

TONGWEI CO., LTD.

Photovoltaic Module Operation and Maintenance Manual



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Preface

During the operation and maintenance (O&M) of solar photovoltaic (PV) power plants, PV modules serve as the core components, and their long-term stability directly determines the power generation efficiency and economic returns of the power plant. This manual is designed to provide the customer's O&M personnel with guidelines for routine inspection, troubleshooting, and maintenance operations of Tongwei PV modules, ensuring the safe, efficient, and stable operation of PV power plants.

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<https://en.tongwei.cn/download.html> to obtain the latest version of the O&M manual.

Chapter 1 Routine Inspection Items for PV Modules

1.1 Routine Inspection of PV Modules

PV modules require periodic inspections to ensure that their surfaces, connectors, mounting structures, and other components remain intact and undamaged, thereby preventing system operational anomalies caused by equipment faults. During power plant operation, PV modules shall be inspected regularly for abnormalities and addressed promptly.

If the power plant is equipped with an intelligent monitoring platform, daily automated system-side checks are recommended to monitor module operating status. If abnormalities in branch current/voltage or power/yield are detected (e.g., a branch current or voltage value deviates by more than 5% from the average current or voltage of other branches in the same combiner box; or under identical operating conditions, the power output or yield of a combiner box is over 15% lower than that of other combiner boxes connected to the same inverter), on-site inspection and prompt remediation must be conducted. This chapter outlines common inspection and troubleshooting methods.

1. Surface Inspection:

- Check module surfaces for dirt, bird droppings, tree branches, or other shading obstacles.
- Use a thermal imaging camera to detect hot spots on modules to prevent module damage caused by localized overheating.

2. Terminal Inspection:

- Check whether connectors are loose or scorched to ensure secure electrical connections.
- Inspect junction boxes for signs of deformation, burn marks, or other damages.

- Use a thermal imaging camera to inspect connectors for overheating.
3. **Mounting Structure & Rack Inspection:**
 - Check whether mounting structures and installation systems are secure, and whether bolts and clamps are loose.
 - Inspect racks for corrosion or deformation; reinforce or replace them as necessary.
 4. **Backsheet & Glass Inspection:**
 - Check glass for breakage, cracks, or structural compromises.
 - Inspect backsheets for scratches, burn marks, or aging.

1.2 Troubleshooting Common Module Faults

1. Hot Spot Issues:

- If a hot spot is detected, first clear any shading obstacles, then replace or repair the module as necessary.
- If overheated solar cells are detected via thermal imaging, perform immediate repair or module replacement.

2. Connector Issues:

- Check whether connectors are loose or scorched; tighten loose connections or replace damaged connectors upon identifying issues.
- Measure connector temperature using a thermal camera; replace connectors promptly if abnormal temperatures are detected.

3. Module Damage Issues:

- If module glass is broken or the backsheet is damaged, replace the module promptly to prevent solar cells from being exposed to the ambient environment, which poses electrical safety hazards and compromises power generation performance.

1.3 Troubleshooting Common Non-Module Quality Faults

1. Rainbow Pattern / Iridescence:

Phenomenon: Rainbow-like discoloration visible to the naked eye on the module glass surface under direct sunlight, mostly appearing in strips or patches.



Common Causes:

Surrounding environmental pollution sources, such as chemical plants, steel mills, synthetic fiber plants, etc.

- 1) Foreign object coverage on the module surface, such as windblown debris or uncleaned mud belts accumulating at the bottom edge of modules over long periods.
- 2) Prior use of strongly acidic or alkaline cleaning agents.
- 3) Moisture exposure or rainfall inside packaging containers during transit/storage, or exposure to rain during site installation.

Remediation Plan:

Rainbow patterns cause irreversible optical damage to glass. Increase cleaning frequency during routine O&M and mitigate surrounding environmental pollution sources in a timely manner.

