which is reduced by dozens of times; the silicon wafer / cell size has also evolved independently to include M1 (156.75-ϕ205mm), M2 (156.75-ϕ210mm), M4 (161.7-ϕ211mm) and other specifications, while wafer thickness continues to be thinner.

In the industry, after the mainstream silicon wafer size maintained stably at 156.75mm for several years, G1 (158.75-ϕ223mm) and M6 (166-ϕ223mm) emerged recently. On the one hand, these slightly larger wafer sizes are compatible with the existing cell and solar glass production lines to realize immediate cost saving. On the other hand, the module size increases by less than 10%, and the original M2 module can be replaced in all applications, and BOS cost can be saved to a certain extent when the original boundary conditions remain unchanged at the system side.

With rapid capacity expansion of the PV industry chain, manufacturers may consider a new size beyond the limitation of existing production line compatibility. Indeed, some manufacturers have introduced 12” silicon wafer G12 (210-ϕ295mm) that matches the semiconductor chip, aiming to further reduce the cell manufacturing cost and the system cost through high-power modules with larger sizes. However, The reason behind the M10 (182-ϕ247mm) is that, unlike the semiconductor industry chain, the manufacturing cost of PV cells is not the core factor to consider for size change due to its low proportion in the industry chain cost; the boundary conditions for design and application of PV modules shall be considered comprehensively, so that the size of silicon wafer shall be obtained from the optimal module size. After an in-depth analysis of the whole industry chain (manufacturing, transportation, installation, power generation performance and system matching), M10 (182-ϕ247mm) is now introduced.

(Note: The 12” semiconductor silicon wafer is 50μm thicker than 8” silicon wafer, and it never replaces the 8” silicon wafer, but mainly used for chips ≤ 28nm to lower the chip processing cost)

2. Design Idea - Boundary Conditions for Module Size

- Packaging and transportation of modules

PV modules are usually packaged vertically at landscape orientation to ensure stability and minimize damage during transportation. If laying flat in package, the weight and vibration during transportation will likely introduce μ-cracks and damage to modules. If packaged vertically at portrait orientation, stability is compromised and tipping risk is much higher, posing significant challenges during unpacking. In 40HC container commonly used for overseas shipment, double stacking of pallets is common practice, so the height of the two pallets of modules cannot exceed the container door height of 2.57m. In addition, considering the surface undulation on the project site, it is necessary to leave about 10cm of operating margin for forklift unloading, and the width of modules is limited to about 1.13m. With typical 6 row layout in module, each cell and wafer width is limited at 182mm.

$$2570 - 100 - (105 \times 2) = 1130 \times 2$$

Container door height; Loading and unloading of allowance; Pallets and packs; Module width (Unit: mm)

Figure 1. The 182mm Wafer Size Module is packaged in a horizontal way, which maximizes the utilization of container space and provides about 10cm of loading and unloading margin allowance. The module can be placed stably on the project site.

- Manual handling and installation of modules

Within a certain range, the size and weight of PV modules can be increased to reduce manual handling and installation costs on per Watt basis. Beyond the limit, manual installation will become more difficult as workers are prone to fatigue and the breakage rate during installation will be significantly increased.

The width of PV modules used to be about 1m, and the installation workers could hold the modules with open arms. After the module width is increased to about 1.13m, two persons can still move them stably on a flat terrain. However, the module width should not be further increased to ensure the stability during handling.

The weight limit for frequent handling by a single person is approximately 20-25kg, and the weight limit for two persons is not simply multiplied by 2, but the coefficient of 0.666 needs to be considered, that is, the limit weight for handling by two persons is:

$$25kg \times 2 \times 0.666 = 33.3kg < 35kg$$

For this reason, the module weight should be controlled within 33.3kg, and the maximum weight should not exceed 35kg. The 72c-182 bifacial double-glass PV module weighs about 32kg, which can be handled and installed easily by two people in almost all scenarios except for the rugged mountainous regions, thus saving labor cost compared with the current mainstream 72c-166mm wafer size module.

