Hi-MO3: Reducing PV LCOE by the Mono PERC Bifacial Half-cell Technology

1. Introduction

LONGi released the Hi-MO3 module in 2018 by combining P-type mono-silicon bifacial PERC technology and the half-cell technology. This product has inherited the high efficiency and low degradation of the Hi-MO1 mono-silicon PERC module as well as the high bifaciality of the Hi-MO2 bifacial PERC module. The half-cell technology further enhances the module's power and reliability. It can minimize the LCOE When applied to the large scale PV projects in areas rich in light resources together with fixed mounts or horizontal single-axis tracker or significantly enhance the project's IRR (Internal Rate of Return) when applied to distributed PV stations where the ground has undergone high reflective treatment (such as paint white).

The P-type PERC bifacial technology is a new bifacial technology emerged in 2015[1]. Compared with the traditional N-type or heterojunction bifacial cells, the bifacial PERC cell adopts lower-cost P-type silicon wafers and aluminum fingers on the backside, but can also obtain high cell efficiency and a bifaciality up to 80%. So it has a very high performance/price ratio. The bifacial cell efficiency of LONGi in R&D was 23.11% on the front side and 18.97% on the rear side tested by Fraunhoer-ISE (2018.5, bifaciality-82.1%). And the front-side efficiency of mass produced cells has already exceeded 22%.

The high efficiency of PERC cell endows LONGi's modules with excellent low irradiance performance and low value of power temperature coefficient, which won the first place in the TÜV Rheinland 'All Quality Matters' PV Module Energy Yield Simulation in 2017 and 2018; The low-degradation technology makes LONGi's PERC modules perform better in outdoor operation, as In the "PV magazine test", energy yields of LONGi's monofacial and bifacial PERC module both ranked first among the same types of products[2].

The half-cell technology halves the operating current of the cell to significantly reduce the energy loss on the ribbons. The high current because of the mono PERC technology and the operating current gain brought by the light received on the rear side makes the bifacial PERC cell very suitable to apply the half-cut technique, and brings improvements in power, energy yield and reliability.

2. Product Features and Performance Advantages

LONGi's Hi-MO3 uses reliable encapsulating material to ensure the anti-PID performance and further improve its long-term reliability. The front and rear glasses of the framed Hi-MO3 module are both 2mm thick. As a result, the module is lighter, and is easier to be installed and match with the tracking system; The glass coated with white ceramic mesh is optional to be the rear glas, which can enhance the front-side power of a 60-cell bifacial module by nearly 5W; Hi-MO3 adopts a frame with a B-side width of 30mm so that it can withstand a static load of 5400Pa on the front side. The short frame adopts a "no C-side" design to reduce its shadow on the rear side of the cell, which can enhance the energy yield of the bifacial module compared with conventional frames; in the low-load area, unframed 120 half-cut cell module (with 2.5mm thick glass) can be used to save the module cost and avoid the shadow of the frame on the rear side; in addition, the use of a rod-shaped split junction box also won't shade the rear side of the cell.

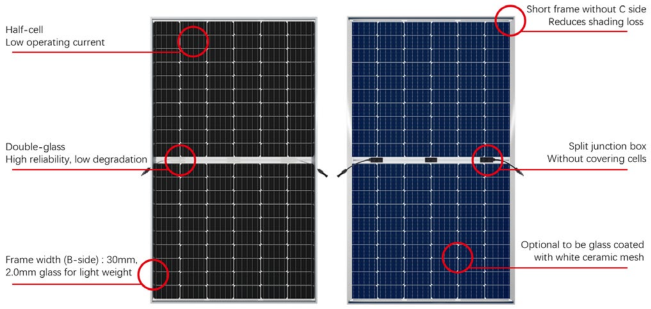

Figure 1: Hi-MO3 Module

The photovoltaic module is inevitably partially shaded by bird droppings, leaves and so on in the outdoor PV station. If they are not removed in time, the continuous hot spot effect will cause irreversible degradation or even failure of the module. Theoretical analysis[3] and experimental data both show that the half-cell technology can reduce the hot spot temperature by 10-20°C, which will further improve the reliability of Hi-MO3.

