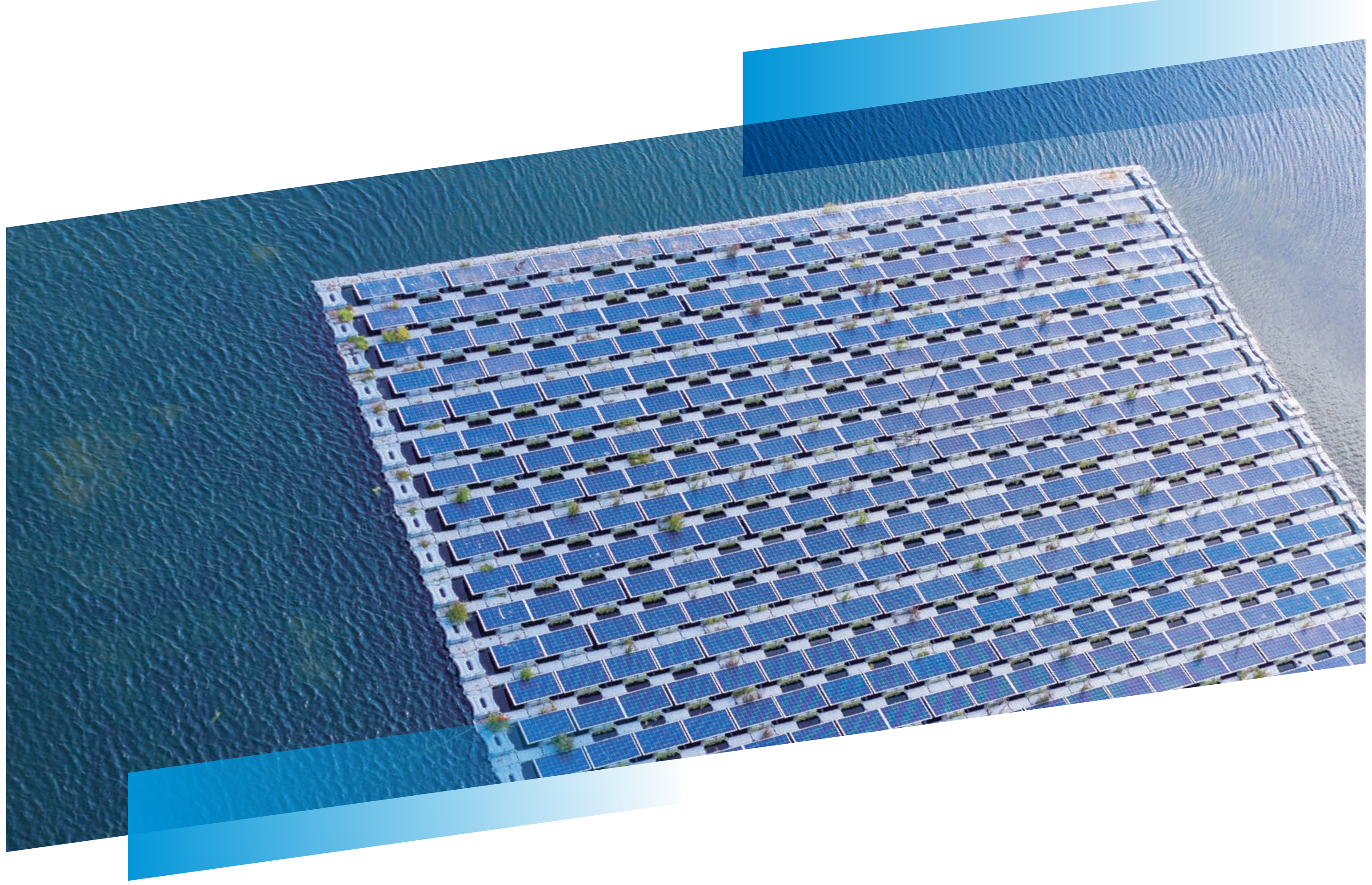

Trina solar

Offshore PV Module White Paper

Offshore PV Module White Paper

Foreword

As a new application scenario, Offshore PV will face severe marine environment challenges, such as high temperature, high humidity, salt spray corrosion, gale, wave, precipitation. The modules need to have higher reliability. This white paper aims to provide the matters to be noted during the usage of PV modules in coastal regions and offshore for the reference of the application clients of PV systems.

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01

Background and Offshore PV classification

In recent years, with the continuous growth of land-based PV installations, land resources are becoming a key factor restricting the development of PV on a large scale. While the ocean is vast and unshaded, particularly with high irradiation, the space for development is quite considerable. The global potential capacity of offshore PV is about 4000GW, and the overall potential capacity is very huge.

1.1 Offshore PV in China

Driven by the new energy policy of the Chinese government, China's coastal provinces have actively responded to the goal of realizing "Carbon Peaking and Carbon Neutrality Goals", and have successively switched their focus on the development of Offshore PV. Here are main reasons for the change: the power consumption in coastal areas is large, and the development of solar farm is limited by land resources (centralized power stations involve land, and distributed photovoltaic contributions are insufficient); Coastal provinces and cities have rich marine resources, and the collaborative development of Offshore PV and wind power can effectively optimize investment costs (submarine cables, power transformation facilities, etc.); Offshore PV can also be combined with aquaculture, which can improve the overall investment return; The power generation efficiency of Offshore PV has a certain gain compared with that of onshore PV under the same lighting conditions. China's coastline is more than 18,000 kilometers, and the coastal beach area is more than 15,000 square kilometers, of which the pile-based offshore PV can be installed in an area of more than 1,800 square kilometers, and the beach pile-based photovoltaic can be installed in an area of more than 2,000 square kilometers. In theory, China can install more than 100GW of offshore PV.

