TrinaTracker

Trina Smart Tracking Technology

A White Paper on SuperTrack

SuperTrack

Contents

SuperTrack

1 Abstract

1.1 Abbreviations

STA: Smart Tracking Algorithm	SBA: Smart Backtracking Algorithm
BIM: Bifacial Irradiance Model	IAM: Incidence Angle Modifier
MPPT: Maximum Power Point Tracking	TCU: Tracker Control Unit
NCU: Network Control Unit	SCADA: Supervisory Control and Data Acquisition
CGC: China General Certification	GCR: Ground Coverage Ratio

1.2 Introduction

According to forecast of the International Renewable Energy Agency, the power generated from renewable energy sources will account for 86% of the world's total by 2050, of which photovoltaic plants will account for 25% of the world's total. At the Climate Ambition Summit, Chinese leader made a solemn commitment that China will achieve targets of Carbon Peak And Neutrality, and made it clear that the installed wind and photovoltaic power generation capacity will reach above 1.2 billion kilowatts by 2030.

As China's new photovoltaic installed capacity increases day by day and subsidies for electricity per kWh have been removed, the "decline" of photovoltaic feed-in tariff has become an inevitable trend. In such case, the construction of domestic centralized photovoltaic power stations also face the problem of increasingly less flat land available, more complex terrain and higher land price. In order to further improve economic benefits, more and more domestic enterprises begin to choose tracking system.

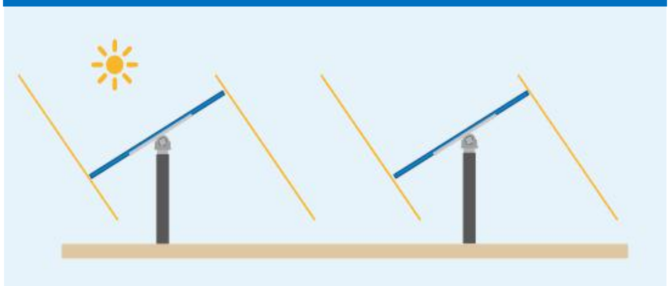
At present, trackers have demonstrated its advantages over fixed structures on levelized cost of energy (LCOE) for photovoltaic power stations. As module technology becomes increasingly mature, there is little room for cost reduction through technology improvement; Material cost has no trend to go downward, and there is even a rebound trend occasionally. All those factors determines the importance of technologies to generate more energy gain, which will contribute to higher IRR and lower LCOE. Compared to fixed structure, tracker can effectively improve power generation so as to maintain a lower LCOE. According to Bloomberg's survey, the LCOE of trackers worldwide has been lower than that of fixed structures since the second half of 2020.

Although the performance of tracking system that uses conventional tracking algorithm has been improved, in order to increase the adaptability of tracking system to uneven terrain, improve the power generation under different weather conditions, and expand the application scenarios of tracking system, smart tracking algorithm emerges.

2 Background

2.1 Introduction of conventional tracking algorithm

Figure 1: Schematic Diagram of Tracking Angle of Astronomical Algorithm

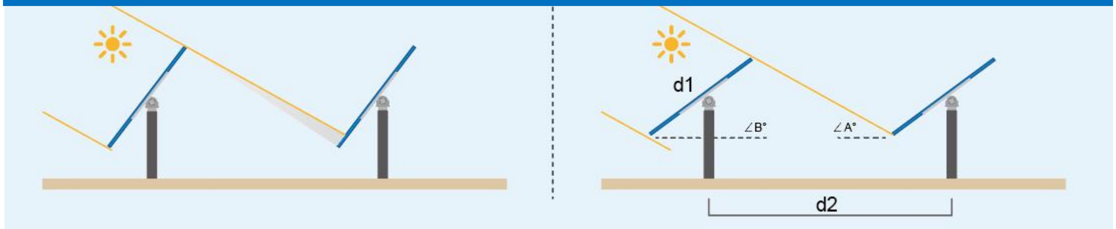


The conventional tracking algorithm consists of the astronomical algorithm and the backtracking algorithm. The scheme is characterized by simple control logic and strong engineering practicability, so that it is widely used in the horizontal single axis tracking system .

Of which, the astronomical algorithm refers to the algorithm that obtains local longitude and latitude, time and other information based on the solar-terrestrial relationship to calculate the relative position of the sun (i.e. the incidence angle of solar rays), and that gets the theoretical horizontal single axis tracking angle according to the principle that the smaller the angle between the normal vector of module and incident solar rays, the higher the irradiance received by the module.(Figure 1)

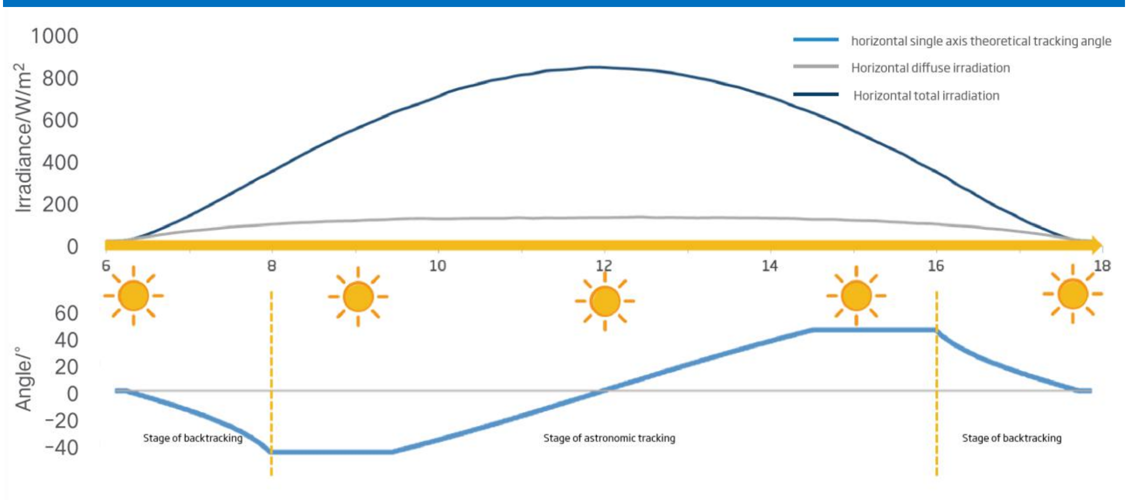
The solar altitude is lower in the early morning and late afternoon, so that the tracking angle calculated according to astronomical algorithm is larger, in which case shadows are found between arrays, leading to power generation loss. Therefore, the backtracking algorithm shall be adopted in the early morning and late afternoon,that is, the tracking angle gradually increases/decreases as the sun rises/sets, which is in the opposite direction of solar motion, so it is known as backtracking. The angle of backtracking can be obtained according to the incident solar rays, array pitch and array width, and it shall be guaranteed that the front array will not shade the rear array, as shown in the figure. (Figure 2)