In the laboratory front-side lighting test, the half-cell technology can reduce the heat loss of the ribbons by more than 5W (60-cell PERC module), and in high radiation outdoor conditions, considering the irradiance on the rear side of the bifacial module, the reduced heat loss may exceed 8W, the operating temperature of the bifacial half-cell module will be significantly different from that of the full-cell bifacial module. The maximum temperature difference can reach more than 1°C, so the power generation capacity can be improved. Based on the significantly reduced internal heat loss and low operating temperature at high irradiance, the Hi-MO3's advantage in power generation is particularly obvious in areas with rich light resources (where the temperature is generally high), such as western China, the Middle East, northern and southern Africa, Australia, western United States, Mexico and Chile. The field test carried out by Enrique Cabrera at ISC-Konstanz[4] shows that when the albedo of the ground is 90%, the half-cell technology can improve the performance ratio (PR) of the bifacial module plant by 2.7%; when the irradiance is above 900W/m2, the PR improvement can reach 4.3%. As to the operating temperature, because the rear side of the bifacial PERC cell uses aluminum fingers instead of the fully covered aluminum electrode to reduce the absorption of infrared light with strong thermal effect[5], the operating temperature of the bifacial PERC module is equal to or even slightly lower than that of the monofacial PERC module.

At present, the mainstream half-cell modules in the market all adopt the design of upper and lower parts in parallel. Half of the module being shaded won't start the bypass diode, therefore, when the half-cell module is installed in portrait orientation, and the lower half part of the module is being shaded by modules in the front row in the morning or evening, the upper half part of the module can still generate electricity (Figure 2a); for the same reason, if the installation height is not high or the terrain or ground environment is complex, the amount of light received by the upper and lower parts of the bifacial module will be quite different, and the power generation performance of the half-cell bifacial module will be better than that of the full-cell bifacial module (Figure 2b).

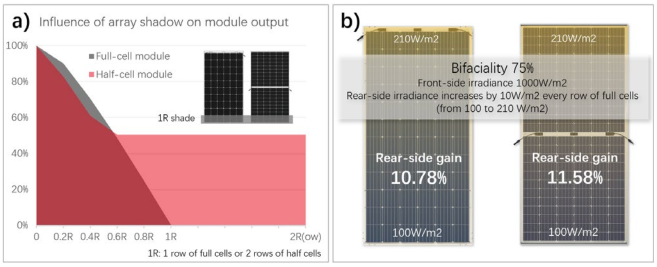

Figure 2: a) Power output of half-cell module and full-cell module (installed in portrait orientation) when shaded by the front-row modules; b) Comparison of bifacial gains of half-cell bifacial module and full-cell bifacial module when uneven rear side lighted.

The advantage of not starting the bypass diode when a large part of the module is shaded does not hinder the diode's protection of the half-cell module from hot spot. According to the experimental and theoretical analysis, in the power generation status, the half-cell module starts the bypass diode when 90% of a half cell is shaded, while the full-cell module starts the bypass diode when 50% of a full cell is shaded. For a PV system composed of multiple modules, 12 for instance, the bypass diode is started when 20% of a half cell of a half-cell module is shaded, while for a full cell the shaded area is 13%.

