Fusionsolar

Dive Deeper for a Safer Future

Smart Module Controller Safety White Paper

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HUAWEI

CONTENTS

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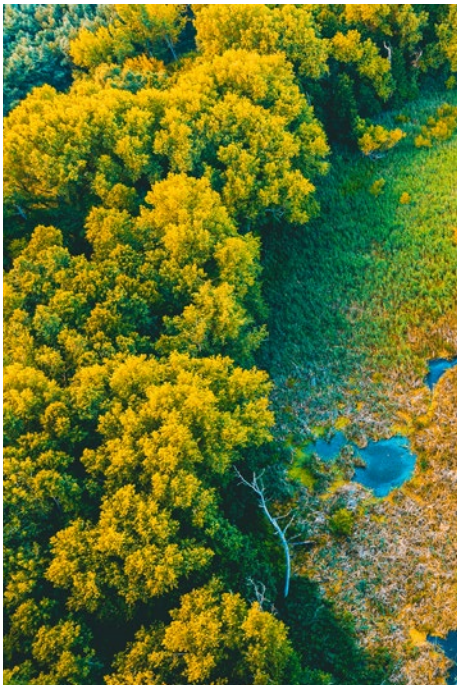
Background

1.1 Development of MLPE



Countries around the world are facing global warming and energy crisis. As countries announce carbon peak and carbon neutrality goals one after another, the global photovoltaic (hereinafter referred to as PV) industry has ushered in a new round of vigorous development.

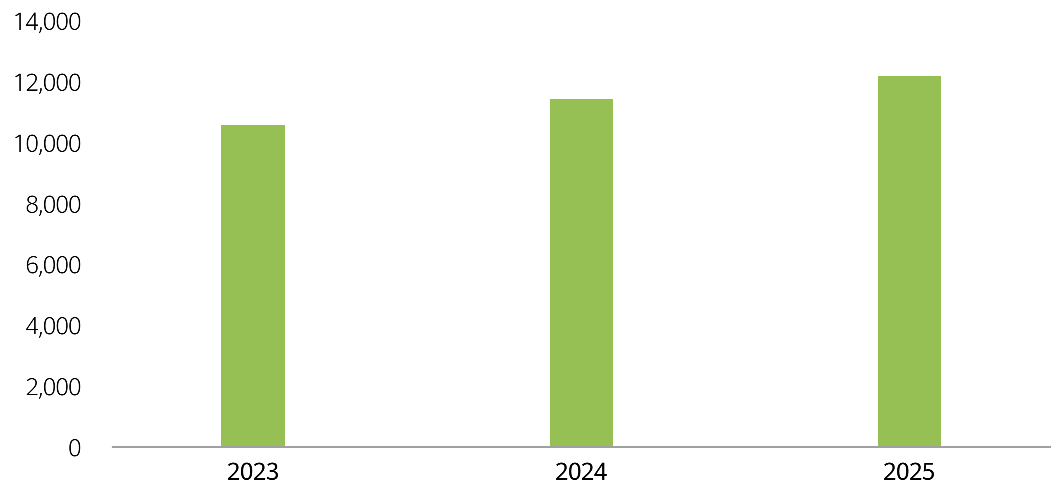
With the growing installed PV capacity in recent years, consumers are requiring improved monitoring and management of PV systems. To address the need for more sophisticated management and various application challenges, multiple PV industry leaders have introduced different solutions. Technologies and products based on Module-Level Power Electronics (MLPE) are gradually entering the market. As early as 2014, more than 55% of residential PV systems in the United States had used various MLPE products [3]. Smart module controller (hereinafter referred to as optimizer) is a systematic solution that adopts the MLPE technology. Its main function is to convert power through DC-DC circuits and eventually achieve higher yield and intelligent management at module level. As more customers are paying more attention to features such as safety and high energy yield, the market potential, acceptance, and share of optimizers have been increasing rapidly.

[1] 'Photovoltaic Systems with Module-Level Power Electronics', [Online]. Available: https://www.nrel.gov/docs/fy15osti/64876.pdf

Forecasts

According to IHS statistics, the global annual shipment of optimizers in 2021 is 8.2 GW, accounting for 7.47% of the installed distributed PV capacity that year. By 2027, the global annual shipment of optimizers is expected to increase to 77 GW, and the penetration rate of optimizers is expected to reach 20% to 30%.

Global optimizer shipment forecast (MW)



Looking back, the evolution from central PV inverters to string PV inverters has increased the energy yield by more than 3% and has optimized power generation and monitoring at the string level. The evolution from string inverters to MLPE technologies, further refines the PV system management granularity, making power generation safer and smarter.

1.2 Typical Challenges in Distributed PV Scenarios

The distributed PV market is embracing a period of both opportunities for vigorous development and numerous challenges.

Shading reduces PV capacity and complicates system design

The benefit or yield of a distributed PV system depends on the conditions of the rooftop, such as irradiance, climate conditions, and other factors such as shading, which must be considered during the design of a distributed PV system. Although the levelized cost of energy (LCOE) keeps falling and distributed PV is gaining popularity, it is increasingly difficult to find a rooftop without shading for PV installation. For a sloped roof or a roof subject to shading, it is challenging to design a PV system with an optimal yield at a minimized cost.

High DC voltage brings safety risks

The PV module generates direct current (DC) under the light, and high voltage (usually 600–1000 V) still exists on the PV string even if the circuit is disconnected, which poses a serious threat to personnel safety.

High DC voltage remains one of the biggest safety risks of PV application from the early stage of construction to the subsequent operation and maintenance (O&M) stage, and even in the post-accident rescue. Once a fire occurs, firefighters are unable to rescue in time since they cannot use conventional fire extinguishing methods, which puts properties in danger.

Although PV systems have been in use for many years, the current standard operating procedures are still inadequate to address the increasing safety risks. Fire and Emergency Services staff may face solar module-induced incidents on a daily basis. Without adequate tools, procedures, and training, hazardous situations may become more common and will jeopardize life and property.

PV power plant O&M is just like a black box

Compared with utility-scale power plants, distributed ones are small in size, scattered in distribution, large in quantity, and short in man-power. This causes many difficulties to the O&M management. Distributed PV power plants are mostly installed on the roofs, agricultural sheds, fish ponds, and other facilities. Professional, efficient, safe, and visualized O&M has become a major priority to ensure that distributed PV plants are operating at full potential.