1.2 Offshore PV in other regions

The Asia-Pacific is another blue ocean region for the development of offshore PV. Especially in Southeast Asia with dense population,offshore photovoltaic has become one of the main development direction of its energy transition. From a theoretical point of view, the Asia-Pacific region, especially in Southeast Asia, is capable of installing more than 50GW of offshore PV modules.Thus, the market prospect is broad.

Latin America also focuses on offshore PV. There are long coastlines in Latin America; the power consumption in coastal areas is huge; new energy development is limited by the constraints of land resources. Offshore PV development can effectively solve the energy and consumption problems.

02

Offshore PV classification and current challenges

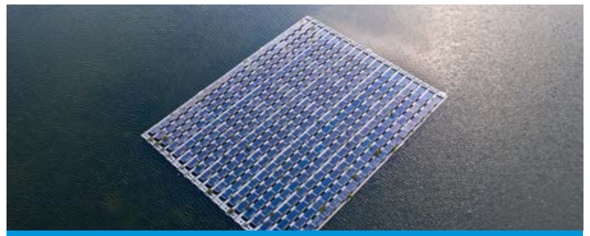
2.1 Classification of offshore photovoltaics

As a new type of energy utilization and resource development mode, offshore photovoltaic power generation utilizes photovoltaic technology to set up power stations on the ocean, which is characterized by high power generation capacity, low land occupation, and easy integration with other industries. Compared with onshore PV, offshore PV has natural environmental advantages: the water surface is open and free of obstructions, and the sunshine duration is long and fully utilized (reflected light on the water surface), which can significantly increase the power generation capacity. Depending on the water depth and distance from the shore, offshore PV is mainly categorized into pile-fixed and floating types.

Pile-based fixed photovoltaic power station, is often applied to shallow water area with no site subsidence and other geologic hazards and small water level changes, such as aquaculture ponds, salt farms draining ponds and so on. It is applicable to beach sites with a water depth of less than 8 meters, stable geology and small water level changes, and is currently the mainstream of offshore PV construction. This type of power station can adopt the construction mode of "Agriculture - PV solar combination", which is to utilize the marine resources of ponds in areas where aquaculture is concentrated to develop and build photovoltaic power generation projects. The mode of marine power generation and underwater aquaculture is adopted to realize the complementary development of multiple industries.

Floating photovoltaic power plant (FPV), utilizes floating materials and anchoring systems to make photovoltaic modules, inverters and other power generation equipment float on the sea surface for power generation, and is suitable for the water area whose depths are greater than 8 meters, and the impact of typhoons are not big waters.In the long term, FPV is expected to be the main form of offshore PV applications in the future. Floating photovoltaic power plants have a wider range of application scenarios and less environmental problems. From a global point of view, there are currently more than 60 countries actively promoting the construction of floating PV power stations at sea, of which more than 35 countries have 350 floating PV power stations. According to another study published by research organization GlobalIndustryAnalysts, the global deployment of floating PV installed capacity is 1.6GW in 2021,which is expected to grow to 4.8GW by 2026.


Pile-based fixed photovoltaic power station


Floating photovoltaic power plant (FPV)

2.2 Main environmental challenges and failures of offshore PV

Compared with land, the environmental challenges faced by offshore PV modules are more complicated than those faced by onshore PV due to its special environment. The load on the floating body structure under wind, waves and currents increases dramatically, and the system safety faces serious challenges: the combined effect of the "three highs and three strongs" (high temperature, high humidity, high salt spray, strong gale, strong waves and strong precipitation) on the PV modules leads to a decrease in power generation efficiency and a shortened life span.

Module destroy

Water vapor intrusion

Gale

High temperature & humidity

Mist effect

Birds

Frame/Tracker corrosion

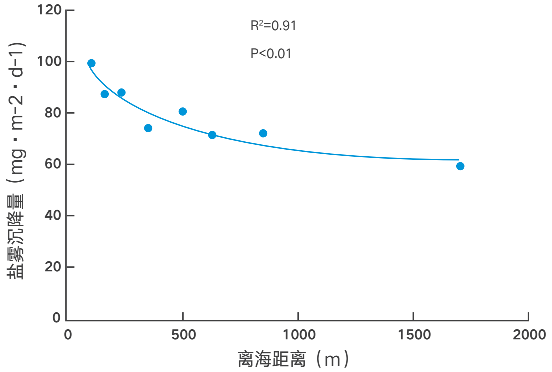
Heat spots from bird droppings shield

03

Offshore photovoltaic module solutions

3.1 Module Solutions

According to the correlation study between salt spray deposition and distance from the coast in different seasons [1], in the distance of 500m from the coast, salt spray deposition decreases with the increase of distance from the coast, and when the distance exceeds 500m, it decreases slowly. When it comes more than 2000m, the salt spray deposition is in the range of 60mg·m⁻²·d⁻¹.