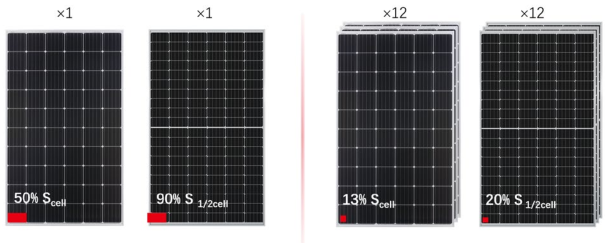

Figure 3: Shade erea of cell required for bypass diode start-up of full-cell and half-cell modules

It can be seen that the half-cell technology makes it easier for the diode to start when a small part of the module is shaded to

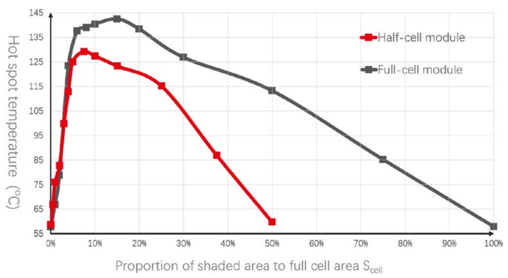

Figure 4: Hot spot temperatures of full-cell and half-cell modules with different shaded areas of cell

improve the protection of the module from hot spot effect. In addition, the maximum temperature rise caused by hot spot occurs when about 10% of the full cell erea is shaded (Figure 4), at the time, the starting condition of bypass diode has not been reached, and the reliability of the module is significantly improved with the half-cell technology by reducing the hot spot temperature by about 10~20°C.

3. Design of PV Station

The rear side of the bifacial module can receive the light reflected from the ground, can also directly receive scattered light, and in some conditions, can receive direct light. These irradiances can increase the operating current of the bifacial module and hence obtain significant energy gain. Therefore,

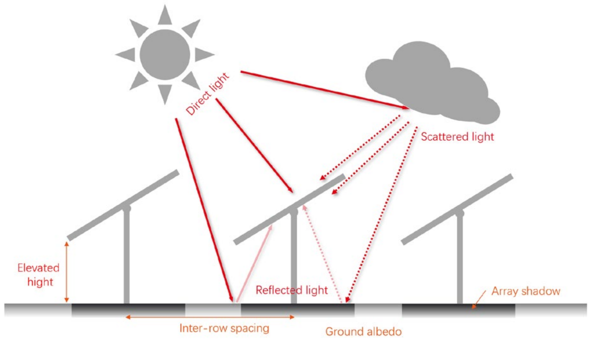

Figure 5: Irradiance on the rear side of bifacial module

factors influencing the energy gain of the bifacial module include the albedo of ground; the proportion of scattered light in total irradiation; the elevated hight of bifacial modules, the inter-row spacing (or GCR: ground coverage ratio), the sun zenith angle, etc.

The albedo of ground is the most important factor affecting the energy gain of bifacial modules. The order by albedo of common grounds is: water (nearly 10%), grassland (15-25%), land (20-30%), concrete & sand (25-40%) and reflective film & new snow (70-90%). The albedo varies with the density of grass, the color of land or concrete, and other specific conditions.

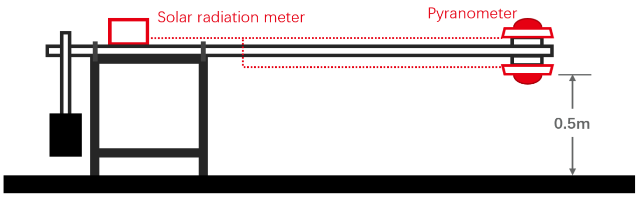

Figure 6: Schematic diagram of ground albedo measurement

Table 1: Albedo of different grounds in field measurement according to the <ASTME1918-16> standard

Ground type	Project location	Measured albedo
Cement	Taizhou, China	25.15%
Reflective film		71.44%
Grassland	Ding'an, Hainan, China	16.01%
Cement		43.10%
Sand		40.46%

The albedo of actual PV project can be measured according to the <ASTME1918-16> standard, using two irradiance meters back to back to measure the front-side irradiance and the reflective irradiance on a flat ground with a diameter greater than 4m.