2. Thermal Adsorption / Static Dust Adhesion:



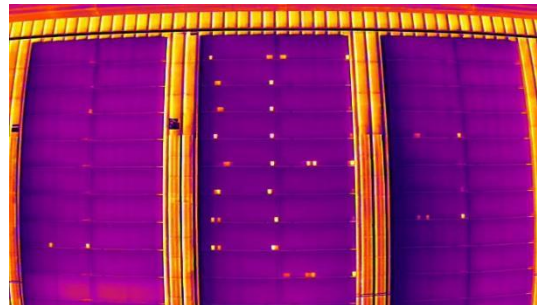
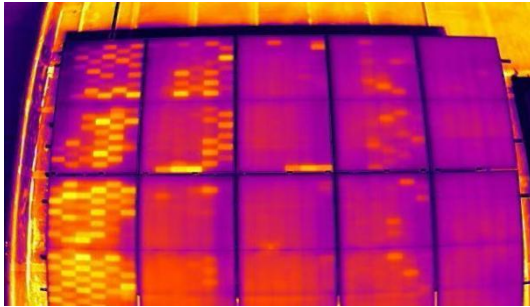
Phenomenon:

Individual solar cells on the module surface display whitish discoloration with severe dirt accumulation that is difficult to clean.

Remediation Plan:

During project design, avoid dust-polluted environments; prior to construction, rectify surrounding pollution sources. If discovered post-construction, modify pollution exhaust vents/outlets and clean the modules. Solvent naphtha/pine solvent may be used carefully for extremely persistent stains.

3. Single-Cell Hot Spot:

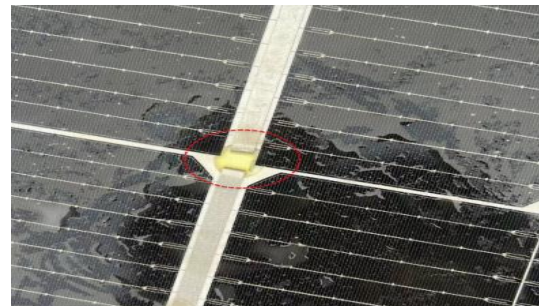


Phenomenon: During infrared thermal inspection, single or multiple cells within certain PV modules exhibit significantly higher temperatures compared to adjacent cells.

Remediation Plan:

Conduct on-site inspections for surface shading obstacles such as bird droppings, edge dirt accumulation, leaves, shading from utility poles or parapet walls, particulate emissions, clamp shading, or mud belts at the bottom edge of modules. For bifacial glass-glass modules, if the rear side is shaded by mounting structure crossbeams, reflected sunlight from the ground onto the rear side will cause shaded cell temperatures to rise, forming localized hot spots.

4. Yellowing of Center Hole:

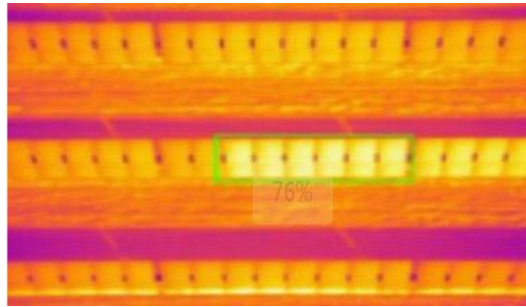


Phenomenon: Yellowing observed at the center hole position on the front side corresponding to the rear junction box.

Remediation Plan:

Center hole yellowing does not affect module performance, power output, reliability, or safety as long as open-circuit voltage remains normal. If open-circuit voltage is abnormal, contact Tongwei customer service personnel for handling.

5. Full-String Hot Spot / String Overheating:



Phenomenon: During infrared testing, an entire module string exhibits significantly higher temperatures compared to neighboring strings.

Remediation Plan:

Generally caused by installation anomalies, such as reversed positive/negative polarity during installation or string loop formation without connecting the DC side to the inverter. On-site O&M personnel must troubleshoot wiring topology and reconnect properly.

6. Inter-Module Color Difference:



Phenomenon: Color variation between adjacent modules observed from specific viewing angles.

Remediation Plan: This is a normal physical phenomenon requiring no action and has no impact on module power output or safety. It is suggested to install modules one by one from the same container.