Figure 2: Schematic Diagram of Backtracking Algorithm



Meanwhile, trackers are provided with a limit angle protection, such as 45°. Therefore, the theoretical running curve of the conventional tracking algorithm is shown in the figure below. (Figure 3)

Figure 3: Theoretical Running Curve of Conventional Tracking Algorithm

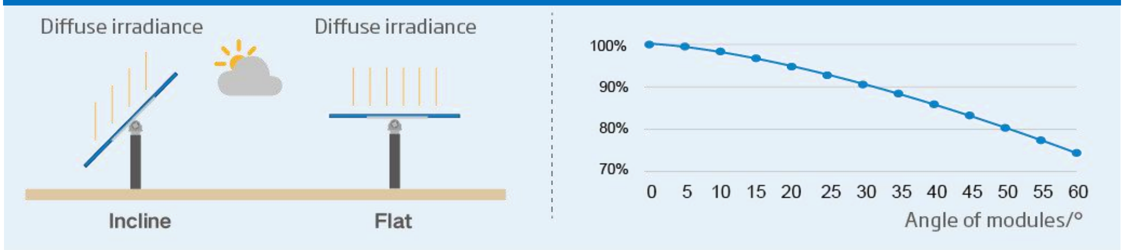


2.2 Deficiencies of conventional tracking algorithm

The conventional tracking algorithm only considers high direct irradiance, flat terrain and maximum irradiance captured by monofacial module. In actual projects, bifacial module is mostly used. Also, due to rugged terrain and construction error, shadows are found at the stage of Backtracking in the early morning and late afternoon, leading to power generation loss; at the same time, conventional tracking algorithm is also adopted for highly diffused irradiance weather (overcast day), and diffuse irradiance is not fully utilized. Therefore, the conventional tracking algorithm fails to give full play to the advantage of tracker in power generation.

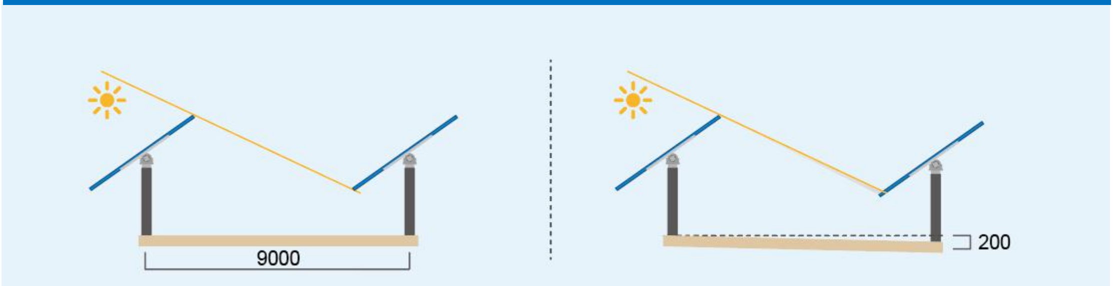
When it comes to the state of real weather, high direct irradiance weather (sunny day), cloudy and highly diffused irradiance weather (overcast and rainy days) may co-exist, and there are more overcast and rainy days in some areas, accounting for more than 50% of the whole year. According to sky diffuse irradiance model, in the highly diffused irradiance weather, as the module angle increases, the diffuse irradiance captured by the front side of the module gradually decreases, the diffuse irradiance captured by the module at a small angle is greater than the tracking angle of astronomical algorithm (as shown in the figure), and the larger the module angle is, the bigger the difference is. For example, when the tracking angle at the stage of astronomical tracking is 45°, the irradiance loss may reach up to 15% compared with being kept flat. (Figure 4)

Figure 4: Diffuse Irradiance Diagram in Overcast Weather



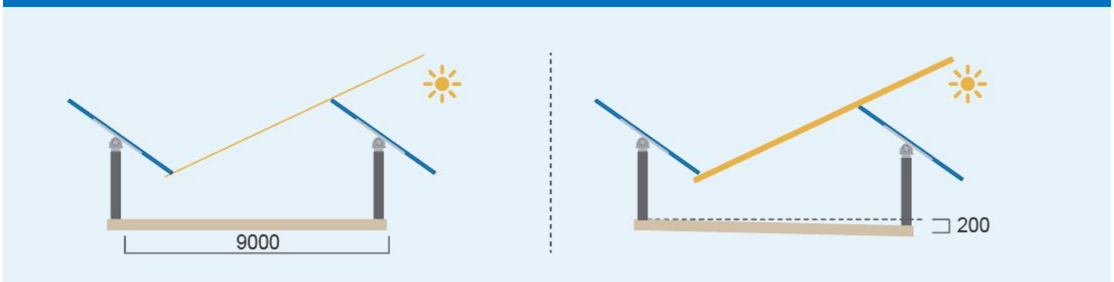
At the same time, in actual projects, the project site is not completely flat terrain. Also, as uneven terrain projects increase year by year,there is a relative altitude difference between arrays due to rugged terrain and installation error. If the backtracking angle of flat terrain is adopted, shading occurs between arrays, leading to power generation loss. For example, if the array pitch is 9m, there is a 20 cm altitude difference between arrays, shadings of arrays will occur at the stage of Backtracking,in which case the instantaneous generated power loss may reach 40% in the high direct irradiance weather.(Figure 5)

Figure 5: Schematic Diagram of Shadows Caused by Altitude Difference between Arrays



At the same time, due to different terrains between arrays, if shade is caused in the morning, light leakage may be found at the stage of backtracking in the afternoon, thereby leading to inadequate utilization of resources. (Figure 6)

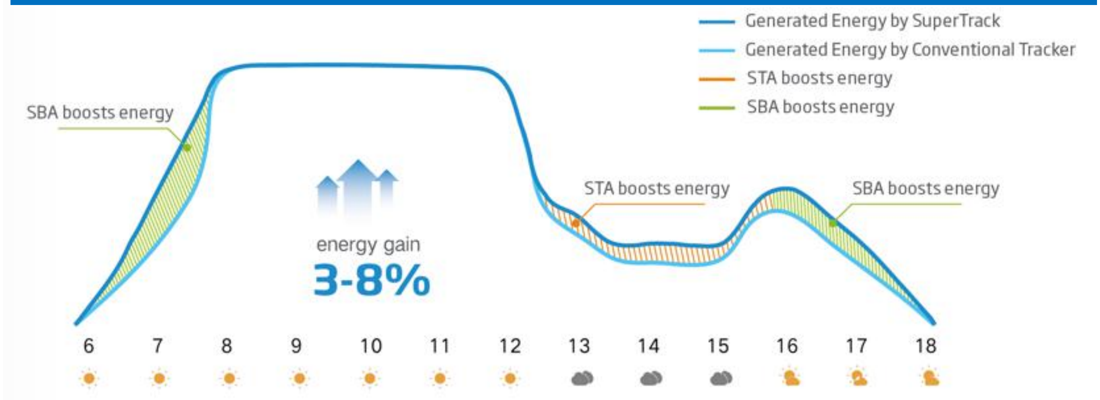
Figure 6: Schematic Diagram of Light Leakage Caused by Altitude Difference between Arrays