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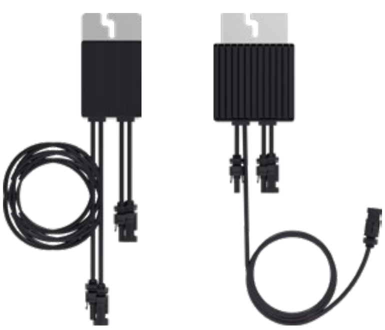
Smart Module Controller Solution Introduction

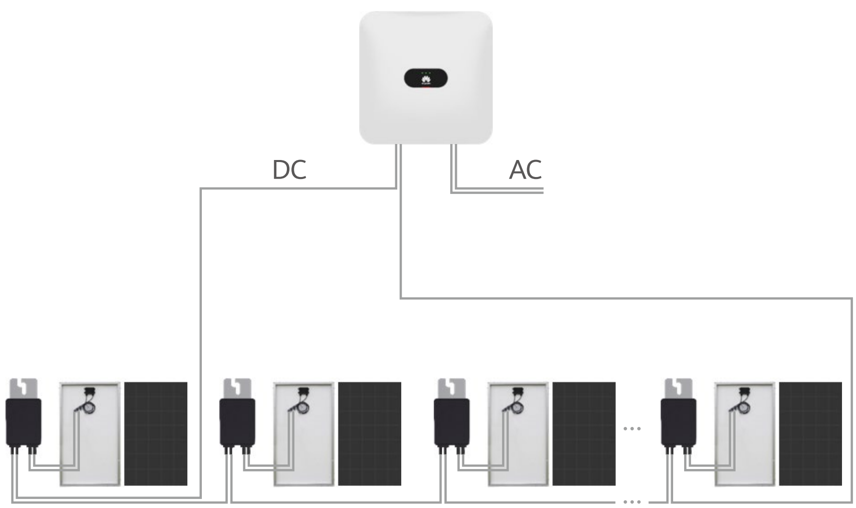
2.1 Principles of the Smart Module Controller

Based on the buck circuit, Smart Module Controller Solution adopts the "optimizer + two-stage inverter" architecture. With optimizers installed, PV modules are optimized independently to achieve maximum yield.

The DC-DC circuit in the optimizer changes the output I-V characteristic curve of the PV module. As a result, the maximum power point of the module is no longer a fixed point and becomes dynamic along the curve.



SUN2000-450W-P2/600W-P   MERC-1100/1300W-P



2.2 Key Values of Smart Module Controller

2.2.1 Flexible Design increasing capacity by more than 30%

According to traditional design guidelines for PV systems, the installation and arrangement of modules on a roof are subject to many limitations such as obstructions and shades. Modules in the same string must be of the same orientation and dip angle. Otherwise, the consequent mismatch will reduce the overall energy yield. For a small roof, the number of modules that can be installed in the unshaded area is not enough to meet the minimum voltage requirement for inverter input. As a result, such roofs are completely ruled out for PV installation.

In C&I scenarios, a lot of roof areas are ineligible for PV mounting due to the shading caused by parapets, billboards, base station antennas, etc. Such roof spaces are left unused, lowering the revenue of PV owners.

The preceding problems can be avoided with the Smart Module Controller Solution. The circuit in the optimizer can adjust the current and voltage of each module separately to prevent them from interfering with each other. Therefore, even modules with different power, orientations, and dip angles can be connected to the same string without causing series mismatch. This will improve the DC capacity of the system, the overall energy yield, and the value of roofs.

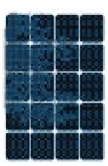
2.2.2 Higher Yields, increasing the energy yield by 5-30%

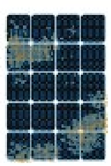
The output current and power of PV modules are closely related to the working environment (especially the sunlight) of the modules. The operating currents of the modules in the same string must be consistent. Therefore, if the current of one module is reduced, the working power point of other modules in the string will also deviate with the reducing current, leading to decreased output power of the whole string.

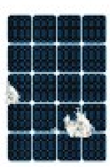
Common factors that cause preceding power mismatch of PV modules include:

- Manufacturing tolerances of modules (small differences in electrical characteristics of the same batch of modules)
- Mismatch due to unpredictable factors (dust, clouds, fallen leaves, bird droppings, etc.)
- Unavoidable shades (chimneys, dormers, trees, etc. in residential scenarios; parapets, stairwells, tall buildings, etc in C&I scenarios)
- Series or parallel mismatch
- Mismatch of modules due to aging and decaying

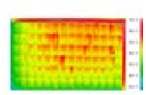

Fallen leaves


Shadow


Dirt


Bird dropping

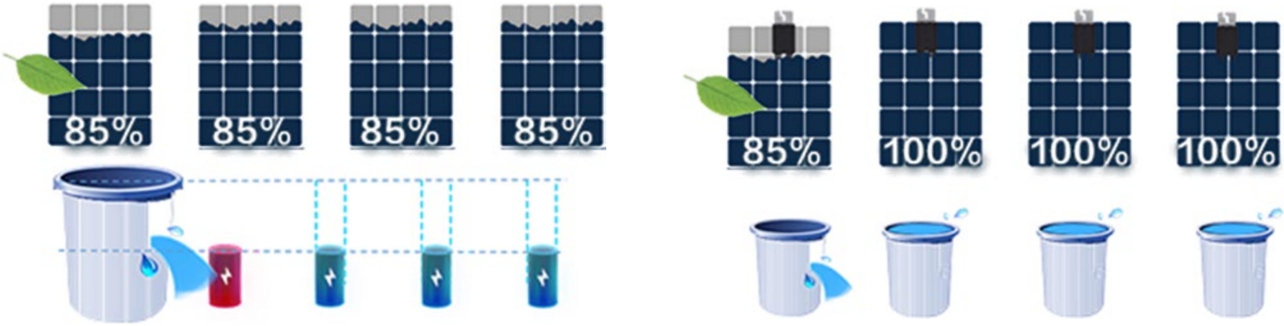

Module manufacturing tolerance


Uneven heating

Adopting the Smart Module Controller solution enables the independent tracking of the MPP of each module to achieve the optimal energy yield of the whole string.

» Ensuring the maximum power output of shaded modules in the current environment

» Reducing the output voltage of the optimizer and increasing the output current to match the MPP current of the unshaded modules to ensure that all modules on the whole string work at their own MPPs without mutual interferences.

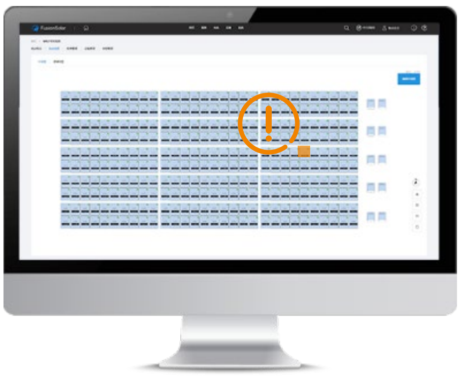


Without optimizer With optimizer

2.2.3 Smart O&M, achieving Module-level management

The Smart Module Controller can measure the operation data of each module in real time, including characteristic parameters such as current and voltage. In addition, physical layout can be recognized and generated in 5s, and real-time and historical module information can be viewed in the physical layout page. In a PV system fully equipped with optimizers, once a disconnection between optimizers or between an optimizer and an inverter occurs (including arc fault), the disconnected position will be accurately located through the monitoring interface of the debugging app to improve fault diagnosis efficiency.