7. Glass Deflection / Inward Sagging:



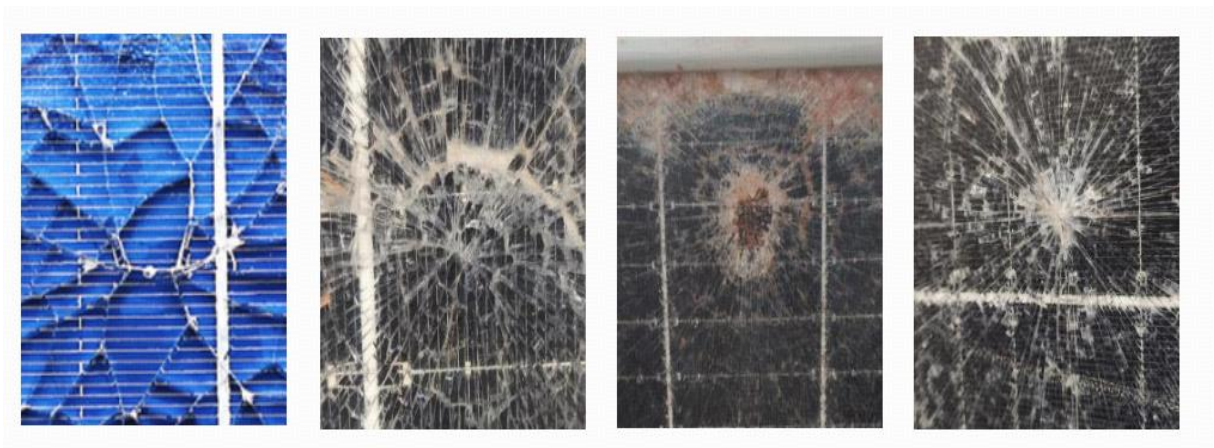
Phenomenon: Slight inward center deflection observed on the module glass from specific viewing angles.

Causes: Slight center deflection due to self-weight is a common phenomenon across the industry. Tongwei has conducted simulation modeling and outdoor empirical field testing, confirming that it does not affect module quality or structural reliability.

Remediation Plan: Tongwei recommends an installation tilt angle of $\geq 10^\circ$, allowing rainwater to wash away surface dust, reducing cleaning frequency while facilitating drainage to prevent water pooling marks that affect appearance and performance. Small tilt angle modules should be installed with drainage and desilting clips to prevent mud belt formation.

8. External Force Shattering:

Single-Glass Module Shattering: Tempered glass shatters under direct mechanical impact, showing white powdery indentations at impact points, typically displaying a radial fragment pattern centered from the impact point outwards.



Double-Glass Module Shattering: Point impact on heat-strengthened glass produces radial fracture lines; surface compression generates "figure-8" or butterfly-shaped patterns; single fracture lines extend internally with slight white specks and missing glass. External forces causing glass bursting include trampling by construction/O&M personnel, flying gravel, sharp metal impacts, hail, transportation collisions, improper handling during installation, and unreasonable rack or clamp installations.



Preventive Measures:

- 1) Conduct regular power plant inspections and replace broken modules promptly.
- 2) Handle modules gently during lifting and positioning to prevent external impacts.
- 3) Avoid trampling on modules during O&M, and guard against flying gravel, sharp metal impacts, and bumps.

9. Lightning Strikes:

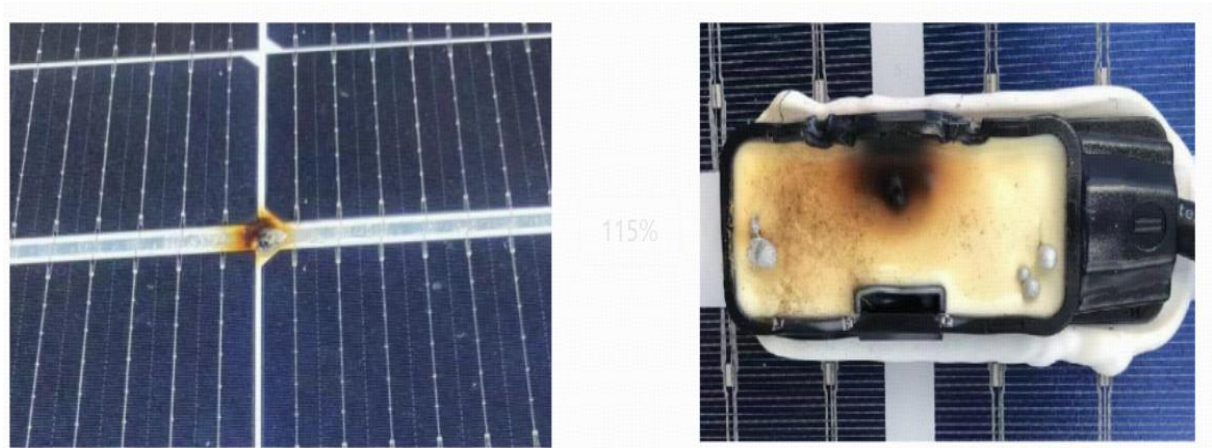
Direct Lightning Strike Phenomenon: Module displays burn-through holes, melted pits, and structural destruction. Confirmed as direct lightning based on weather conditions and failure patterns.