Figure 2. The size and weight of 182mm Wafer Size Module basically reach the upper limit of convenient handling and installation by two persons.

- Load capacity of module

The primary factor that determines the load capacity of PV modules is glass, followed by the frame. In consideration of module cost and weight control, the glass thickness of the bifacial double-glass PV module is preferably 2mm. On the premise of 2 + 2mm double-glass structure and reasonable control of the frame cost, the size of the module should be within a limit, otherwise its ability to resist static and dynamic load will be weakened seriously. Under laboratory test and outdoor application conditions, frame damage, glass burst and large amount of micro-cracks are prone to occur, leading to excessive degradation on module power throughout its lifetime.

Based on theoretical analysis, the frame stress of 182mm wafer size module is within safe limit under load (the left image in Figure 3 shows the frame stress simulation under 5400Pa load). Obviously, the increase in width leads to a bigger stress increase than that in length increase. Under static load of 3600Pa when no beam is installed on the back, a module of 1.13m width has lower deformation, and the power degradation of the module is less than 2%. Therefore, from the perspective of risk control of investment return of PV power station, the module size, especially the width, should not be further increased.

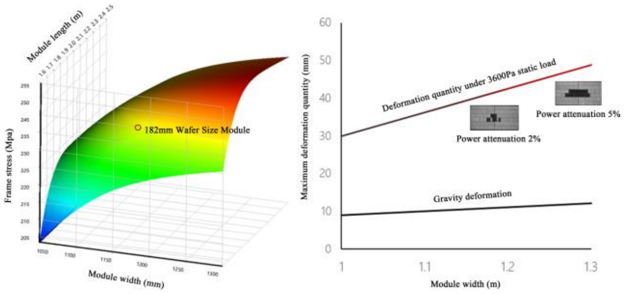

Figure 3. The mechanical loading capability of 182mm Wafer Size Module is within the safety limit. When the width of the module exceeds 1.2m, the deformation under load will bring micro-cracks and power degradation obviously.

3. Product Profile

- Dimensions, weight, electrical parameters

Based on the above analysis, and considering the limitation of module size and weight, the classical half-cut module design is still adopted, and the side length of 182mm silicon wafer can be deduced. The area of 182mm (M10) silicon wafer is 330.15cm^2, which is 20.4% larger than that of 166mm (M6) silicon wafer of 274.15cm^2. Thus, we can find that the area, weight and current of module are increased correspondingly. Typical parameters of 72C 182mm and 166mm wafer size modules are listed below:

Module type	72C-166mm Wafer Size Module	72C-182mm Wafer Size Module
Length / Width	2.10/1.04 m	2.27/1.13 m
Module area	< 2.2 m^2	< 2.6 m^2
Weight of single-glass module	~23.5 kg	~27.5 kg
Weight of double-glass module	~27.5 kg	~32.5 kg
Typical power	450 Wp	540 Wp
V_{oc}	49.5 V	49.5 V
I_{mpp}	10.9 A	13.0 A

It can be seen that 182mm wafer size module provides an optimal solution for large-scale utility photovoltaic power station due to its relatively reasonable size and weight.

- Mass production

A 182mm wafer size module is a standard-sized module designed for the new capacity of cells and modules, which breaks through the limitation of existing capacity compatibility and has the largest common divisor after 166mm in the industry. By the end of 2021, LONGi, Jinko and JA will each establish at least 30GW production capacity of 182mm cells and modules. Total capacity of 182mm wafer size modules for the whole industry will be more than 100GW.

The first batch of 182mm wafer size modules have been mass-produced and supplied in Q4 in 2020. A higher maturity of industry chain is maintained due to module size variations of less than 20%. The silicon rod and silicon wafer maintain the same manufacturing yield as 166mm silicon wafer; the cell conversion efficiency and yield of the 182mm cell also reach the same level as 166mm product; the mass production power of bifacial modules is 535 / 540Wp, and the loading capacity and hot spot temperature of modules are all within the safety zone.