This function will allow the accurate location of the defective modules, which will reduce the O&M costs of power plants and minimize the need for onsite maintenance.



Smart Module Controller Solution Introduction

2.2.4 Active safety protection and rapid shutdown ensure personal, electrical, and property safety

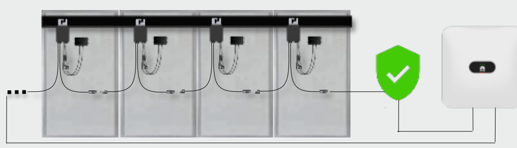
In rooftop PV projects, the voltage of PV modules usually reaches 600 V to 1000 V, which imposes potential risks on owners, construction and O&M staff, as well as rescuers in case of an emergency, such as a fire.

In addition, due to the high voltage on the roof, it was impossible to extinguish the fire conventionally with water, making rescue more difficult. The rescuers have to wait for the PV modules to burn down before extinguishing the fire, thus affecting the rescue process and possibly causing more casualties and property losses.

The Smart Module Controllers are equipped with the module rapid shutdown function. Every module is connected to an optimizer to measure its output. In case of an emergency, the rapid shutdown function can be triggered by power grid outage or interruption of communication with remote emergency switch, or manually activated through the DC switch.

PetroChina Gas Station with optimizers (120 kW)

Qiuling Gas Station with optimizers (110 kW)



Before rapid shutdown: 900 V VS After rapid shutdown: Safe Voltage

03

Active Safety

3.1 Safety Standards Development Introduction

Distributed PV system is mainly installed on the roofs of households, enterprises and institutions, and C&I facilities. However, with the expansion of distributed PV deployment, safety incidents such as fire accidents increased exponentially. Electrical safety concerns have become a major obstacle in the development of distributed PV.

In the traditional solution, the PV strings will be constantly energized under the sun. Even when the inverter is turned off, there is still a high DC voltage of 600–1100 V, which cannot be eliminated. More importantly, when fire occurs in a roof PV system, firefighters are unable to extinguish the fire effectively due to the risk of electric shock since all the PV wires are carrying high DC voltage. The only option is usually to let the PV system burn in a controlled way until all the PV modules burn out. This method will prolong the fire and cause heavier property losses. It is necessary to adopt comprehensive measures such as rapid shutdown technology combined with intelligent arc fault detection to improve the safety of distributed PV.

Standards in different countries

Country	Standard
US/Canada	NEC2020 690.12
Mexico	NOM-001-SEDE-2012
China	Ministry of Housing and Urban-Rural Development, Technical Specification for Integrated Intelligent System of Photoelectric Building
Germany	VDE-AR-E 2100-712
Italy	N.1324-2012
Thailand	EIT Roof PV design code
Australia	AS5033:2020

Standard NEC 2020 690.12 stipulates that the PV output voltage should be reduced to below 30 V within 30 seconds outside the 1 foot (30 cm) range. Within the range of 1 foot (30 cm), the PV output voltage should be reduced to below 80 V in 30 seconds. Module-level shutdown is required; reliable emergency stop is mandatory; self-check function is required, and the rapid shutdown function should be available in case of a single point of fault.

The specific provisions of the German VDE-AR-E 2100-712 are as follows: the voltage of PV wires installed through a room should be less than 120 V; string-level shutdown is required, and a circuit breaker should be installed in the house; firewalls should be installed in the wire troughs.

Thailand's EIT requires compliance with the NEC2020 standard in terms of rapid shutdown: the output voltage should be reduced to less than 80 V within a PV array and less than 30 V outside the PV array within 30 seconds.

In China, standard T/CECS 941-2021 Technical Specification for Integrated Intelligent System of Photoelectric Building has been approved and issued. According to the Regulations, PV power generation system installed in buildings should have rapid shutdown function on its DC side, namely, the rapid shutdown of modules. In case of an emergency, voltage of any two points in the PV array should fall below 120 V in 30 seconds, and the voltage outside the 1-meter range of the PV array should be reduced to 30 V in 30 seconds.

3.2 Verifying the Safety Shutdown Function

Test site: Roof of a shopping mall in XX City

Test solution

Basic situation	The Huawei optimizer solution applied on a mall roof was tested. The system capacity was 44.88 kW, a 30 kW inverter was used, and the modules are fully configured with optimizers.
Test method	A voltmeter was used to measure the MPP voltage of one input line of the inverter. An emergency scenario was simulated through various trigger modes, such as disconnecting from the grid or turning off the DC switch. The time needed for the voltage to drop to 0 V when the rapid shutdown function is triggered was recorded.
Test process	To verify the normal operation of the PV system, the time is recorded for the voltage to drop to 0 V by manually turning off the DC switch of the inverter and the switch of the distribution box on the AC side respectively.

Test results and analysis

Two triggers were used: disconnecting the DC switch and the switch on the AC side. The MPPT voltage at the input of inverter 1 dropped to 0 V, and the shutdown time was 25s and 11s respectively, which met the requirements of the standard NEC 2020 690.12.

04

Flexible Design

4.1 Module Layout Rules

Traditional Module Laying Solution:

In the traditional PV system design solution, PV modules are spaced in a way that no module casts shade onto any neighboring module during the period of 9:00–15:00 (local apparent solar time, during which irradiance is strong), to avoid yield decrease of the entire system.