Change of annual salt spray deposition with the change of distance from the sea

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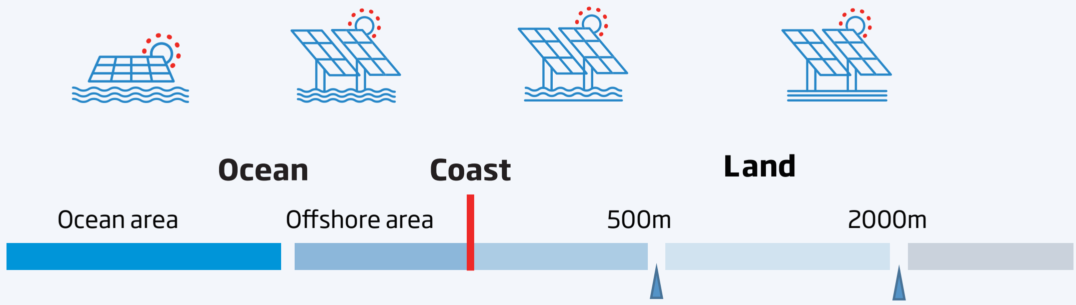
[1]侯梦莹,李芊芊,袁甜甜.南方滨海地区盐雾沉降的时空分布———以福建古雷半岛为例[J].生态学杂志,2019,38(8)：2524-2530

Based on this,Trina Solar provides two types of product solutions,floating PV module solution (FPV) and pile-based fixed PV module solution:



	Ocean area	Offshore area		500m	2000m
Distance:					
Area:	Ocean areas and some offshore areas	Offshore area	Within 500m from the coast	Onshore within 500m to 2km from the coast	≥ 2km from the coast
Installation:	Floating PV	Pile-based fixed	Pile-based fixed	Conventional	Conventional
Module:	Trina's dual glass products (recommend NEG21C.20, DEG21C.20, NEG19RC.20, DEG19RC.20) Dual glass + Dual Coated Front Panel Glass Frame AA15 IP68 Junction box and connectors + Dust Plugs	Trina's dual glass products (recommend NEG21C.20, DEG21C.20, NEG19RC.20, DEG19RC.20) Dual glass + Dual Coated Front Panel Glass Frame AA15 IP68 Junction box and connectors + Dust Plugs		Conventional Dual Glass Products	Conventional Products
Other requirements:	Antiseptic Bolt & Tracker	Antiseptic Bolt & Tracker		Standardized	Standardized

Definition	Offshore Distance	Module Solution	Bolt Requirements	Tracker Requirements
Floating photovoltaic power plant (FPV)	Ocean areas and some offshore areas	Dual Glass + Dual Coated Front Panel Glass + AA15 Frame + IP68 Junction Box & Connectors + Dust Plugs Recommended: double protection for connectors + waterproof cables	Antiseptic	Antiseptic
Pile-based fixed photovoltaic power station	Offshore areas and within 500m from the coast	Dual Glass + Dual Coated Front Panel Glass + AA15 Frame + IP68 Junction Box & Connector + Dust Plugs Recommended: double protection for connectors	Antiseptic	Antiseptic
Other locations	Onshore within 500m to 2km from the coast	Conventional Dual Glass Products	Standardized	Standardized
	≥ 2km from the coast	Conventional Single/Dual Glass Products	Standardized	Standardized

Connector dust plug:

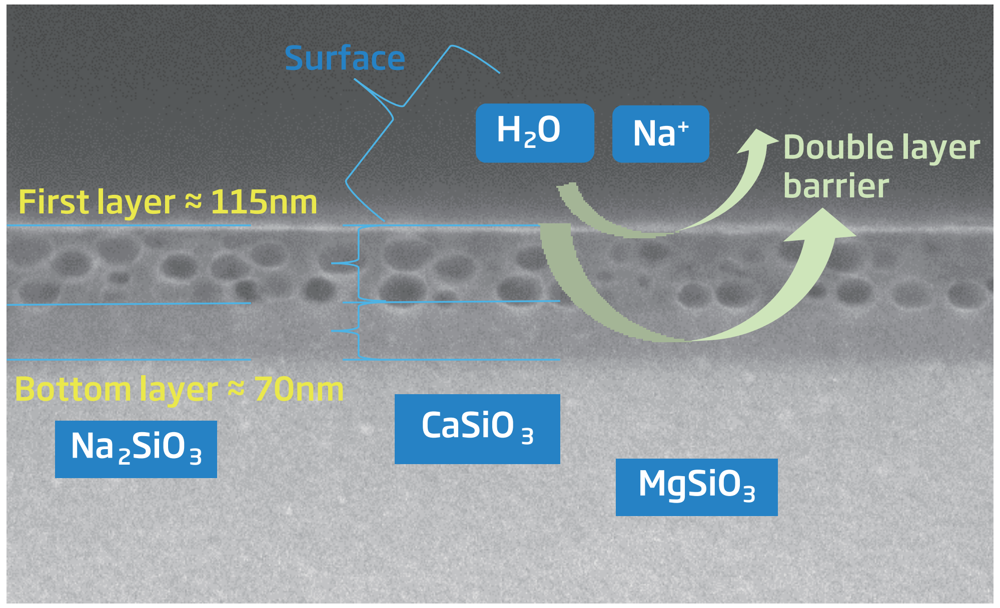
It is designed to solve the problem of condensation vapor intrusion into the connector part during the installation of module.