The rear side of the bifacial module can directly receive scattered light, so when the proportion of scattered light in total irradiation is high, the energy gain of the bifacial module will be high. A comparison of bifacial module and monofacial module by single-day energy yield shows that the bifacial gain ratio is stable at noon and apparently rises in the morning and evening; the field test also finds that the bifacial gain ratio in cloudy, rainy or foggy weather is higher than in sunny weather. Considering that the proportion of scattered light is usually high in the areas with poor light resources, the use of bifacial modules can help these areas obtain acceptable IRR on PV power stations.

The shadow of the bifacial module array can reduce the irradiance on the ground, thus affecting the reflected light received on the rear side of the module, so the bifacial gain of single bifacial module is higher than that of single row of modules, and definitely higher than that of multi-row modules; for multi-row modules, when the inter-row spacing is larger (the GCR is smaller), the bifacial gain will be higher. When the module's ground clearance is low, the shadow is darker and the influence on rear-side irradiance is greater, therefore, the bifacial module's minimum ground clearance should not be less than 1m, and preferably should be more than 1.5m. The solar zenith angle can affect the area of the shadow on the ground. When the angle is small, the shadow is small, which is benificial for bifacial gain. The bifacial energy gain at middle and high latitudes throughout the year shows an obvious trend of being high in summer and relativly low in winter, because, on the one hand, the solar zenith angle is small in summer; on the other hand, the sunrise and sunset last longer in summer, when high proportion of scattered light also leads to higher bifacial gain.

PVsyst uses View Factor model to calculate the irradiation on rear-side of bifacial modules. Since version 6.65, it has been able to well simulate the energy yield of PV station using bifacial modules[6], therefore, the module's ground clearance, the tilt angle, inter-row spacing and DC/AC ratio can be optimized for better IRR considering the cost and energy yield of PV stations.

Due to the high operating current of bifacial modules, the inverter should be able to bear high string current. Currently, mainstream inverter manufacturers have already increased the maximum string current to 12.5A~13A to match bifacial modules. Hi-MO3 supports 1500V system voltage and is suitable to work with 1500V inverter and cables to form a large MWp array, which can reduce the system cost and line loss, and enhance the PR. For large array covers a large area, the albedo may be uneven, leading to different power output of modules in different positions. Therefore, it is recommended to use the inverter with multi-MPPT function to reduce mismatch loss.

With respect to the mounts, due to the rear-side light exposure requirement, it is recommended to use the mounts that won't shade the rear side of the module, avoids or reduces the shade of cable, combiner box or string inverter on the rear side of the module. Based on the analysis of installation reliability, the bifacial module should be installed on the long frames (so LONGi's bifacial module is designed to eliminate C-side of the short frames), so the steel purlins are on both long sides of the module (Figure 7). Under this requirement, compared with the 2-row installed in the potrait orientation, the 4-row landscape installation on fixed mounts generally uses less steel, but requires longer cables and more cable connection workloads. PV station designers may choose according to the specific cost situations. If it is inevitable to use mounts shading rear side of the bifacial module, the distance between the steel purlins and modules should not be less than 50mm in order to reduce the adverse effect on the bifacial energy gain.

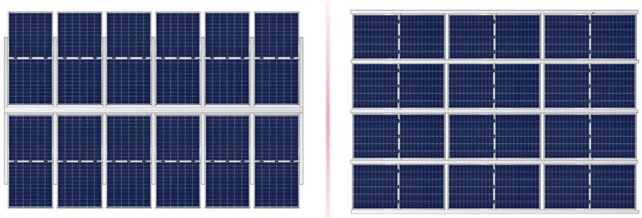

Figure 7: Diagram of mounts when bifacial modules installed in the portrait and landscape orientation without shade on the rear-side

In the area with low latitude and high proportion of direct irradiation, horizontal single-axis tracker (HSAT) can be adopted to obtain high energy gain. When bifacial modules are used on the HSAT, the tracker can maximize the front-side irradiation, and bifacial modules in tracking can still receive irradiation on the rear side, leading to quite lower LCOE. In general, it is suitable for bifacial modules to match the 2P (portrait) tracker to avoid the shade on the rear side, while the Hi-MO3 bifacial half-cell modules match the 1P tracker well, because the inter-cell spacing in the middle of the module is up to 33mm. The front light can pass through the spacing and reflected by the high albedo centre shaft to the rear side of the shaded cells, significantly reducing the adverse effect of the centre shaft on the bifacial energy gain.