The disadvantages of traditional array laying solution are as follows:

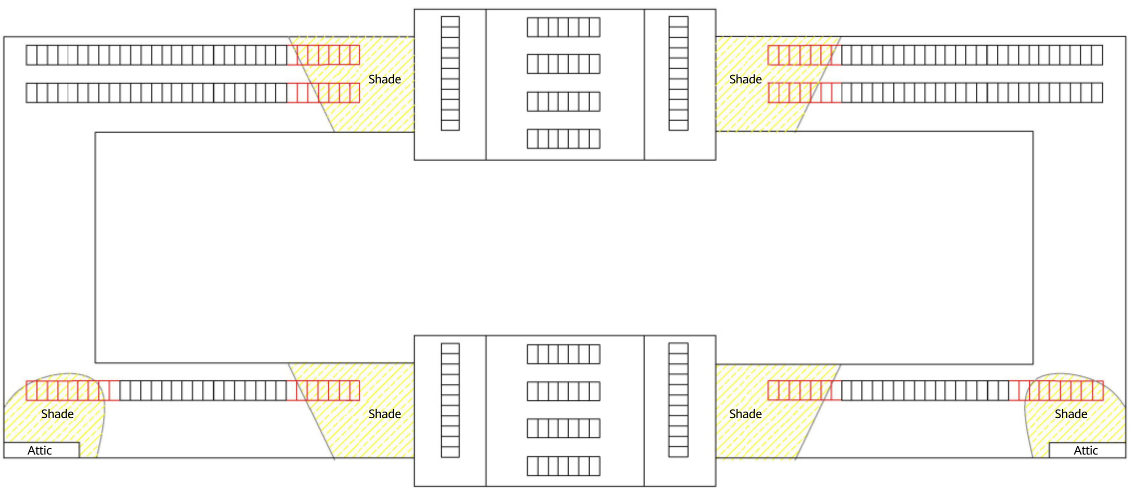
- Rooftop distributed PV systems are easily shaded, leaving little space for laying modules, and resulting in the low utilization rate of roof resources.
- When some modules are shaded, the energy yield of the whole string will be affected.
- In principle, modules with different orientations and dip angles cannot be connected to the same string. This requirement complicates module design.

Module Laying Solution Using Optimizers:

With optimizers, each module can generate power independently at its own MPP so that shaded modules will not impact other modules. Breaking the traditional module laying rules, optimizers make full use of the roof area to achieve higher installed capacity in limited space because PV modules can be installed in areas with temporary shadow. However, despite of the benefit, installing modules in areas prone to shading for extended periods of time is not recommended.

4.2 Smart Module Controller Application Cases

Case 1: The installed capacity on the roof of a teaching building has been increased by 25.9%



The figure above is the module layout design for a teaching building. The modules indicated in black lines are modules that can be installed according to the traditional rules, with a total installed capacity of 125.28 kW. The modules indicated in red lines are additional modules that can be installed after using optimizers, which increase the system capacity to 157.68 kW by 25.9%.

Case 2: The installed capacity on the roof of a detached house has been increased by 40%

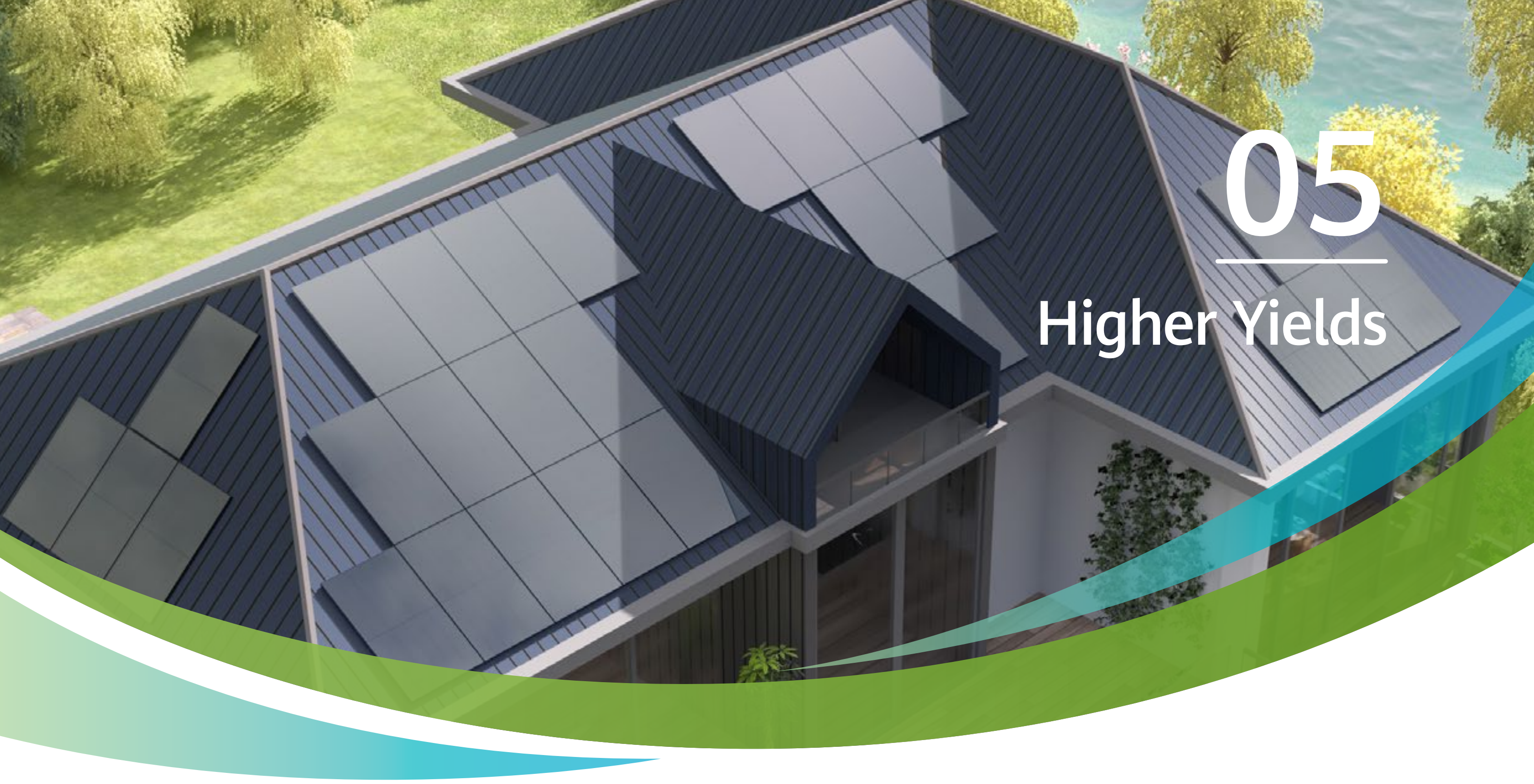
The left picture above shows the traditional module layout design for a detached house. Roof area 1 and area 2 are shaded. To avoid the impact of the limiting factors on the overall energy yield, modules will not be installed in the shaded areas. Moreover, modules can be installed in only two directions because the inverter has only two MPPTs.

The right picture shows the Smart Module Controller solution. With optimizers, modules can be installed in the shaded areas without affecting the energy yield of other modules in the string, and modules with different orientations can be connected to the same string. This simplifies system design, maximizes installed capacity and increases energy yield.

4.3 Summary

Smart Module Controller solution breaks the traditional rules of module layout design, reduces the impact of shades on module layout, and makes full use of the limited roof space. Compared to the traditional design, more modules can be installed on the same roof area. This reduces the cost of project survey and design, dilutes the cost of construction, equipment, and materials, and eventually reduces the cost of construction per watt.