Connector double protection:

The connector is IP68 grade / salt spray S8, which provides enhanced water and salt spray resistance by adding the connector protective cover.

Double-coated glass:

The front glass can effectively protect the PV glass substrate from water vapor and salt spray corrosion by adding a layer of dense SiO_2 layer, with better climate resistance.



3.2 Offshore PV Module Certification

Trina's vertex series modules have been certified by TÜV Rheinland Offshore PV2 PfG 2930/02.23,which is the first offshore certificate and an important milestone for PV products in offshore applications.

Zertifikat *Certificate*

TÜVRheinland®

Zertifikat Nr. *Certificate No.*
PV 50586842

Blatt *Sheet*
0001

Ihr Zeichen *Client Reference*
Z.Z.

Unser Zeichen *Our Reference*
01-QLS-CN23DVKI 001

Ausstellungsdatum *Date of Issue* *(day/mo/yr)*
15.06.2023

Genehmigungsinhaber *License Holder*
Trina Solar Co., Ltd.
No. 2 TianHe Road, Trina PV
Industrial Park, New District
Changzhou City,
213031 Jiangsu
P.R. China

Fertigungsstätte *Manufacturing Plant*
Refer to latest revision
of the annex list of factories

Prüfzeichen *Test Mark*
TÜVRheinland®
CERTIFIED
Inshore PV Module
Regular Production
Surveillance
www.tuv.com
ID 1111269512

Geprüft nach *Tested acc. to*
2 PfG 2930/02.23

Zertifiziertes Produkt (Geräteidentifikation)
Certified Product *(Product Identification)*

Lizenzentgelte - Einheit
License Fee - Unit

PV Module

Type Designations:
Max. System Voltage: up to 1500 VDC (Voc at STC):
With half cut mono c-Si cells:
TSM-xxxDEG21C.20 (xxx=625-675, in steps of 5, 132 cells)
TSM-xxxDEG20C.20 (xxx=570-605, in steps of 5, 120 cells)
With 182mm x 105mm mono c-Si cells:
TSM-xxxDEG19RC.20 (xxx=540-595, in steps of 5, 132 cells)
Remarks:
Valid in conjunction with TÜV Rheinland certificate
PV 50572870 Page 0001-0024.
Test performed with Test Method 8
according to IEC 61701:2020 .
Only for the material combination as listed in the above
mentioned test report.
Conditions:
The product test is voluntarily according to technical
regulations. Any change of the design, materials, components
or processing may require the repetition of some of the
qualification tests in order to retain type approval.
This certificate is valid until 14 June 2028.

Dem Zertifikat liegt unsere Prüf- und Zertifizierungsordnung zugrunde.
Das Produkt entspricht den o.g. Anforderungen, die Herstellung wird überwacht.
This certificate is based on our Testing and Certification Regulation. The product fulfills above mentioned requirements, the production is subject to surveillance.

TÜV Rheinland LGA Products GmbH, Tillystraße 2, 90431 Nürnberg
http://www.tuv.com/safety E-mail: markcheck@tuv.com
Fax: +49 221 806-3935

Zertifizierungsstelle
Dipl.-Ing. Matthias Grzam

3.3 Trina's 700W + offshore solution

In addition to dealing with the technical difficulties of reliability, offshore PV cost control is also extremely critical. Take a agriculture-solar project as an example: compared to the reference modules, the BOS cost of the 210-66 N-type module can save ¥0.03-0.06/w or more.

Products	Trina's N type	Reference N type A	Reference N type B
Size（mm）	2384*1303	2465*1134	2465*1134
Power（W）	680	610	610
Voc （V）	47.4	51.47	55.25
Isc （A）	18.18	15.01	14.11
Number of blocks of a single string component	29	26	24
Low-voltage electrical costs（¥/W）			
Inverter	0.0241	0.0242	0.0242
Convergence box（including construction）	0.0013	0.0017	0.0018
MC4 connector（including construction）	0.0015	0.0019	0.0020
Cables（including construction）	0.0247	0.0258	0.0264
Low Voltage DC Cable（including construction）	0.0687	0.1020	0.1162
Grounding wire（including construction）	0.0026	0.0029	0.0029
Bridge（including construction）	0.0062	0.0078	0.0085
Cable gutter（including construction）	0.0096	0.0094	0.0120
Inverter Installation	0.0005	0.0005	0.0005
Total amount	0.1391	0.1761	0.1945
Difference	BL	0.0370	0.0554
Structural costs（Pile exposed 5.5m）（¥/W）			
Racking（including construction）	0.2605	0.2648	0.2541
Pile foundation（including construction）	0.2793	0.2701	0.2926
Total amount	0.5398	0.5350	0.5468
Difference	BL	-0.0048	0.0070
land rent（¥/W）			
Total amount	0.1375	0.1385	0.1382
Difference	BL	0.0010	0.0007
Cost of BOS（¥/W）			
Total amount	0.8164	0.8495	0.8795
Cost differential of BOS（¥/W）			
Total amount	**BL**	**0.0331**	**0.0631**

Offshore PV projects have some noticeable features based on the complexities of marine environment.First of all, Ocean is vast and unshaded, which is more suitable for the arrangement of long array bracket; secondly, due to the external sea water depth and waves, complex wind conditions, and the possibility of icing in some areas, so the fixed PV project pile foundation design is longer and the pile type is larger. Compared with onshore PV, its foundation materials and construction costs are much higher. In addition, because the marine environment requires high resistance to wind, corrosion, humidity and heat, and aging of materials, effectively reducing the amount of materials brings better economic benefits than land-based PV projects.