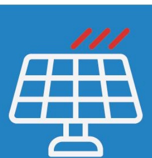


3 Definition and Main Value Points of SuperTrack

The conventional tracking algorithm did not fully stimulate the potential of horizontal single axis tracker power generation, so TrinaTracker originally developed the smart tracking technology-SuperTrack, including smart algorithm, multi-source data and software platform. Based on the optimal power generation performance of the module, it can calculate the optimal power generation angle of the bifacial module in real time for different weather states, and identify the characteristics of the rugged terrain in an intelligent way, independently optimize the angle of Backtracking in each row, avoid or reduce being shaded by front and rear shadows, and fully dig the power generation potential of tracker. Compared with conventional tracking algorithm, the power generation gain is as high as 3-8%. (Figure 7)

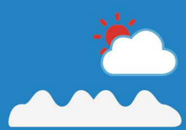
Figure 7: Schematic Diagram of Gain Effect of SuperTrack Algorithm





High energy yield

- Compared with conventional tracking algorithms, SuperTrack can increase energy generation by up to 3-8%;



High adaptability

- Meeting the diversified needs of customers;
- Adapting to complex terrains and various weather conditions;

High intelligence

- Self-perception, self-learning, self-decision making;
- Proprietary technology for the power generation model;

High stability

- Long-term test data analysis;
- Reducing the rotation of the tracker

4 Introduction of SuperTrack Algorithm

SuperTrack comprises two key algorithms:

1 | Smart Tracking Algorithm (STA) is used to optimize high diffuse irradiance weather;

2 | Smart Backtracking Algorithm (SBA) is used to solve the shading problem brought by complex terrain.

Figure 8: Block Diagram of SuperTrack Smart Control Logic

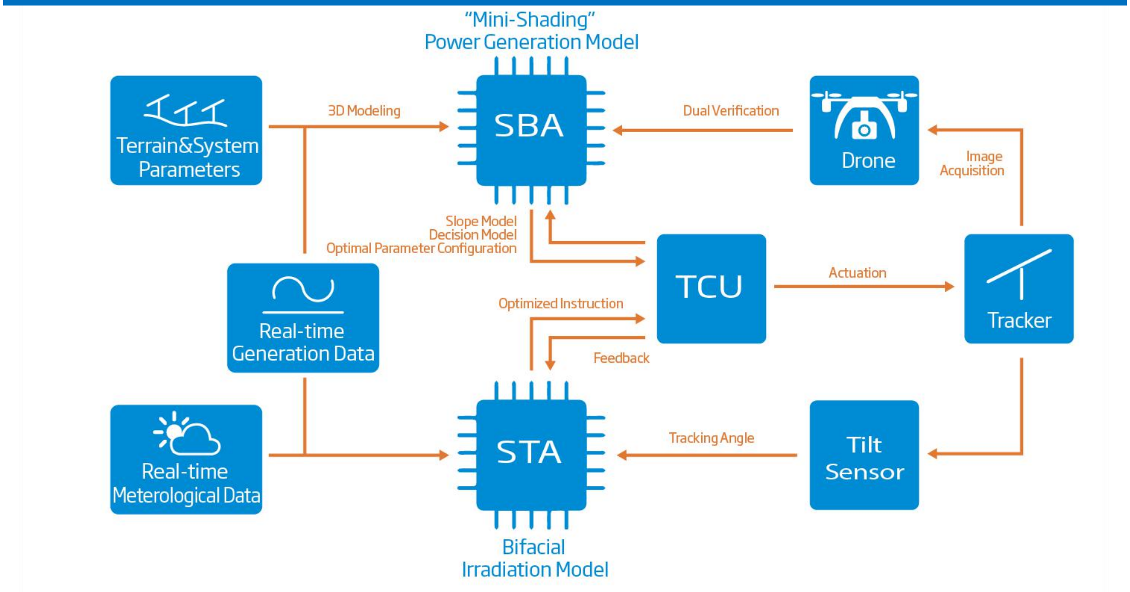
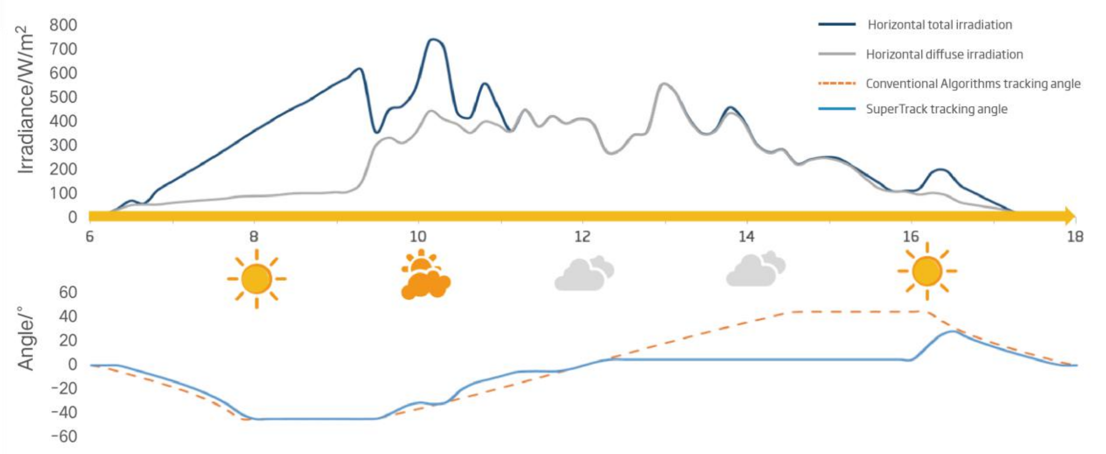


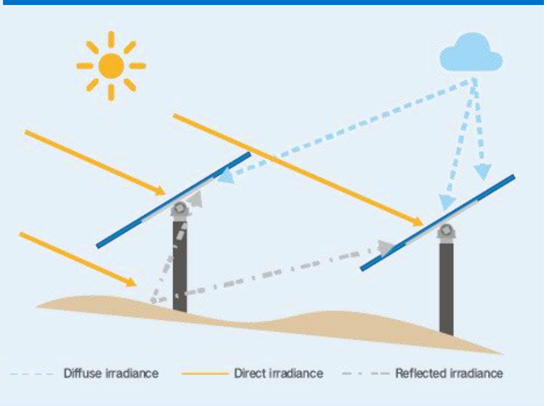
Figure 9: Contrast Diagram of Tracking Angles between SuperTrack and Conventional Algorithms