In addition, the optimizer solution makes it possible to develop and install modules on roofs that are previously disqualified for PV installation based on traditional design specifications. This helps make full use of the limited roof resources, and greatly expands the depth and breadth of the distributed PV market.



05 Higher Yields

The Smart Module Controller solution independently controls the voltage and current of each module to achieve module-level power optimization, which resolves the mismatch caused by a variety of factors, including module manufacturing tolerances, unpredictable environmental impacts, fixed shades on the system, and decaying and aging modules.

To verify the effect of the optimizers, Huawei joins hands with TÜV Rheinland, an authoritative international third-party certification body, to conduct large amount of yield research and investigations. Several typical application scenarios of the distributed PV projects have been selected for the testing. Corresponding testing plans have been formulated and the testing system has been set up. Credible testing results were generated from relevant test-based verifications, data collection and analysis under the witness and supervision of TÜV Rheinland, which will serve as a reference for users and stakeholders to understand and employ optimizer solutions and products.

5.1 Typical Residential Scenarios without Fixed Shades

In this scenario, there are usually no fixed shades, but there are shades caused by unpredictable factors such as clouds, bird droppings, dust buildup, dirt, etc., which will result in about 2.5% of mismatch. The following is an empirical case of enhanced yield in scenarios without fixed shades.

Test site: The residential roof in XXX Village

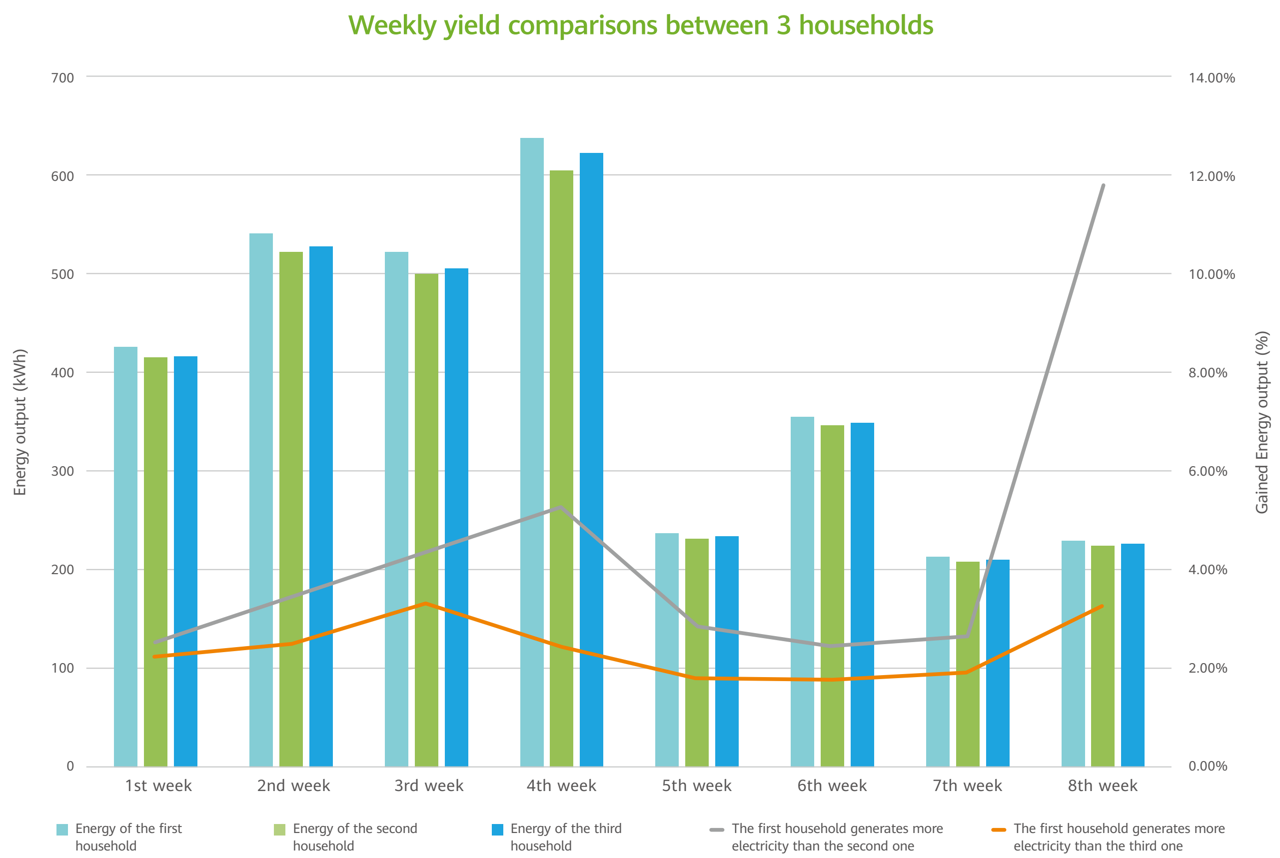
Higher Yields

Test solution:

Basic situation	The houses of three farmers were aligned in a row from east to west. The orientations and dip angles of the PV systems were the same, and all the AC meters installed had been calibrated by the power grid company, which is a typical residential scenario without fixed shades. The system capacity of each household is 27 kw with 50 monocrystalline silicon 540W modules installed per system, equipped with Huawei inverters.
Test method	A contrast test was carried out. The eastern household was selected as the experimental group with optimizers, while the other two households as the control group without optimizers.
Test process	After confirming that the system debugging was completed, the formal test began. Special personnel were assigned to read the output energy of each AC meter every day and measure the test data of the inverter through the management system to ensure the stability of the system connection. They would also record the weather during the test, such as sunlight and temperature.
Test period	57 days in total

Test results and analysis

Over the entire test period, based on meter data, the PV energy yield of the first household equipped with optimizers was 3.56% and 2.73% higher than that of the other two households respectively.



5.2 Typical Public Building Scenarios with Stairwell Shades

The roofs of public buildings such as schools, hospitals, and Subway Station are ideal resources for distributed PV deployment. However, such buildings are prone to shades caused by stairwells, parapets, and billboards etc.