Induced Lightning Strike Phenomenon: Yellowing at the front lead-out hole, confirming a thermal hot spot at the rear junction box; zero or low voltage output; rear junction box deformed, bulged, or cover detached. Upon removing the cover, potting silicone appears yellowed, cracked, with solder beads; thermal anomaly is centered at the diodes. Upon removing silicone, internal busbar-to-ribbon soldering remains intact (no cold solder/defects).

Preventive Measures:

- 1) Periodically inspect equipotential bonding jumpers between module frames and between frames and mounting structures for looseness, rust, or disconnection.
- 2) Periodically test string grounding and grounding resistance; recommended grounding resistance is $\leq 4\Omega$ in general areas, or compliant with standards in high soil resistivity regions.
- 3) Check status indicators of Surge Protection Devices (SPD) on combiner boxes and inverter DC/AC sides (normally green); replace immediately if tripped/red.
- 4) Evaluate or install lightning rods/air terminals in lightning-prone areas to ensure protection coverage over the entire PV array.



Chapter 2 Periodic Inspection and Testing Items

2.1 Periodic Inspection Items

Before commencing inspection work, personnel must wear safety equipment such as insulating gloves and insulating boots. Recommended periodic inspection items are listed below; defects identified during prior O&M/inspections shall also be incorporated into the inspection scope.

The recommended inspection cycle is **once per month** (or shortened based on actual power plant conditions).

2.2 Inspection Items Table

Inspection Item	Inspection Content	Inspection Method & Tool	Remediation / Maintenance Measures
Module Surface Inspection	Check for dust, bird droppings, tree branches, debris, or other shading obstacles. Ensure light absorption is unimpeded.	Visual inspection; clean with a soft brush or compressed air; avoid hard objects.	Use gentle cleaning tools to avoid damaging glass surface; automated cleaning robots may be used.
Glass Breakage Inspection	Check glass for breakage, cracks, scratches, or signs of aging.	Visual inspection.	Replace damaged modules immediately.
Backsheet Inspection	Check rear backsheet for scratches, burn marks, aging, discoloration, or swelling.	Visual inspection.	Replace damaged modules immediately.
Junction Box Inspection	Check junction box for deformation, bulging, burn marks, moisture ingress, or corrosion.	Visual inspection; test voltage and grounding integrity using a multimeter/tester.	Disconnect module connections immediately and replace the junction box if anomalies are found.
Connector Inspection	Check connectors for looseness, mechanical damage, burning, or terminal overheating.	Visual inspection; measure connector temperature using a thermal imaging camera.	Replace damaged connectors promptly and verify connection port temperature with infrared camera.
Mounting Structure Inspection	Check stability of mounting structures, loose bolts, frame deformation, or corrosion.	Visual inspection; verify bolt/clamp torque with a torque wrench; use corrosion tester in high-humidity/high-salt areas.	Tighten loose bolts and clamps promptly; perform rust removal and anti-corrosion coating on severely corroded racks.
Hot Spot Inspection	Check for hot spots; use thermal camera to detect abnormal thermal zones on module surfaces.	Inspect module surface temperature (excluding frame) with thermal imaging camera to pinpoint hot spots.	Perform periodic hot spot checks; clear shading obstacles or replace damaged modules promptly.
Module Grounding Inspection	Check if module grounding devices are functional, loose, or corroded.	Visual inspection; measure grounding resistance with a ground resistance tester.	Ensure grounding resistance meets standards to prevent equipment damage due to poor grounding.
Electrical Connection Inspection	Check cables, wire connectors, and terminal blocks for looseness, corrosion, or aging insulation.	Visual inspection; check electrical integrity using an infrared thermal camera and insulation megohmmeter.	Replace broken, exposed, or aged cable sections promptly.
Lightning & Grounding Inspection	Inspect lightning protection facilities and grounding systems to ensure resistance complies with standards.	Check grounding resistance with a ground resistance tester; inspect SPD condition.	Increase inspection frequency before and after thunderstorm seasons to ensure proper operation.