4.1 Tracking angle optimization STA for high diffuse irradiance weather

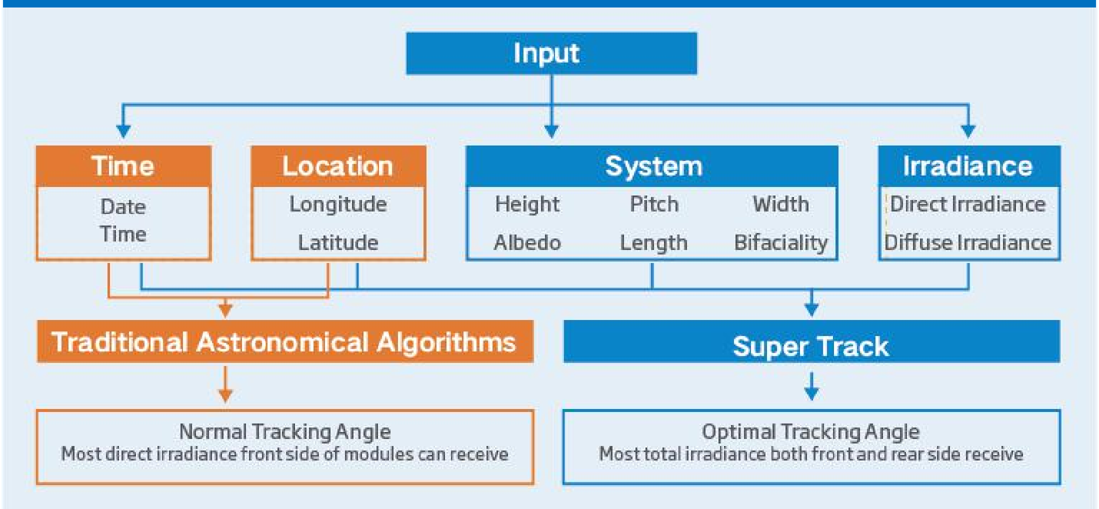
4.1.1 BIM

Figure 10: Schematic Diagram of Irradiance Captured by Bifacial Module



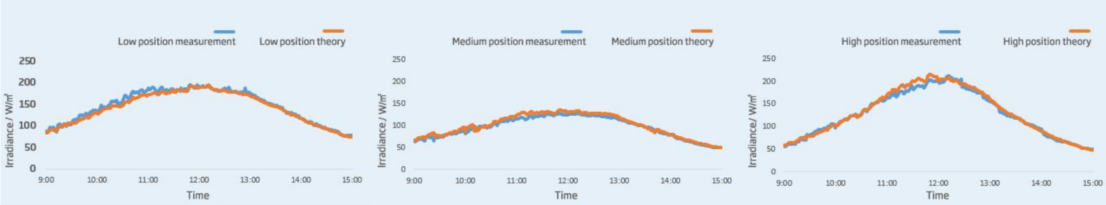
As the proportion of bifacial module applications increases year by year, it has been a trend that monofacial module in horizontal single axis tracker system will be replaced by bifacial module. The conventional astronomical tracking algorithm only considers maximum front irradiance, while bifacial module needs to take into account maximum front and rear irradiance. Therefore, there is a certain difference in the tracking angles of bifacial and monofacial modules under different conditions. The BIM originally developed by Trina takes into full account 12 key factors, calculates front direct irradiance, diffuse irradiance, reflected irradiance and rear reflected irradiance and diffuse irradiance, and finally gets the total irradiance of bifacial module.

Figure 11: Main Factors Affecting Power Generation of Bifacial Module



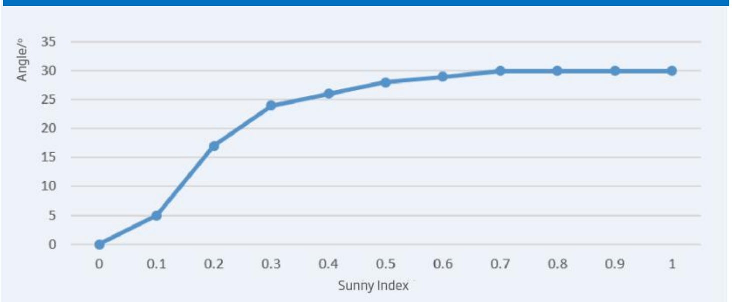
As shown in the figure, the accuracy verification experiment for the irradiance model was carried out at the Changzhou Test Center at different time points, different surface albedo, weather states and positions. The long-term experiment results show that measured values are basically consistent with the predicted values of the model, and the overall error is within 5%, so that the model is accurate and reliable. (Figure 12)

Figure 12: Curve Charts of Differences between Theoretical Rear Irradiance Value and Measured Value



4.1.2 Tracking angle optimization for high diffuse weather

Figure 13: Optimized Tracking Angles under Different Sunny Indexes

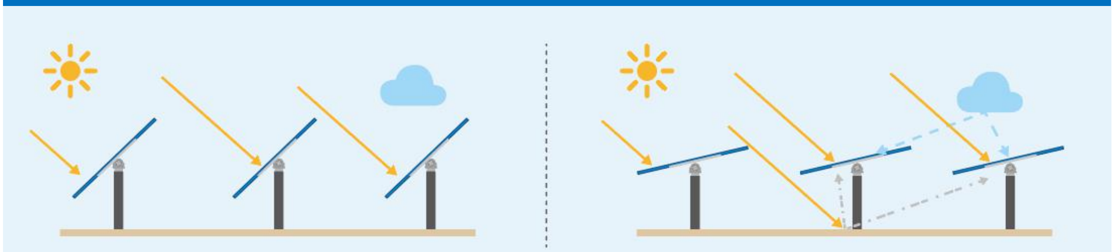


Based on the BIM, the tracking angles are different under different weather states. Specifically, sunny index (0-1) is defined different weather states, the higher the sunny index is, the sunnier the day is, the higher the proportion of direct irradiance is, and the lower the proportion of diffuse irradiance is. On the contrary, the lower the sunny index is, the higher the proportion of diffuse irradiance, and the lower the proportion of direct irradiance. For example, when calculating the optimal tracking angle of bifacial module under different sunny indexes at a certain time point during the autumn in Changzhou, as shown in the figure 13, the astronomical tracking angle is 30°. If the sunny index is higher, the astronomical angle shall be used. If the sunny index is lower, such as 0.2, the maximum tracking angle of total irradiance is 17°. If the sunny index is extremely low, i.e. rainy days, the theoretical tracking angle is 0°, and the total irradiance reaches the maximum.

SuperTrack smart tracking algorithm relies on the proprietary technology of BIM to deeply learn the power generation characteristics under the multi-parameter impact of bifacial module, dynamically seeks the optimal tracking angle in real time and improves power generation in highly diffused irradiance weather according to meteorological and system operation data.

TrinaSolar has been deeply engaged in the field of photovoltaic power generation for many years. As shown in the figure 14, through the research on long-term power generation performance of photovoltaic modules, Trina has accumulated rich experience, established power generation model for multi-dimensional analysis, and further optimized the tracking angle, such as placing at a small angle on overcast days, so as to ensure the optimal long-term power generation of the modules.