Trina's N-type Vertex 700W+ module, with its low Voc and higher power output , has a more obvious BOS cost advantage in offshore applications.

3.4 Coastal and Offshore Considerations for Offshore PV Modules

3.4.1 Bird droppings

There are many flying birds in the sea, and the long stay of birds and bird droppings will make the module produce hot spots.Therefore, it is suggested to consider the solution from the following three aspects:

1. Using infrared interference to avoid birds approaching;
2. Using special frequency band acoustic wave interference to avoid birds approaching;
3. Regular cleaning by manual operation and maintenance.

3.4.2 Wave dissipation

Offshore PV needs to avoid wind and waves directly hitting the surface of the module. It is recommended that:

1. Pipe pile elevation to make surethe lower edge of the module is higher than the highest wave in past 50 years;
2. Breakwaters reduce the impact of waves.

04

Reliability tests for Trina Solar’s Offshore PV

Offshore PV modules need to be toughened in face of challenges from load, salt spray, PID, DH, etc. Trina Solar has collaborated with a third-party testing organization to carry out a series of toughened tests.

4.1 Mechanical loads:

Uneven snow load

Withstands 2.8 metres of uneven snow loads

Extreme low temperature

-40 ℃ high reliability

Dynamic load fatigue

+1500Pa @20000 times dynamic cycle

Hail test

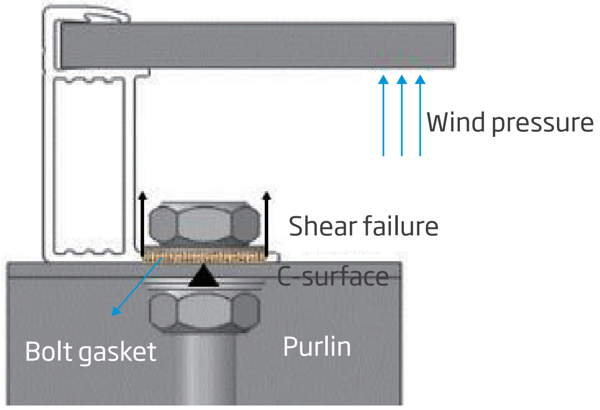
Passed 35mm hail test

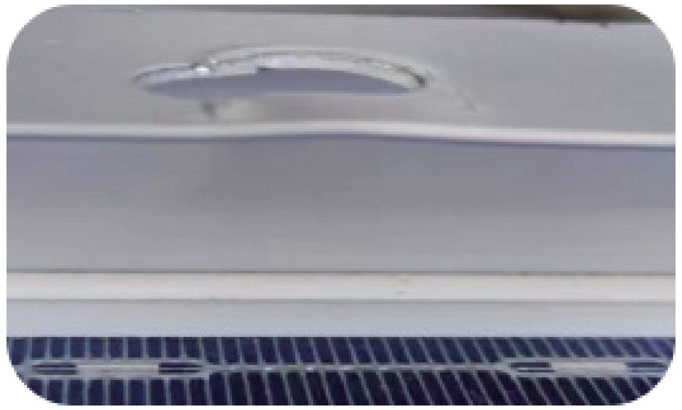
wind tunnel test

Passed category 17 hurricane test

Trina’s Vertex modules have passed five rigorous load tests,which demonstrates that Vertex modules can maintain highly reliable load performance under extreme climatic conditions.

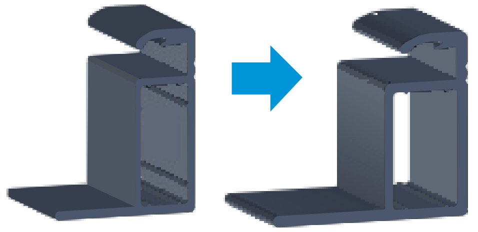
Analysis of modules damage principle under high winds:





For torn edges and loose bolts brought about by windy weather in the marine environment, enhancements were made in the following two aspects:

1) Increase the wall thickness of the modules bezel to reduce the force arm, select appropriate bolt spacers, and install them in strict accordance with the user’s manual to ensure the torque.



Groups	B Height (mm)	C Width (mm)	C Thickness (mm)	C d-length (mm)
210-66	33	28.5	1.8	18.1

2) It is recommended to use anti-loosening bolt to avoid torque attenuation and installation strength degradation caused by frequent vibration of the components under strong winds.

Program	Principle	Picture	Vibration time（S）	Residual axial force/ initial axial force
Metal Locking	Use of interference fit for threads to increase friction		240	98.00%

Strong wind test:

1) Strong wind tunnel experiments with beam screw mounting, 210 large-size modules can withstand wind speeds of over 60m/s.