2.3 Periodic Testing Items

Power plants equipped with professional testing instruments should schedule regular testing by qualified technicians.

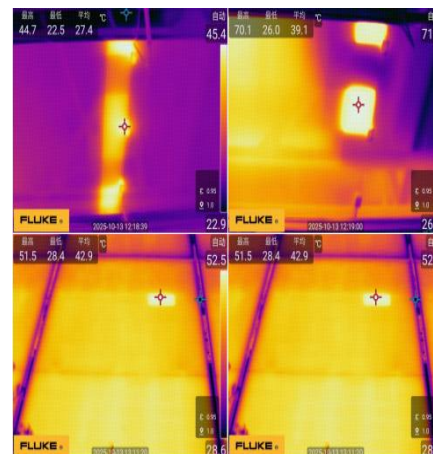
Testing Item	Testing Method	Abnormal Condition	Preventive & Remedial Measures
Module Temperature	Infrared Thermal Camera	Max cell temperature within module $\geq$ average surface temperature (excluding frame) $+40^{\circ}\text{C}$.	1. Check for surface shading; clean per manual. 2. If overheating persists without shading, mark the module and consult Tongwei customer service.
Insulation Test	Insulation Resistance Tester (Megohmmeter)	For Strings: Positive-to-ground or negative-to-ground insulation resistance $< 1\text{ M}\Omega$. For Single Module: For module area $\leq 0.1\text{ m}^2$, resistance $< 400\text{ M}\Omega$; for area $> 0.1\text{ m}^2$, (tested resistance $\times$ module area) $< 40\text{ M}\Omega \cdot \text{m}^2$.	1. Locate substring/area via monitoring platform for field inspection. 2. Perform insulation testing with megohmmeter. 3. Mark defective modules and consult Tongwei customer service. 4. Check for system faults (e.g., damaged cable insulation contacting racks).

(1) Module Temperature Testing Guidelines:

Infrared thermal imaging is typically employed to troubleshoot abnormal module heating. For utility-scale projects, professional drones equipped with thermal imaging cameras can be utilized to improve inspection efficiency.



Hand-on device thermal imaging



Drone thermal imaging



- **Testing Conditions:** The power plant must be grid-connected and operating under irradiance $\geq 600 \text{ W/m}^2$ and wind speed $\leq 2 \text{ m/s}$.
- **Testing Method:** Aim the lens directly at the module under test. Dynamic high/low temperature tracking points must fall entirely within the solar cell region of a single module.
- **Evaluation Criteria:**
 1. Drone thermal imaging currently provides high-temperature spot identification; close-range handheld IR inspection is required for precise temperature differential (ΔT) measurement.
 2. Maximum cell temperature within module $\geq$ average surface temperature (excluding frame) $+40^\circ\text{C}$ indicates an anomaly.
 3. If junction boxes or connectors exhibit abnormal heating, inspect for bulging, loose contacts, or poor connections.
 4. If an entire string overheats, measure open-circuit voltage (V_{oc}) using a multimeter to confirm string anomalies.

(2) Insulation Testing Guidelines:

A portable megohmmeter is typically used to evaluate module insulation performance.

- **Testing Method:**
 1. Wiring: Connect the "E" terminal of the meter to the module frame or grounding line, connect the "L" terminal to the circuit wire under test, and connect the "G" terminal to the protective guard ring to eliminate surface leakage resistance influence.
 2. Range Selection: Select the required resistance range or step up from $\text{M}\Omega$ to $\text{G}\Omega$. Continuous meter alarm indicates low resistance; step down the range accordingly.
 3. Reading: Read resistance values from the $\text{M}\Omega/\text{G}\Omega$ display at 15-second and 60-second intervals following high-voltage output.
- **Evaluation Criteria:**

Test voltage equals system voltage. For string testing, insulation resistance from shorted positive/negative to ground, positive to ground, or negative to ground $< 1 \text{ M}\Omega$ is abnormal. For a single module ($\leq 0.1 \text{ m}^2$), insulation resistance shall be $\geq 400 \text{ M}\Omega$. For a single module ($> 0.1 \text{ m}^2$), (resistance $\times$ area) shall be $\geq 40 \text{ M}\Omega \cdot \text{m}^2$.