Figure 14: Difference in Tracking Angles on Overcast Days between Conventional Tracking Algorithm Array and SuperTrack Algorithm Array



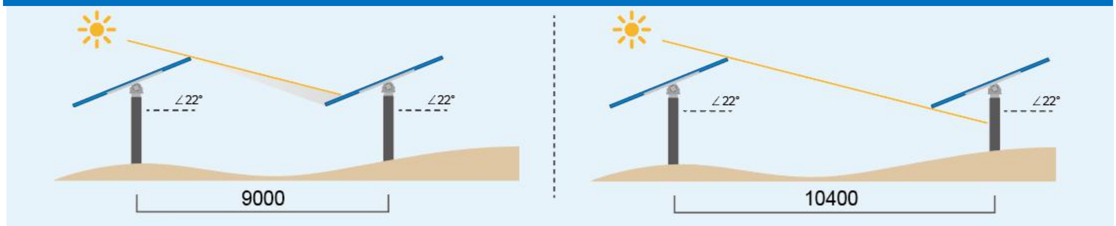
At the same time, in highly diffused weather, STA can obviously reduce the rotation count and angle of the structures, and extend the useful life of motors and structures. The high diffuse areas, such as Changzhou, have typical overcast days. As shown in the table 1, compared with conventional tracking algorithm, SuperTrack can reduce the rotation angle and count by 80%, in which case the annual average rotation angle can be reduced by about 17%, and the rotation count can be reduced by about 28%.

Table 1 : Comparison between Conventional Algorithm and SuperTrack in Rotation Angle and Count on Typical Overcast Days

Conventional Ttacking Algorithm		SuperTrack		
Rotation Angle	200°	Rotation Angle	40°	-80%
Rotation Count	200	Rotation Count	40	-80%

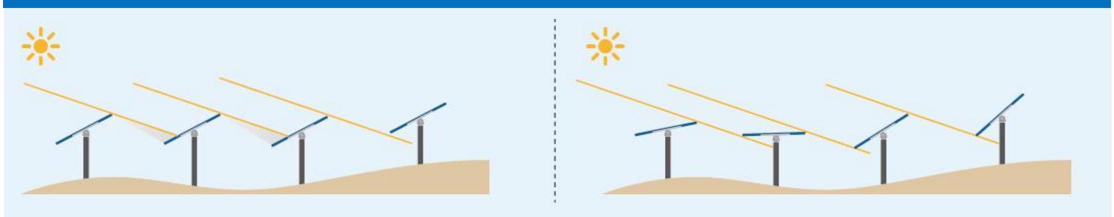
4.2 SBA, backtracking angle optimization for complex terrain

Figure 15: Avoid row-to-row shading by Enlarging Array Pitch



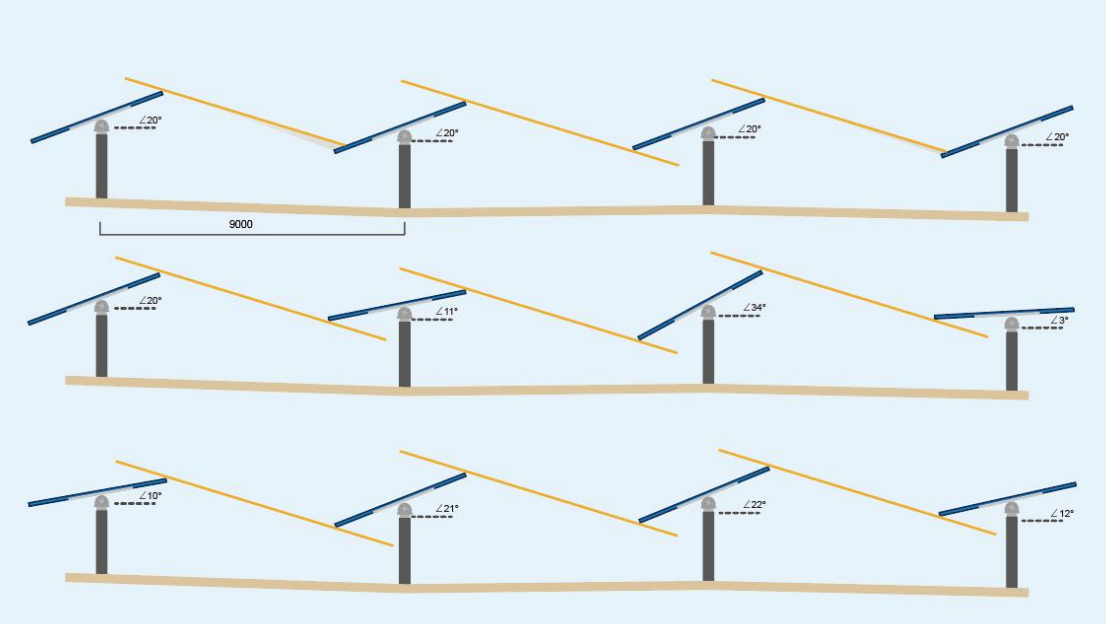
As shown in Figure 15, it is possible to compensate for the deficiency of conventional backtracking algorithms by increasing the array spacing theoretically, but in actual projects, the array spacing remains basically the same, while the height difference between arrays varies, and after appropriately increasing the spacing, some of the arrays will still be shaded, while some arrays have light leakage. Moreover, from the perspective of land cost, the solution of adjusting the backtracking angle of each row is of higher applicability.

Figure 16: Diagram of SBA of SuperTrack



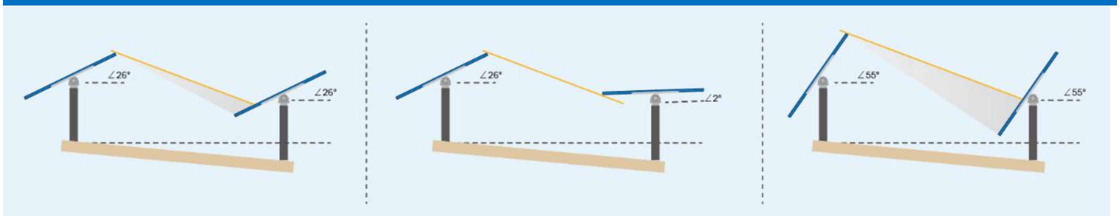
As shown in the Figure 16， SuperTrack smart backtracking algorithm adopts system operation data to perform disturbance training and (or) adopts UAV sensing technology to identify shading and construct three-dimensional terrain. Based on machine learning algorithm and Mini-Shading Model, it outputs the optimal backtracking angle group for overall power generation through iterative decision-making and effectively enhances the power generation at the stage of backtracking, and consequently achieves the identification and optimization of complex terrain and gives full play to the power generation advantage of tracker.