Test site: Roof of the main teaching building of a Junior High School in XXX Town

Test solution

Basic situation	The main teaching building of the Junior High School of XXX Town is a rectangular-ambulatory structure, and the stairwell is located in the middle between the north and the south building. Therefore, there are stairwell shades. 96 modules were installed on the east and west sides of the roof respectively, each with a capacity of 51.84 kW, which totaled 103.68 kWp of DC capacity. Two Huawei 40kW inverters were connected to the east and the west respectively. Each inverter has four MPPT channels, each MPPT channel has two MPPT strings, and each string has 12 modules.
Test method	In the contrast test, all modules on the east roof (the experimental group) were equipped with optimizers, which are connected to an inverter. Those on the west roof (the control group) were connected to an inverter without optimizers. AC meters were installed on the AC output ports of the inverters of the two groups respectively to measure the energy yield. It was ensured that the PV system could run normally after being connected to the grid with sound communication configurations. The management system could log the energy yield data of the inverters.
Test process	When the test began, special personnel were assigned to record the output yield of each AC meter, measure the test data of the inverters through the management system, and record the weather during the test period, such as sunlight and temperature.
Test period	61 days in total

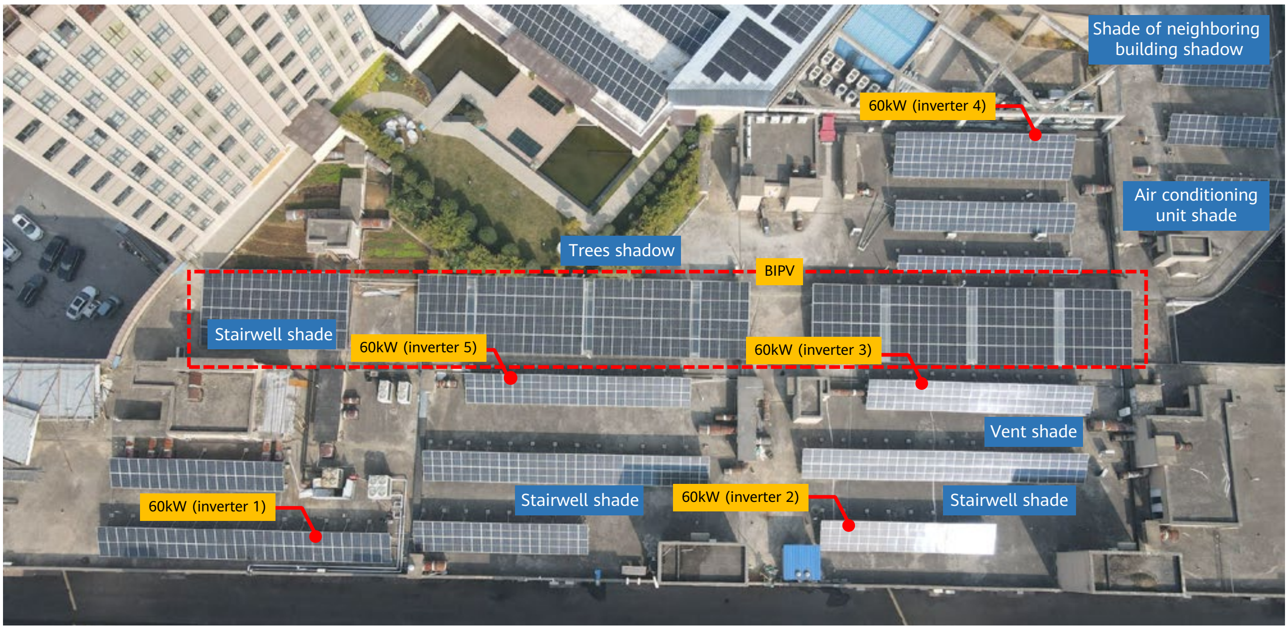
Test results and analysis

During the test period, the average yield on the east side was 9.47% higher than that of the west side, indicating that the optimizers significantly increased PV energy yield in public building scenarios.

Comparisons of PV yield between the east and the west sides of the teaching building

5.3 Typical C&I Building Roof Scenarios

Test site: Roof of a shopping mall in XX City



Test solution:

Basic situation	The roof was initially installed with two PV systems, both using traditional solutions. The BIPV used 304 pieces of 440/445W modules with a DC capacity of 133.76 kWp and configured with two 60kW inverters. A multi-row PV system was equipped with 560 pieces of 310W modules with a DC capacity of 173.6 kWp and three 60kW inverters. The project has been in operation for about 3 years. In the initial planning of the project, in order to guarantee the scale, there were inevitably shades caused by parapet walls, stairwells, trees, monitors, air conditioning units, nearby high-rises, ventilation ducts, etc., which significantly reduced yield.
Test method	Benchmark test and comparison test were adopted. First of all, the output port of each inverter is equipped with a calibrated electricity meter for benchmark test; then, the inverter with the lowest annual specific energy was replaced with a Huawei inverter, and PV modules were fully equipped with optimizers; finally, a yield increase verification test would be finished.
Test process	4 inverters numbered #1-#4 were selected for the test. The benchmark test was carried out for 1 month. Based on the output data recorded by the AC meters, inverter system #1 with the largest output loss in the real environment was selected as the experimental group, and the rest became the control group. The 60kW inverter of the experimental group (#1) was replaced with 2 Huawei 30kW inverters, a two-in-one combiner box was used, and PV modules were fully equipped with optimizers. The control group remained unchanged. Yield increase verification tests were carried out and the daily yield values displayed on the meters were recorded for statistical analysis.
Test period	Benchmark test: December 15 to February 08 Formal test: February 14 to March 15

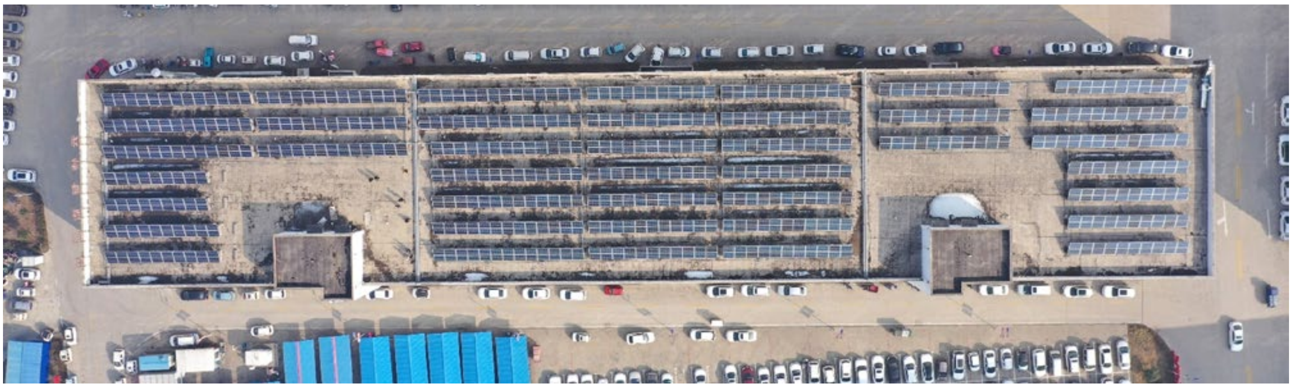
Test results and analysis

After the test was completed, data from the benchmark test and the formal test were displayed in the following table respectively.