Megohmmeter

2.4 Key Inspection Items for Different Power Plant Environments

For different power plant environments, key areas should be inspected as outlined below; please refer to the table for specific inspection items and criteria.

Project Site Type	Site Characteristics	Key Inspection Items	Inspection Method
Rooftop Distributed	Low mounting clearance above roof, restricted rear space, limited rear ventilation/heat dissipation.	• Surface shading • Cable, connector, and junction box condition • Operating temperature • Insulation resistance • Abnormal module troubleshooting	• Visual • Visual • Thermal Camera • Megohmmeter • System Platform
Mountainous / Coastal	High wind loads and mechanical stress.	• Surface shading • Fastener looseness • Frame deformation / tearing • Cable securing stability • Glass breakage / backsheet scratches • Operating temperature • Abnormal module troubleshooting	• Visual • Visual • Visual • Visual • Visual • Thermal Camera • System Platform
Water / Floating / Offshore	High moisture/humidity, severe risk of metal component corrosion.	• Surface shading • Cable, connector, and junction box condition • Frame corrosion • Insulation resistance • Abnormal module troubleshooting	• Visual • Visual • Visual • Megohmmeter • System Platform
High Lightning Activity	Frequent lightning surges and atmospheric discharges.	• Lightning protection device operation • Junction box condition • Insulation resistance • Abnormal module troubleshooting	• Surge Test / SPD Check • Visual • Megohmmeter • System Platform

Chapter 3 Module Cleaning Methods

3.1 PV Module Cleaning

Accumulation of dust, bird droppings, ice, and snow on module surfaces reduces power output. Localized shading can cause hot spot formation; hence, modules require periodic cleaning.

3.1.1 Water and Cleaning Agent Requirements

1. **Water Quality:** Municipal tap water may be used. If alternative water sources are utilized, the following criteria must be met:

pH: 6 – 8

Chloride / Salinity Content: 0 – 1000 mg/L

Turbidity: 0 – 30 NTU

Conductivity: $\leq 3000 \mu\text{S/cm}$

Total Dissolved Solids (TDS): $\leq 1000 \text{ mg/L}$

Water Hardness: 0 – 450 mg/L

Water with high mineral content is not recommended, as minerals will deposit on the glass surface, reducing light transmittance and long-term yield.

- **Temperature Difference:** The temperature difference between cleaning water and module glass must not exceed 10°C . Cleaning is prohibited when ambient temperature is below 5°C to prevent thermal shock glass cracking.
- **Water Pressure:** When using high-pressure water flushes, the maximum water pressure shall not exceed 4 MPa.
- **Cleaning Agents:** Auxiliary cleaning agents (e.g., commercial glass cleaner, alcohol, methanol) may only be used when water alone fails. Strictly prohibit abrasive powders, scouring pads, polishing machines, sodium hydroxide, benzene, nitro thinners, strong acids, alkalis, or harsh chemicals.
- **Prohibited Methods:** Steam jets or corrosive chemical agents must never be used to accelerate cleaning.

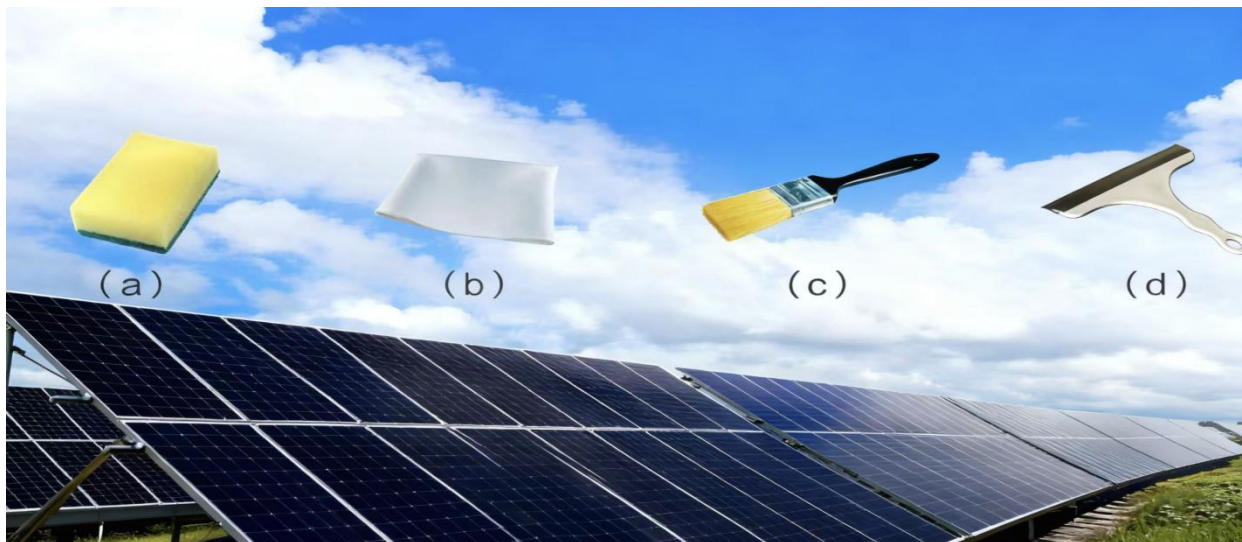
3.1.2 Cleaning Tools & Equipment Requirements