Figure 17: Example of SuperTrack Backtracking Optimization Angle



Based on TrinaSolar's long-term study on the power generation characteristics of PV modules with/without shading, secondary optimization is performed on the theoretical backtracking angle, such as analyzing the impact of mismatch between arrays to get the backtracking optimization angle group. As shown in the figure 17, there is an altitude difference between arrays. If they still rotate at the flat backtracking angle of 20°, power generation loss due to shadings will occur in the second and fourth rows. SuperTrack can effectively identify terrain information through UAV sensing technology and (or) power generation data, reduce the shaded array angle according to real terrain, and enlarge the light leakage array angle to get the angle groups of 20°, 11°, 34° and 3°. At the same time, it can perform secondary angle optimization by analyzing the mismatch loss with decision-making model through iterative simulation, so as to finally get the optimization angle groups of 10°, 21°, 22° and 12°. In addition, it can reduce IAM loss of modules and MPPT mismatch loss of inverters, so as to ensure maximum global output power.

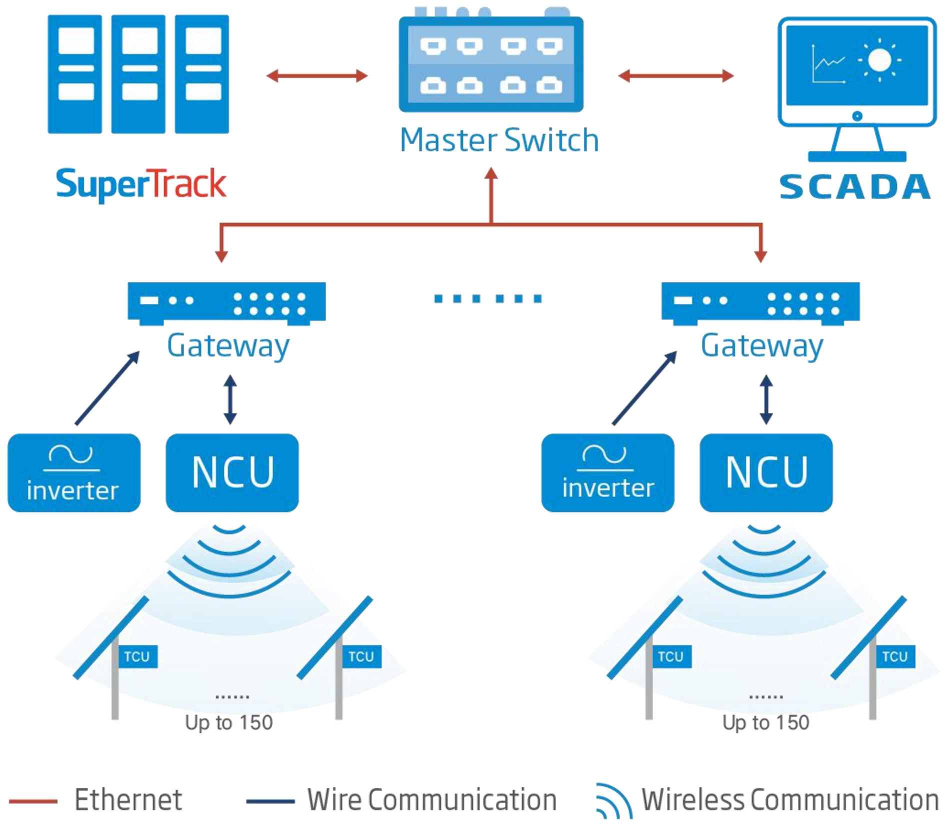
Figure 18: Comparison between the Scheme that Reduces the Angle Until Not Shaded and the Scheme that Increases the Angle Until Half Shaded



As shown in the figure 18, in view of the problem that tracking array is shaded, general optimization algorithm will reduce the tracking angle until the module is not shaded. However, in case of greater terrain difference, the method needs to reduce excessive angle or it is still shaded even it is kept flat, which means that the irradiance captured by the module reduces and IAM loss is great. Therefore, it might be a better optimization method to reduce the angle until partially shaded or increase a certain angle compared with reducing angle. As a result, it is the most reasonable to ensure the optimal overall power generation by comparing the output results of different optimization methods.

5 SuperTrack System Architecture

Figure 19: SuperTrack System Architecture



Trina smart tracking system consists tracker structures, tracker control unit (TCU), network control unit (NCU), SuperTrack platform and SCADA. Also, it can flexibly match with inverter and other equipment, thereby building integrated solutions to photovoltaic tracking system. (Figure 19)(Table 2)

Table 2: 100MW PV Station Configuration Table

	Tracking	TCU	NCU	Software Platform	Sensor
SuperTrack	1500 sets	1500	10~20	1set	1set
Conventional Tracking System	1500 sets	1500	10~20	/	/

(Note: Sensing equipment shall be flexibly increased according to project zoning.)

6 Test Data and Gain Simulation

6.1 Test data

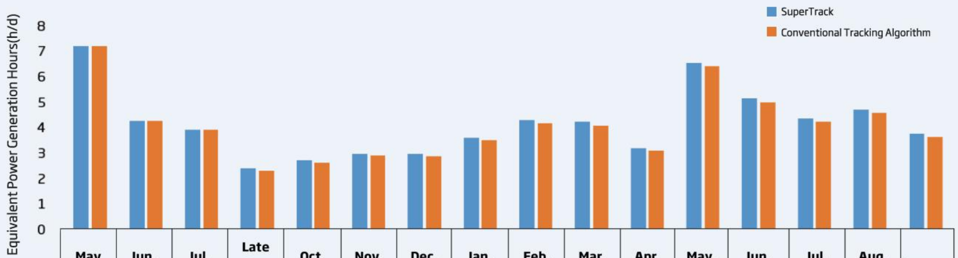
6.1.1 30MW mountain project in Tongchuan

The power station is located in Yijun County, Tongchuan City, Shaanxi Province, China. It adopts bifacial module + horizontal single axis tracker system and selects megawatt-level photovoltaic arrays with similar terrain for verification. Specific project information is shown in the table 3:

Table 3: List of Conditions for 30MW Mountain Project in Tongchuan

Project site	Tongchuan, Shaanxi	Test time	May 2020 - September 2021
Longitude and latitude	35.14°N，109.17°E	Terrain	Average slope is about 3%
Operating temperature	-21.0℃ ~ 39.7℃	Module	TSM-NEG6MC.20(II) 335W bifacial module
Irradiance	1300kWh/m²~1400kWh/m²	trackers	Vanguard 2P
Proportion of diffuse	53%	GCR	0.41
Surface condition	Grassland	Height	3.5m

Figure 20: Comparison of Equivalent Power Generation Hours and Power Generation Gain in Different Months