- Industry chain compatibility and product standardization

The 182mm wafer size module experiences some change in size and current, which set new requirements for the support by BOM and system end.

In terms of BOM, the new PV glass manufacturing and deep processing capacity can be compatible with 1.13m wide glass, and there is no problem with the supply of encapsulants and backsheets; due to the current increase of about 20%, the 182 bifacial module uses a junction box with a rated current of 25A (the junction box uses 3 large-size bypass diodes), which maintains sufficient safety margin and fully guarantees the reliability under long-term operation with large current.

Bifacial module	I_{sc}	I_n (junction box)	I_n/I_{sc}	Design requirement	Safety margin
156.75	10.0 A	18 A	1.800	(1+30%×75%)×1.25 =1.531	17.6%
166	11.6 A	22 A	1.897		23.9%
182	13.9 A	25 A	1.799		17.5%

The system side mainly involves the matching of string inverter and horizontal single-axis tracking system. According to the bifacial gain of about 15%, the bifacial modules with an Imp of 13A need to adopt 15A string inverter, which can be realized by minor adjustment of the previous mainstream 13A string inverter, without changing the core IGBT chip. The product can be downward compatible with 166mm and other specifications of modules, thus avoiding the risk of product fragmentation and core element change.

The length and width of the 182mm wafer size module are increased by about 9%. Tracker can bear modules with the same number of strings through moderate structural strengthening. The increase of the total power of the modules can reduce the support cost per watt. At present, the mainstream 1P and 2P trackers are compatible with the 182mm wafer size module. As described in Section 2, it is not advisable to apply wider modules on tracker (especially 2P tracker) after taking into account module deformation under wind load and the power degradation due to cracks.

4. System-side value

The BOS cost saving of high-power modules is realized mainly in 3 aspects: A-The larger racking design is adopted to improve the total power of PV modules carried on the single racking, so as to reduce the support and pile foundation costs per Wp; B-The total length of PV cables connecting PV strings and combiner boxes (or string inverter) is reduced with increase in string power; C-The module size is moderately increased to reduce the labor cost.

Figure 4. Single support length is limited in case of serious terrain undulation, but ultra-long supports can be available for flat terrain.

For a power station on hills region with serious terrain undulation, the length of single rack is limited and it is difficult to move large modules. Therefore, the 182mm wafer size module is mainly applicable for relatively flat terrains. The cost can be reduced greatly by combining the design of ultra-long racking and the optimized spacing of pile foundations. For fixed racks, the length of single rack shall be limited to about 120m due to the thermal expansion and contraction of steel. The 182mm wafer size module is compatible with the design of two rows of vertical (2P) and four rows of horizontal (4L) racks, and can adapt to different terrain conditions by adjusting the number of strings on a single rack. The typical length of 2P fixed rack is shown in the following table (calculated as 26 182mm wafer size modules per string):

Number of strings on a single rack	1	2	4	6	8
Length of single rack	15m	30m	60m	90m	120m

Similar to the fixed tilt racking, there is a restriction on the length of the tracker. Further increase of module size and string power will reduce the number of strings on a single tracker, which cannot improve the total power borne by the single tracker, and thus cannot save the tracker cost.

In terms of cable cost, as shown in Figure 5, with the increase of module current and string power, the cost of 4mm^2 PV cable is reduced gradually and slowly, yet, the cost due to cable power loss increases almost linearly. Taking these two costs into consideration, the current at the optimal cost point is about 14 ~ 15A, that is, the working current of 182mm bifacial module. Besides, the cable cost will be further saved after the two channels of strings are converted into one channel and then connected to the combiner box (or string inverter) by a 6mm^2 photovoltaic cable.