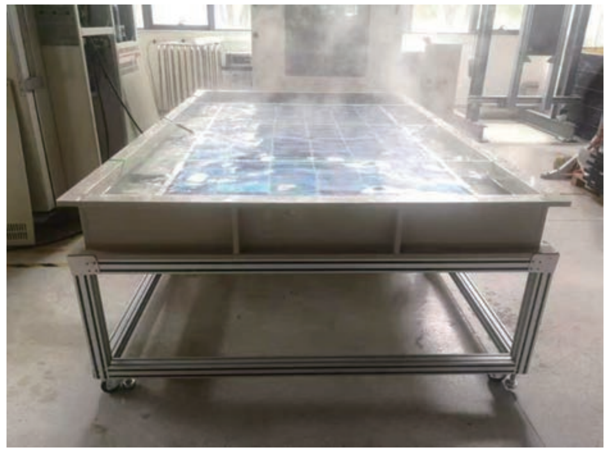
Wind rating	12	13	14	15	16	17
Name	Cyclones	Cyclones	Cyclones	Cyclones	Cyclones	Cyclones
air velocity (m/s)	32.7-36.9	37.0-41.4	41.5-46.1	46.2-50.9	51.0-56.0	56.1-61.2

2) According to the “reliability test requirements of PV modules under the application scenario of flexible stent”, we designed large-size modules with flexible stent simulation excitation experiment: vibration frequency of 6Hz, amplitude of 10mm and 20mm, simulated wind pressure of 1.0kN/m2, the total number of vibrations reaches 2.3 million times of excitation test, and vibration times can be enveloped in 80% of the regions in the country. After 2.3 million times of simulated excitation, the module did not show obvious hidden crack phenomenon. There are no cracks, breaks, tears, etc. in the aluminum alloy frame of the module, while the prestressing cable structure, connectors and bolts of the module are intact.

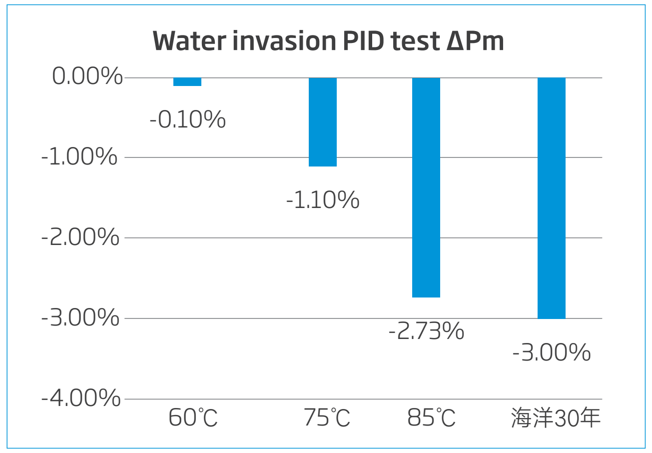
3) Field test base in Jiaxing, Zhejiang: In 2022, after Typhoon Meihua passed,the 210 Modules were intact.

4.2 High temperature and humidity:

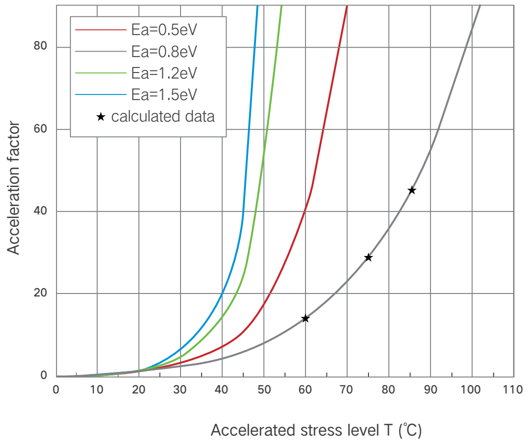
1) Rigorous DH test: Vertex dual-glass module passed DH3000 test. EL is no abnormality, and power attenuation is only 1.31%;
2) Rigorous PID test: Vertex dual-glass module passed the humid-heat-water immersion PID test and was corrected by Arrhenius equation, and the degradation is no more than 3% within 30 years of offshore life cycle.

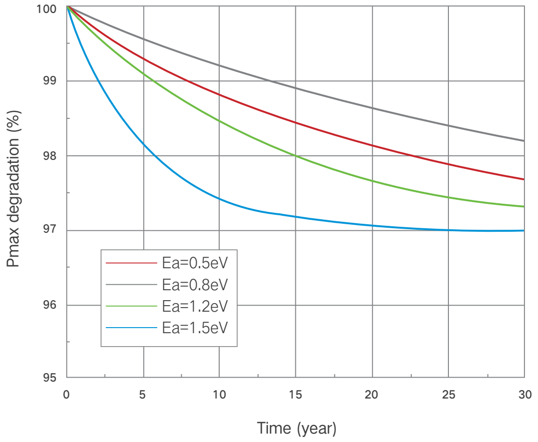


PID test device
（60℃、75℃、85℃，3.5% saline soak PID）



65℃、75℃、85℃，3.5% saline soak
PID power degradation





Acceleration factor simulation

$$AF\left(T,RH\right) = \left(\frac{RH_{试验}}{RH_{实际}}\right)^{n} \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{实际}} - \frac{1}{T_{试验}}\right)\right]$$

$$P(t;temp;H)=P\infty*\{1-\exp(-RU*AF(T;RH)*t)\}$$

4.3 Salt-spray corrosion:

To simulate the ability of PV modules to withstand coastal corrosive environments, international certification bodies use the IEC 61701-2011 & IEC 60068-2-52 standards for testing.