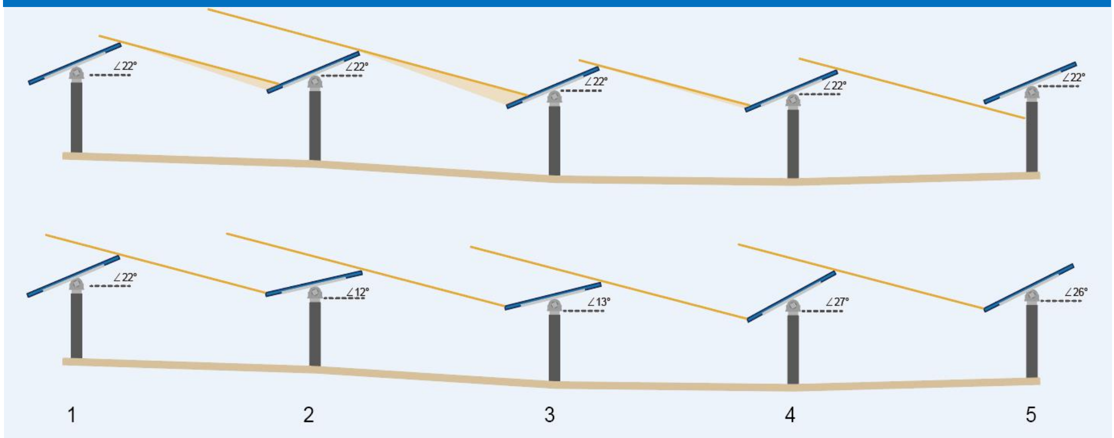
	May 2020	Jun. 2020	Jul. 2020	Late Sep. 2020	Oct. 2020	Nov. 2020	Dec. 2020	Jan. 2021	Feb. 2021	Mar. 2021	Apr. 2021	May. 2021	Jun. 2021	Jul. 2021	Aug. 2021	Average
SuperTrack	7.23	4.28	3.39	2.42	2.74	3.01	2.99	3.62	4.33	4.24	3.23	6.57	5.17	4.37	4.73	3.77
Conventional Tracking Algorithm	7.23	4.28	3.39	2.33	2.66	2.92	2.90	3.52	4.20	4.10	3.12	6.43	5.00	4,24	4.60	3.66
Power Generation Gain	0.07%	0.08%	-0.04%	3.86%	3.09%	2.92%	3.10%	2.96%	3.01%	3.61%	3.43%	2.17%	3.25%	2.98%	2.82%	3.06%

As shown in the figure 20, The power station was connected into grid in May 2020, and it adopted astronomical algorithm for all arrays from May to July. As an evaluation basis for difference between arrays, the comparison test was officially started in September 2020. The conventional tracking algorithm is still adopted for some arrays. By comparing the integrated SuperTrack algorithms for arrays, the average of shaded arrays proportion is about 30%. The test lasted for a year, and the results show that power generation in SuperTrack array was improved by 3.06%, and the test data was verified by CGC.

Figure 21: Live photo of Conventional Tracking Array and SuperTrack Array Shading at the Stage of Backtracking

As shown in the figure 21, i.e. live photos of the test project in Tongchuan on sunny days at the stage of backtracking, shadow shade and light leakage can be found due to terrain difference in conventional tracking array. Therefore, SuperTrack array will optimize different backtracking angles for each row of arrays according to terrain conditions, reduce light leakage as much as possible while avoiding shading, and enhance power generation at the stage of backtracking.

Figure 22: Comparison of Angles between Conventional Tracking Array and SuperTrack Array



Specifically, as shown in the figure 22, there are 5 rows of trackers in the array, with a relative slope of 3.2%, 6%, 1.1% and -2.6%, respectively (positive values indicate that the front tracker is higher than the rear one). At 6:37 a.m., the solar incident angle is 14°, and the backtracking angle is 22° for flat terrain. Due to the existence of relative slope, the tracking angle is 22° according to the conventional tracking algorithm, in which case shadow shading will be seen in photovoltaic modules on trackers 2/3/4. At the same time, the phenomenon of light leakage will be seen between Array 4 and Array 5, resulting in irradiance loss; the optimized tracking angles according to SuperTrack algorithm are 22°, 12°, 13°, 27° and 26°, respectively, and power generation loss can be effectively reduced by avoiding shading and light leakage.

Figure 23: Comparison of Array Angles between SuperTrack Algorithm and Conventional Tracking Algorithm

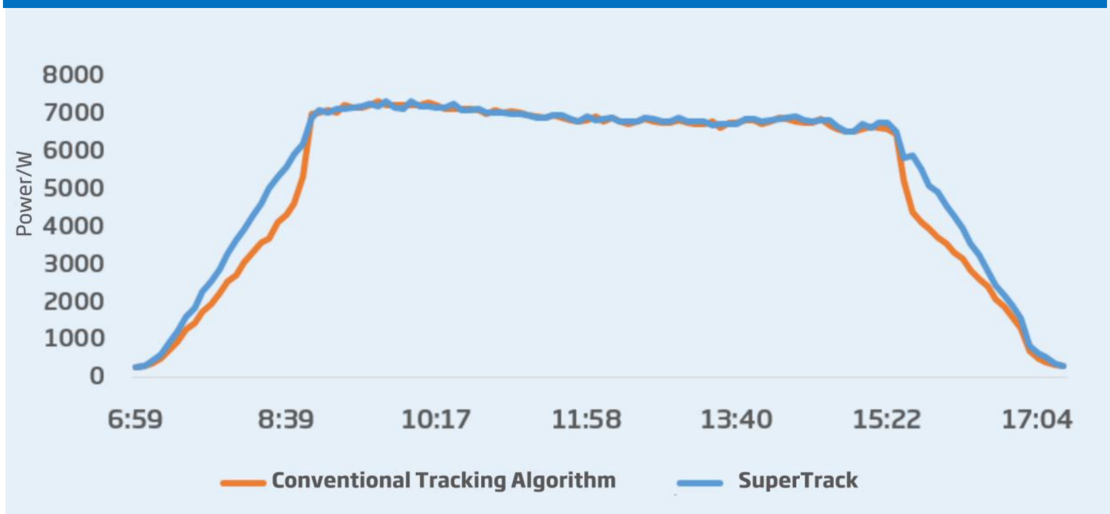
As shown in the figure 23, on overcast or rainy days, SuperTrack will place the tracker at a small angle or keep the tracker flat according to weather conditions. The greater the difference between the array angle of conventional tracking algorithm and the optimized array angle, the higher the gain of SuperTrack power generation. On typical overcast and rainy days, the daily power generation gain may reach 12.86%.

6.1.2 Test field in Changzhou

Trina Solar has also demonstrated that arrays with the SuperTrack intelligent tracking algorithm have significantly increased their power output in Changzhou test center.