Benchmark test stage	Specific energy of the experimental group	78.78 h		
	Specific energy of the contrast group	103.56 h	106.02 h	86.56 h
	Contrast ratio %	–23.93%	–25.69%	–8.99%
Optimizer test stage	Specific energy of the experimental group	94.18 h		
	Specific energy of the contrast group	77.47 h	89.18 h	83.23 h
	Contrast ratio %	21.57%	5.61%	13.17%
Increase %		45.5%	31.3%	22.16%

5.4 Typical 5-Year-Old Power Plant

Test site: Roof of XXX Clothing Factory



Test solution

Basic situation	This rooftop PV project has been put into operation for more than 5 years. Two sets of inverter systems were selected for testing. System #1 had a DC capacity of 53.76 kWp and was configured with a 40kW inverter; System #2 had a DC capacity of 52.08 kWp and was configured with a 40kW inverter. Due to the long operation time, there were potential factors that would have impact on the energy yield, such as unpredictable environment shades, module attenuation and mismatch, heat spots, and damages, etc.
Test method	A benchmark test and a yield increase verification test were performed. The benchmark test was performed first, and the formal optimizer test was carried out on the system with a lower yield in the benchmark test.
Test process	After confirming the completion of system commissioning, the formal test began. The test data of the inverter was monitored through the management system to ensure the sound communication of the system. At the same time, weather conditions were recorded during the test period, such as sunlight and temperature.
Test period	Benchmark test: December 16 to February 08 Formal test: February 26 to March 13

Test results and analysis

In the benchmark test, the specific energy of System #1 was 124.3h, and System #2 was 120.6h.

In the formal test, the specific energy of System #1 was 58.0h and System #2 could be estimated to be 56.27h. In fact, the System #2 achieved 60.38h.

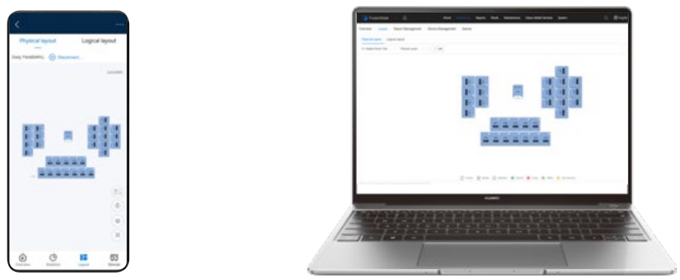
Therefore, based on the result of the benchmark test, the comprehensive evaluation showed that, after adopting optimizer solution, System #2 improved its yield by 7.26%.

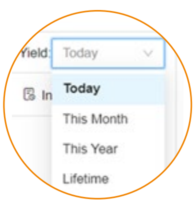
06

Smart O&M

6.1 Module-Level Monitoring

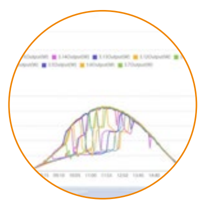
Module-level electrical parameter monitoring:





Query of total energy yield and the yield of a day, week, month, or year

Color-marked inefficient modules on the physical layout



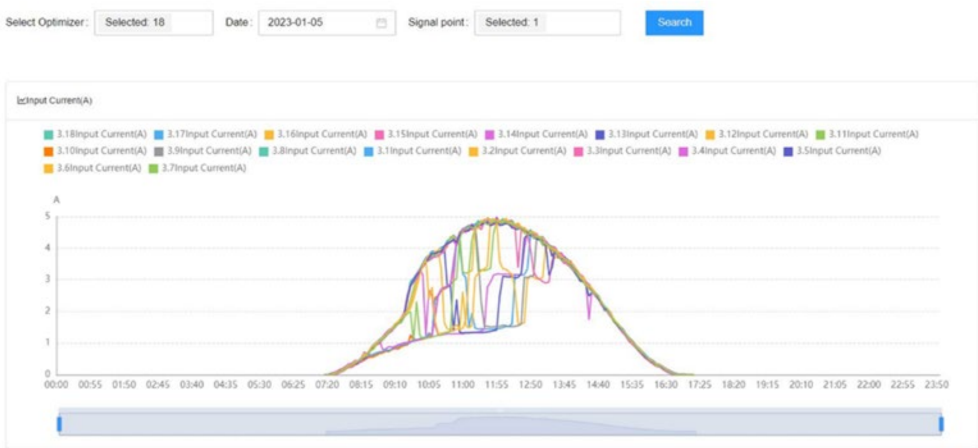
Query of information such as module voltage, current, and power

In the optimizer solution, information such as spatial position and output power of modules, input and output current and voltage of the optimizer will be visually displayed through the display interface to realize intelligent monitoring and visual management at module level. This solution allows you to access the power plant view through web pages, apps, and other ways. Query of realtime and historical information is supported.

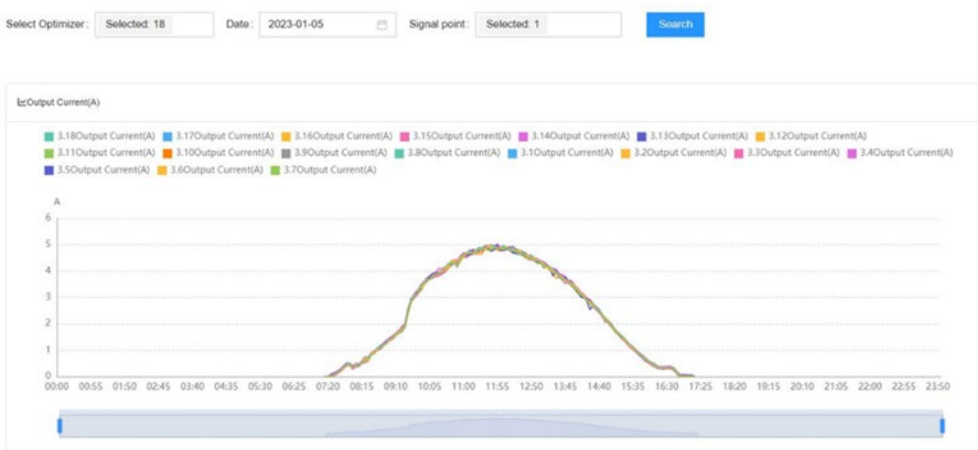
Information such as the power, energy yield, voltage, and current of each module is displayed.