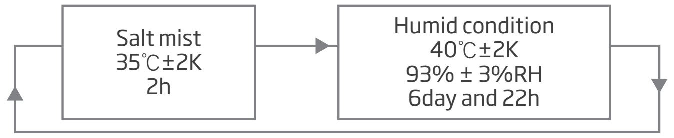
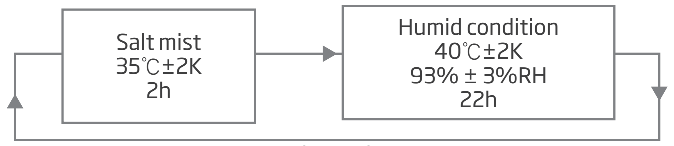
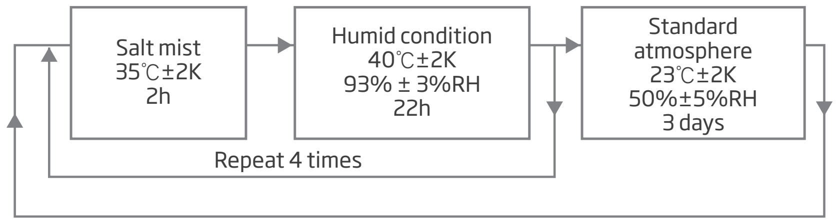
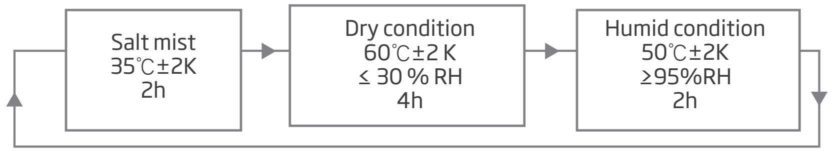
Table A.1 - Simplified guidance for determining corrosivity classifications according to ISO 9223 and test methods correlating to one-year corrosivity based on mass loss of steel coupons

Corrosivity classification of module location	Location characteristics		One-year mass loss range(g/m^2) of bare steel coupons	60068-2-52 test method achieving similar one-year corrosivity
	Distance from saltwater(km)	Percentage Time of Wetness (ToW)		
C1 (testing per this document not necessary)	--	--	<10	none
C2 (testing per this document not necessary)	≥10	<25%	10-200	2,3
C3	≥10 2 to 10	≥25% <25%	200-400	4(14 days)
C4	2 to 10 <2	≥25% <25%	400-650	1(28 days) 5(28 days)
C5	<2	≥25%	600-1500	6(56 days)
CX	offshore	--	1500-5500	7(90 days) 8(70 days)

According to IEC61701-2020 salt spray corrosion test for PV modules, the corrosion conditions CX for offshore environments can be referred to the test methods of Methods 7 and 8.

Refer to the following table for salt spray test methods:

Table 1 - Test cycles for test methods 1 to 8

Test methods	Details of the cyele	Recommended number of cycles
Test method 1	 Salt mist 35℃±2K 2h Humid condition 40℃±2K 93% ± 3%RH 6day and 22h One cycle = 7 days In the case of manual handling, the transition time (max. 2h) should be included in the humid condition period of 6 days and 22 h .	4 cycles (28 days)
Test method 2	 Salt mist 35℃±2K 2h Humid condition 40℃±2K 93% ± 3%RH 22h One cycle = 1 days In the case of manual handling, the transition time (max. 2h) should be included in the humid condition period of 22 h .	3 cycles (3 days)
Test method 3	 Salt mist 35℃±2K 2h Humid condition 40℃±2K 93% ± 3%RH 22h Standard atmosphere 23℃±2K 50%±5%RH 3 days Repeat 4 times One cycle = 7 days In the case of manual handling, the transition time (max. 2 h) should be included in the humid condition period of 22 h and standard atmosphere period of 3 days.	1 cycles (7 days)
Test method 4		2 cycles (14 days)
Test method 5		4 cycles (28 days)
Test method 6		8 cycles (56 days)
Test method 7	 Salt mist 35℃±2K 2h Dry condition 60℃±2 K ≤ 30 % RH 4h Humid condition 50℃±2K ≥95%RH 2h One cycle = 8 h The transition times (time allowed to reach the temperature and relative humidity specified for a condition after changing to that condition) are within 30 min or between 30 min and 60 min from salt mist to dry condition, within15 min or between 15 min and 30 min from dry condition to humid condition and within 30 min from humid condition to salt mist. Those transition times shall be included in next condition period.	3,6,12,30,45,60, 90,150,180 cycles (1,2,4,10,15,20, 30,50,60 days)
Test method 8		

NOTE The ± tolerances given for temperature and relative humidity are the allowable fluctuations which are defined as the positive and negative deviations from the seting of the sensor at the operational control set point during equilibrium conditions. This does not mean that the set value can vary by plus/minus the amount indicated from the given value.