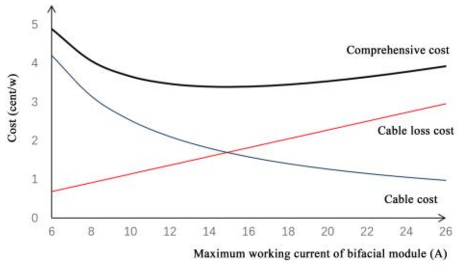

Figure 5. The curve diagram of relationship between the comprehensive cost (= cable cost + cable loss cost) of 4mm^2 cable and the maximum working current of bifacial module (superimposed on back side)

In terms of labor cost, as described in Section 2, there is a limit to the weight of PV module when it is handled and installed by two persons. Beyond that, the workers are prone to feel fatigued due to long working hours, thus the work efficiency will be lowered and the breakage rate during installation will be increased.

Based on the above analysis, the BOS cost of a PV power station has been compared and analyzed under fair boundary conditions. The results verified by TÜV NORD are as follows (the difference in manual installation cost is not considered):

(Conditions: Wind pressure 0.38kN / m^2 [25 years], 0.45kN / m^2 [50 years]; snow pressure 0.21kN / m^2 [25 years], 0.25kN / m2 [50 years]; inclination 34°; the lowest point of the module is 1.5m above the ground; the land cost is calculated based on $ 0.127 / m^2 / year and a lump sum payment for 20 years)

2P fixed rack, centralized inverter (cost unit: $/Wp)				
Product	72c-166	72c-182	55c-210	60c-210
Power	450Wp	540Wp	540Wp	590Wp
DC capacity	3.9852MW	3.96576MW	3.969MW	3.9648MW
String length	27	27	35	32
Number of strings on a single rack	8	8	6	6
Pile spacing	3.5m			
Rack & foundation costs	0.070	0.065	0.066	0.067
Total cable cost	0.017	0.016	0.016	0.016
Electrical equipment	0.046	0.045	0.045	0.045
Floor area	58074 m^2	54941 m^2	56381 m^2	55348 m^2
Land cost	0.037	0.035	0.036	0.035
BOS cost	0.170	0.161	0.163	0.163

The calculation results of the 2P fixed rack meet the expectation: 182mm wafer size module has an obvious advantage over 166mm wafer size module in terms of BOS cost; compared with 60c-210 and 55c-210 modules, there is little difference, but with a slight advantage due to higher efficiency of the module; in the case of vertical installation, the BOS cost of 60c-210 module is lower than that of 55c-210 module, because longer module has a slight advantage in both racking and foundation costs.

The BOS costs of 182mm wafer size module and 55c-210mm wafer size module installed on the 4L support are further compared below. The results show that the former has a slight advantage in racking, foundation and land costs due to higher efficiency. Too wide modules are not considered for comparison due to poor loading capacity when there is no beam, and difficult installation of the top row of modules in case of 4L rack.

4L fixed rack, centralized inverter (cost unit: $/Wp)		
Product	72c-182	55c-210
Power	540Wp	540Wp
DC capacity	3.96576MW	3.969MW
String length	27	35
Number of strings on a single rack	8	6
Pile spacing	3.5m	
Rack & foundation costs	0.068	0.070
Total cable cost	0.016	0.015
Electrical equipment	0.045	0.045
Floor area	56728 m^2	58727 m^2
Land cost	0.035	0.036
BOS cost	0.164	0.166

Excessive working current of a module will lead to significant increase of the heat losses on the metal contact surface of the cell, the ribbon and the bus bar, which will increase the working temperature of the module to a certain extent. This has been proved by comparison and analysis of the working temperatures of half-cut module and full-size module. JA and TÜV NORD have conducted a comparative study on the power generation capability of 182mm wafer size module and a super-large current module in Yinchuan National Photovoltaic Experimental Base, and the data for two months (from February 19, 2021 to April 20, 2021) have been obtained so far. The results are shown in Figure 6. It can be seen that on a sunny day, the average operating temperature of 182mm wafer size module is 1.7°C lower than that of the super-large current module, and the maximum temperature difference can be as high as 4~5°C. Meanwhile, the average energy yield per watt of the former is about 1.6% higher than that of the latter, thus 182mm wafer size module shows an obvious advantage in power generation.