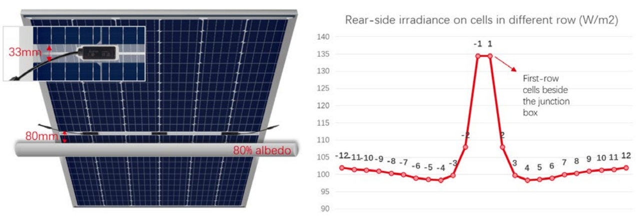

Figure 8: Typical rear-side light exposure of a bifacial half-cell module with a 1P horizontal single-axis tracker

4. Application Cases

LONGi's bifacial modules have been applied to various grounds and climatic environments, their power generation gain and features are consistent with theoretical expectations, and their long-term performance is stable, providing a reference for similar PV station investors. Typical projects are shown in Table 2. The PV station in the Kubuqi desert of Ordos, China has been in operation for more than one and a half years. Compared with 'multicrystalline silicon module + fixed mounts', the combination of bifacial module with 12° titled uniaxial tracker can achieve an energy gain of 25%; although the albedo of the water is relatively low, by virtue of LONGi PERC module's better low-light performance and power temperature coefficient, the bifacial modules in a Hefei project (China) achieved an energy gain of 7% in 2018 compared with F silicon modules; in the tests conducted by third-party institutions, with LONGi's monocrystalline PERC module as the control group, the bifacial module also achieved high energy gain.. In the field test of TÜV SÜD, the module's ground clearance was an ideal 1.5m, so the gain was relatively higher.

Table 2 Field Tests of LONGi's Bifacial PERC Modules

Project location	Ground	Gain	Capacity	Control group	mount	period
Ordos, China	Sand	13%	336kWp	Multi	Titled tracker	17.7~18.12
Taizhou, China	concrete	10%	2.8kWp	Multi	Fixed	17.9~18.8
	Reflective film	25%				
Golmud, China	Sand	15%	20MWp	Mono	HSAT	18.3~18.8
Hefei, China	Water	7%	5.0kWp	Multi	Fixed	18.1~18.12
Ding'an, Hainan, China	Grassland	10%	2.7kWp	Mono PERC	Fixed	18.9~18.11
	Sand	15%				
	concrete	15%				
Chennai, India	White gravel	20%	600Wp	Mono PERC	Fixed	18.9
Thuwal, Saudi Arabia	Sand	9%	600Wp	Mono PERC	Fixed	18.9
Fremont, USA	Light-colored asphalt	7%	1.8kWp	Mono PERC	Fixed	18.8~18.11
Livermore, USA	Gravel	9%	2.1kWp	Mono PERC	HSAT	
Pahrump, USA	Gravel	10%	2.8kWp	Mono PERC	Fixed	

Figure 7 (a) China Kubuqi 336kWp project using bifacial module and oblique uniaxial tracker; b) TÜV SÜD's bifacial field test project in Hainan, China; c)&d) The Chinese Sihong "Top Runner" project using nearly 275MWp Hi-MO3 modules

By virtue of leading module efficiency (>18.7%), nearly 275MWp of the Hi-MO3 bifacial half-cell module was supplied to the Chinese 'Top Runner' project in Sihong (500MWp in total) In the second half of 2018. The module adopts the rear glass coated with white ceramic grid, and the front-side power is up to 315Wp (120 half-cut cells). The total signed order of Hi-MO3 was up to 500MWp the throughout the year.

In conclusion, LONGi's Hi-MO3 module has high power, high energy yield, high reliability. and mature solutions for the PV station design as well as energy yield simulation. PV power stations using Hi-MO3 will obtain ideal return on investment.

Reference:

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