In order to simulate better the corrosion in the actual installation situation, the screw mounting method is used for the alternating salt spray S8 test. Due to the different activities of the aluminum alloy frame, mounting bolts and bracket metal, the connection position is prone to electrochemical reaction (sacrificial anode, cathodic protection) resulting in embrittlement of the mounting holes, reduction of the mounting strength, and corrosion of the bracket to different degrees. Similarly, the same electrochemical corrosion problem appeared in a fishery-photovoltaic power station after 8 years of operation.

	Mounting bolts	**Mounting hole**
Initial Module		
After salty mist S8		
Reference project on the coast (In operation for 9 years)		

Offshore PV has problems of electrochemical corrosion of the frame-bolt connection position, and can be solved from the following two aspects:

1) PV module frame oxide film thickness ≥15μm, PV bracket galvanized layer thickening, mounting bolts with special insulating coating treatment, to avoid galvanic corrosion caused by migration of metal ions in seawater.

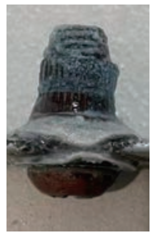
2) After the installation is completed, the connection position is protected by spraying paint and so on.


304 Stainless steel


316 Stainless steel


Aluminium alloy


2205 Duplex steel


Copper alloy


Ni plating


Surface insulation


Hot zincizing + thread glue


Paint film + thread glue


Waterproof cement


Anti-rust + thread glue


Hot zincizing + electrophoresis


PEEK plastic bolts

05

Trina Solar Offshore PV cases

Yantai CIMC Offshore Floating PV Field Test Project

Haiyan,Taishan 100MV Offshore Project

06

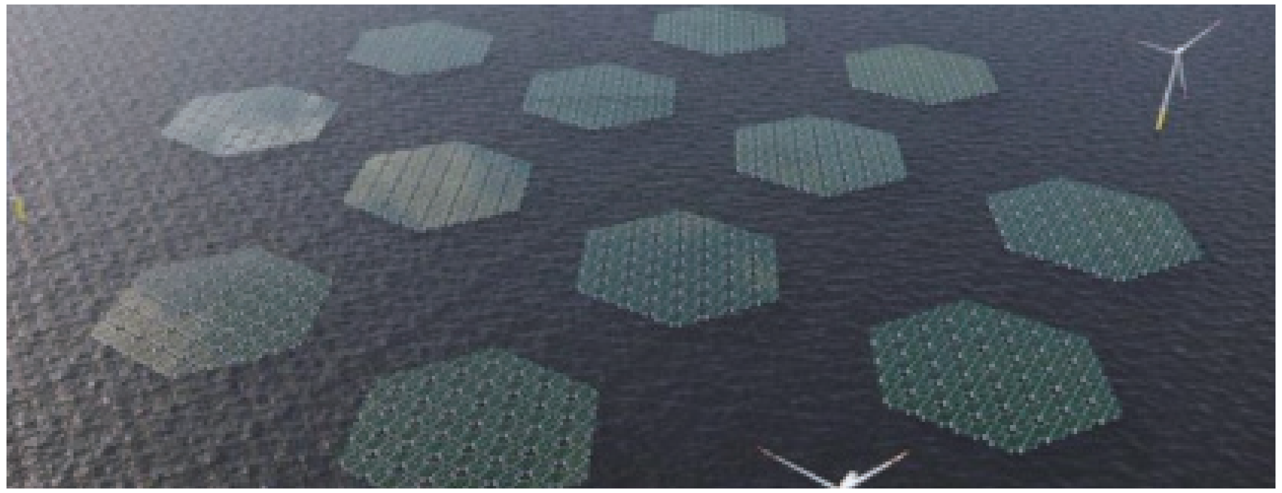
Trends and Prospects of Offshore PV

The Offshore PV functionality will be further enhanced.

Global offshore is growing rapidly, and the growth in market demand has contributed to further reductions in the cost of electricity, and cost reductions are conducive to larger-scale penetration, forming a closed loop of growth. Future Offshore PV will be combined with aquaculture industry, hydrogen production and other industries to maximize the value. In addition, floating photovoltaic does not require complex and time-consuming infrastructure, which is beneficial to the rapid construction of the project, and will become the mainstream of offshore photovoltaic.

Wind-solar combinative power farm will be the main direction for future marine energy development.

Offshore floating photovoltaic can use idle sea space in offshore wind farms; offshore photovoltaic can reuse cables and transmission line equipment with offshore wind power; wind and solar can be effectively realized as complementary from the perspective of resources; offshore photovoltaic can share the piling foundation of offshore wind power and provide more convenient mooring and installation methods; wind-solar combinative power farm can greatly enhance the degree of intensive and economical utilization of resources and increase the output and economic benefit of power generation farms.



The offshore energy island.

The offshore energy island is regarded as the future way of large-scale use of renewable energy, which refers to the inheritance of multiple forms of renewable energy utilization on artificially constructed large-scale offshore fixed or floating structures to form complementary, large-scale power generation advantages. The development of a variety of offshore energy integration on the basis of marine wind and solar complementary, compound use of marine natural resources , the formation of complementary advantages, optimize spatial configuration, improve resource utilization efficiency, promote intensive and economical use of the sea, and promote the integration of technology innovation in the field of marine clean energy.

Offshore PV and hydrogen,ammonia production.

Electricity generated from offshore PV modules will be used in the nearest hydrogen and ammonia production equipment to save power transmission cost.