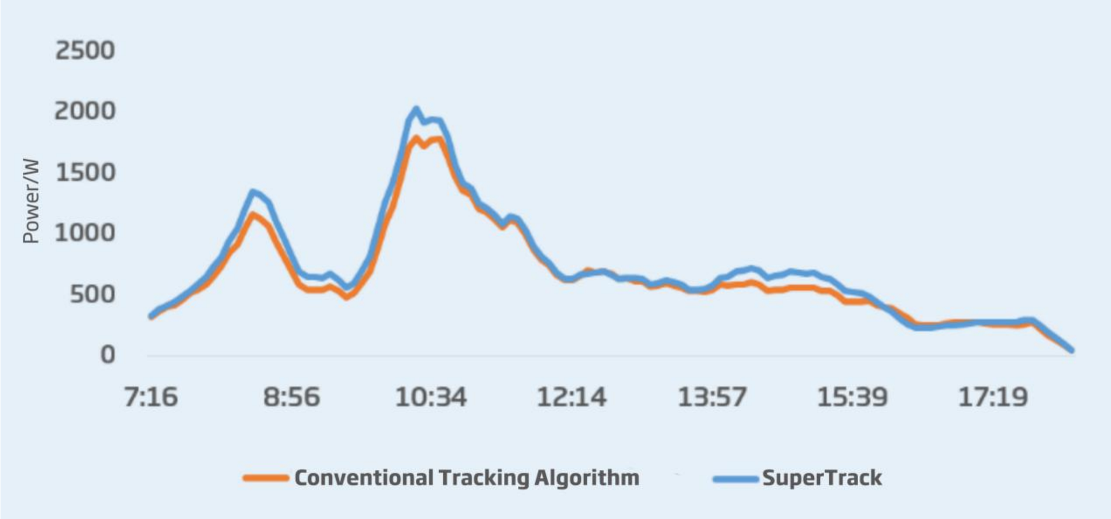
As shown in Figure 24 and Figure 25, on a typical sunny day, the array output power is similar during the tracking stage, while during at the stage of backtracking, the output power of the conventional algorithm array is lower due to shading, while the SuperTrack array avoids shading, resulting in an instantaneous power increase of

Figure 24: Diagram of Power Gain on Typical Sunny Days



(Note: The gain comparison is for single-row tracker which are shaded in both the morning and afternoon)

Figure 25: Diagram of Power Gain on Typical Overcast Days



up to 35% and a power generation gainofup to 4.64%. In typical overcast conditions, the conventional tracking algorithm rotates at an angle to the sun, resulting in a lower output, while the SuperTrack array rotates to a smaller angle, resulting in an overall power gain of 9.41%.

6.1.2 Test field in Nangong

SuperTrack has been applied to 400MW project located in Nangong,China. The tracking system was connected to grid in June 2021. By the end of September, Tracking system had operated for 77 days, including 25 days of highly diffused irradiance weather, and the average power generation gain in highly diffused irradiance weather was 3.84%, including a typical cloudy day with a power generation gain of 8.03%.

6.2 Gain potential estimation and third-party verification

The main factors affecting power generation gain include altitude, terrain difference (shading array proportion and slope), diffuse irradiance proportion and system design (such as array pitch), etc. The simulation results of tracking gain potential in different areas are shown in the table.

Table 4: Table of Simulated Data for SuperTrack Power Generation Gain Potential

Location	Latitude	GCR	Proportion of diffuse irradiance	Shading loss		STA gain	SBA gain	Total gain
				Pvsyst	TrinaTracker model			
Singapore	1.37°N	0.70	56.00%		7.35%	2.23%	5.88%	8.11%
Bangalore	12.99°N	0.64	41.70%	5.83%	6.73%	1.08%	5.38%	6.46%
Bangkok	13.70°N	0.64	55.30%		5.58%	1.70%	4.46%	6.16%
Mexico City	19.43°N	0.60	42.50%		5.84%	0.88%	4.67%	5.55%
Jeddah	22.30°N	0.58	39.40%	4.12%	5.59%	0.59%	4.47%	5.06%
Guangzhou	23.14°N	0.57	66.80%		3.78%	2.26%	3.02%	5.28%
Columbia	34.01°N	0.46	45.60%		4.30%	0.77%	3.44%	4.21%
Tongchuan	35.14°N	0.45	56.80%	2.36%	2.98%	1.16%	2.38%	3.54%
Hokkaido	43.23°N	0.33	54.10%		2.79%	0.91%	2.23%	3.14%

Note:Shading loss and SBA gain are calcuated at the slope of 6% and the proportion of shaded arrays of 50%

Based on self-developed simulation software, TrinaTracker selected typical locations in different latitudes and different climate conditions to simulate the shading loss and evaluate the gain potential. TUV-SUD used the industry-wide authoritative software PVsyst to carry out simulation checking on the shading loss of typical locations, which is basically consistent with the calculation result of Trina's self-developed software.

SGS verified the evaluation process and result of SuperTrack gain. STA gain is mainly associated with the annual diffuse proportion of the project site, i.e. the higher the diffuse proportion, the greater the STA gain. For example, in Guangzhou, STA gain is above 2%; SBA gain is associated with GCR, terrain slope and shading array proportion, i.e. the greater the GCR, the larger the slope, the higher the shading array proportion, and the higher the SBA gain. For example, Singapore, as a low-altitude area, is designed as per standard, where GCR accounts for a larger proportion, and the stage of backtracking lasts for a longer time, so SBA gain has a greater potential. SGS confirmed that the gain result is reasonable and reliable.

At the same time, CGC conducted an authoritative verification on the accuracy and effectiveness of the data. In its report, the CGC drew the following conclusions: The test in Tongchuan lasted for a year, and the results show that power generation in SuperTrack array was improved by 3.06%. CGC indicates that the test data is valid.

7 Conclusions

The market share of the tracking system gradually increases due to its feature of high power generation. TrinaTracker has always been committed to technology innovation, improving power generation of the tracking system, reducing LOCE and improving IRR. SuperTrack relies on BIM, Mini-Shading Model to deeply study the power generation characteristics of the modules, dynamically seek optimal tracking angle in real time, enhance power generation under the conditions of high diffuse irradiance weather and complex terrain, and give full play to the power generation advantage of tracker. Compared with conventional tracking algorithm, the power generation gain improves by 3-8%.

SuperTrack is featured with high intelligent performance and high adaptability, as well as self-perception, self-learning and self-decision-making, without human intervention in the optimization process. Also, it fully matches Trina trackers, meets the diverse needs of customers, and can be flexibly applied to different projects.

Through the outdoor test on many project sites for more than a year, it is found that SuperTrack technology is stable and reliable and can ensure continuous power generation gain of the tracking system. In addition, third party has conducted an authoritative verification on the empirical data, which is authentic and effective.

In the overall context that new energy market develops rapidly, photovoltaic industry is moving towards grid parity, and its eternal pursuit is to improve power generation. In the future, SuperTrack technology will be widely used in Trina tracking system, tap the power generation potential of the tracking system to the most extent, maximize system efficiency, reduce LCOE, bring higher gains to customers, and contribute to achieving Carbon Peak And Carbon Neutrality targets.