The output power curve of all modules in the same string

The input current curve of all optimizers in the same string



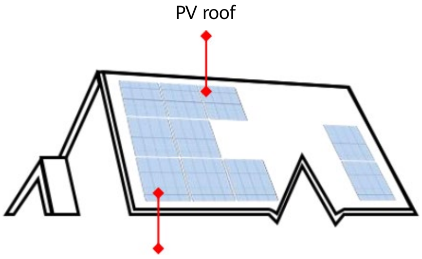
The output current curve of all optimizers in the same string

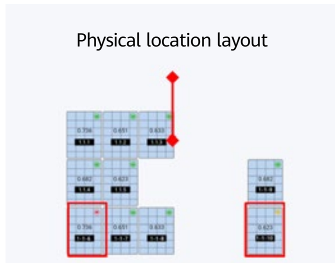


Comparing the input and output current curves of optimizers in the same string shows that some modules in the string were mismatched due to shades, aging, and other reasons. The low output power and output current led to low energy yield of the whole string. When the output current of the module was converted into the input current of the optimizer, the output current rose, and the whole string achieved unified high working current, thus improving the overall yield.

Scan the QR code to generate a physical layout diagram

Upload the physical layout template to the management system. The QR code recognition technology can quickly identify the physical location of modules and generate a physical layout diagram.



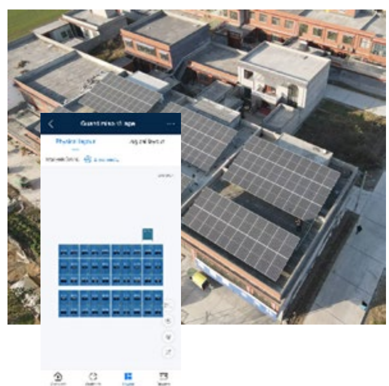


6.2 Intelligent O&M

Inspection in the optimizer solution (once a quarter)	VS	Inspection in traditional solution (2–3 times a quarter)

The refined management will reduce onsite inspection frequency to only once a quarter.

Accurate fault location (instantly)	VS	Traditional fault location (~3 hours)



The layout of modules in the power plant view is accurate. Device data and status are uploaded in real time to help users accurately identity faults and the physical locations of faulty devices. Take a 10kW system as an example, if a module fails, it takes around three hours to locate the faulty module in the traditional solution. However, in the Huawei solution, the physical location of the faulty module is accurately identified in the layout view, thus saving the time for onsite inspection.

07 Summary

7.1 Financial Analysis

7.1.1 Financial value

The economic benefits of the optimizer in the overall PV project include the following three aspects:

» Improved PV installations on roofs will dilute the installation cost. It is calculated that the optimizer solution can increase the installed DC capacity of PV projects on the roof by about 30%, and can effectively dilute the development cost, cranage cost and other costs, reducing the installation cost by 10% to 20%. In general, the shade ratio of C&I and residential scenarios are as follows.

Scenario	Shade Ratio
C&I buildings	5-15%
Residential buildings	10-30%

» Higher yields from PV systems will increase the revenue: PV systems equipped with optimizers can significantly reduce the mismatch between modules, generating higher yield and revenue than traditional PV systems. In shaded scenarios, yield can be increased by up to 30% throughout the whole life cycle.

» Plant O&M costs are minimized: After PV systems are equipped with optimizers, traditional string monitoring evolves to module-level management. Through refined management and module-level fault diagnosis technology, power plant O&M efficiency will be greatly improved, as remote management can minimize the need for field O&M, reducing the cost of project O&M by 15% to 25%.

7.1.2 Comparative financial analysis of typical projects in various scenarios

Generally, the revenue of a PV project depends on the electricity it generates and the mode of maximum self-consumption is commonly adopted to reduce electricity cost.

Based on the electricity price and cost of a PV project, considering the initial investment in the system and the O&M costs, the cash flow statement of the project throughout the whole life cycle is as follows. Different financial indicators of the PV project have been calculated, such as the internal rate of return (IRR) and the payoff period.

Financial analysis of typical projects in residential scenarios

Typical Residential Projects	Traditional Solution	Huawei Optimizer Solution (Without Additional Installations)
Roof area	100 m^2	100 m^2
Module type	400 W	400 W
DC capacity	10 kWp	10 kWp
AC capacity	8 kWp	8 kWp
Power generating hours in the first year	1000 h	1070 h
Optimizer configuration	No	Yes
Self-consumption rate	60%	60%
LCOE	0.1236 EUR/kWh	0.1212 EUR/kWh
Internal rate of return (IRR)	11.00%	11.27%
Payoff period	7.95 y	7.78 y
Life cycle yield	235,600 kWh	252,000 kWh
Life cycle total revenue	25,567 EUR	27,972 EUR
Carbon dioxide emission reduction*	111.89 t	119.72 t

* Calculated as 0.475 kg carbon dioxide emission reduction for per kWh of green electricity

* The above data is for reference only and may vary with specific projects

Financial analysis of typical projects in C&I scenarios

Typical C&I Projects	Traditional Solution	Huawei Optimizer Solution (Without Additional Installations)
Roof area	1000 m^2	1000 m^2
Module type	550 W	550 W
DC capacity	120 kW	120 kW
AC capacity	100 kW	100 kW
Power generating hours in the first year	1000 h	1070 h
Optimizer configuration	No	Yes
Self-consumption rate	75%	75%
LCOE	0.0878 EUR/kWh	0.0866 EUR/kWh
Internal rate of return (IRR)	12.96%	13.12%
Payoff period	6.84 y	6.76 y
Life cycle yield	2,826,700 kWh	3,024,600 kWh
Life cycle total revenue	265,068 EUR	288,727 EUR
Carbon dioxide emission reduction*	1342.69 t	1436.68 t

* Calculated as 0.475 kg carbon dioxide emission reduction for per kWh of green electricity

* The above data is for reference only and may vary with specific projects

7.2 Conclusion

Against the background of carbon peak and carbon neutrality goals, Huawei has proposed an optimizer solution based on MLPE technologies to address mismatch issues caused by shades or aging modules in distributed PV generation markets. Under the supervision of TÜV Rheinland, an authoritative third-party certification organization, the Huawei Smart Module Controller solution has passed empirical tests in typical scenarios. It has been proved that compared with the traditional solution, it increases eligible roof areas for PV and the energy yield. The financial analysis has also verified significant improvement in revenue. The key data collected by the optimizers allows intelligent monitoring at module level. This addresses the inconvenient O&M of scattered distributed PV power plants, thus improving the O&M efficiency at lower costs. The rapid shutdown function also fundamentally ensures the safety of O&M personnel, reduces the secondary damages caused by emergencies.

References

[1] 'Photovoltaic Systems with Module-Level Power Electronics', [Online]. Available: https://www.nrel.gov/docs/fy15osti/64876.pdf

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