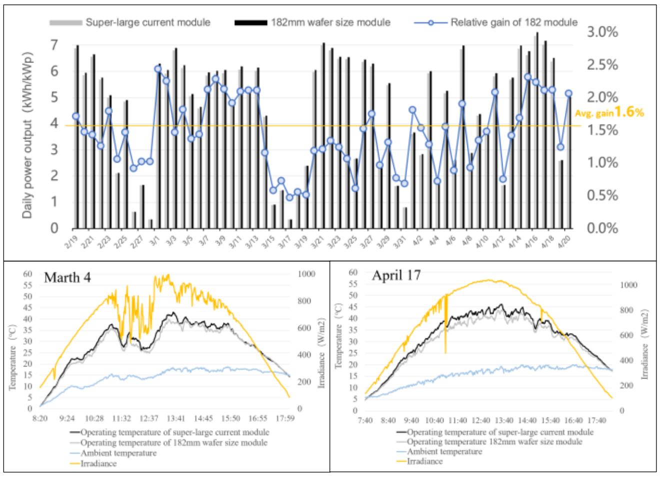

Figure 6. Comparison of Power Generation and Typical Daily Operating Temperature of Super-large Current Module and 182mm Wafer Size Module.

In addition, in the 7th All Quality Matters (AQM) Solar Congress 2021 held by TUV Rheinland, 182mm wafer size module from JA and LONGi respectively won the Energy Yield Simulation AQM Award-Mono Group (Monofacial) and the Energy Yield Simulation AQM Award-Mono Group (bifacial) to further prove its excellent power generation performance (TÜV Rheinland has tested the Pan files of 5 modules from the mass-produced 1000 modules to simulate the power generation at 5 locations in the world).

5. Application Cases

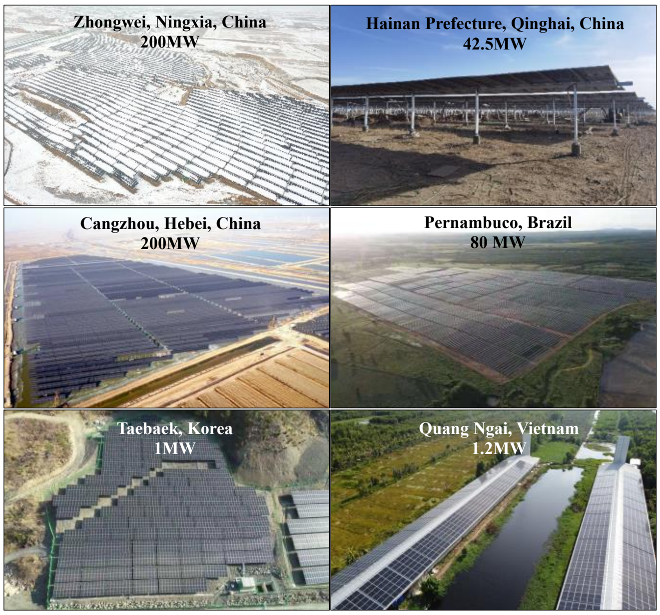

Figure 7. Applications of 182mm Wafer Size Module in Different Scenarios in the World

6. Summary

A PV power stations are designed to work reliably for >25 years, being able to perform well even in extreme weather conditions. Reliability of module and system is the basis for ensuring the return on investment and realizing the value for customers. The 182mm wafer size module is the most cost-effective solution based on the in-depth analysis of various boundary conditions of the whole industrial value chain. Without efficiency improvement, further increase on module power with larger size modules will not achieve lower system cost. At the same time, there is significant increase in reliability risk with oversized modules. Simply increase on module power with larger and larger dimensions is not technological innovation. Instead, standardized module size helps switch the focus of the whole industry value chain (manufacturing equipment, bill of materials, inverters, trackers etc.) to efficiency and energy yield improvement.