(1) Wear protective cleaning gloves to prevent fingerprint marks; bare-hand contact with module glass is strictly prohibited.

(2) Tools or materials that scratch glass surfaces (e.g., blades, steel wool, or abrasive pads) are strictly prohibited.



(3) Soft foam materials, non-woven fabrics, brooms, soft sponges, and soft brushes (nylon bristles $\varnothing 0.06 - 0.1$ mm recommended) may be used. Avoid using hard/rough sides of sponges.



Tongwei modules support automated cleaning equipment, provided equipment guidelines are followed to prevent structural damage.

3.1.3 Cleaning Precautions

- (1) Clean the rear side of bifacial modules; cleaning the rear backsheet of monofacial modules is not recommended.
- (2) Ensure cleaning water does not splash onto electrical cables or connectors; maintain connectors clean and dry to prevent electric shock or fire hazards.
- (3) Do **not** clean modules with broken glass or exposed wires.

(4) Trampling or stepping on modules during cleaning is strictly prohibited.



(5) Avoid cleaning under extreme weather conditions (heavy wind, heavy rain, or snowfall).

(6) **Snow Removal:** Gently clear snow using a mop or soft broom, avoiding patchy partial snow coverage. Never forcefully scrape frozen ice or frost.

(7) Post-cleaning requirement: Module glass surface must be clean, bright, and free of residual dust or stains.

3.1.4 Recommended Cleaning Procedure

Timing: Clean during early morning, late evening, nighttime, or overcast days (recommended irradiance $\leq 200 \text{ W/m}^2$). Switch off inverter DC switches prior to morning/evening cleaning. Overcast/rainy daylight still generates voltage—exercise caution against electric shock.

Cycles & Zoning: Partition the power plant according to electrical topology (combiner box / inverter arrays).

- Rainy regions: Clean at least once every 40 – 50 days.
- Dry/arid regions: Clean at least once every 20 – 30 days.
- Bifacial module rear side: Clean at least once every 6 months.
- Clean immediately if localized non-uniform dirt shades cell areas.

Cleaning Steps:

- **Step 1:** Dry Sweeping: Remove loose dust and fallen leaves using a dry duster or soft cloth.
- **Step 2:** Spot Scraping: For adhering solids (mud spots, bird droppings, plant sap), gently clean using non-woven cloth or soft brushes without hard scraping.
- **Step 3:** Washing: Spray clean water on dirty areas and scrub gently with brushes. For oily residues, apply isopropyl alcohol, allow penetration, and scrub. Use commercial glass cleaner with non-woven cloth for persistent stains. De-energize bifacial modules before rear-side cleaning, and never wash junction boxes directly with water jets.

3.1.5 Cleaning Requirements in Special Environments

(1) Snow Cover:

Gently remove snow using soft brushes, mops, or leaf blowers. Avoid partial snow coverage ("patchy snow"). Never pour hot water onto cold modules (thermal shock will crack glass). Do not attempt to scrape frozen ice.

(2)Arid & Rainy Regions:

Arid Regions: Dust accumulates across the entire surface. Use high-pressure wash trucks (tangential/normal spray angles) or approved automated cleaning robots.



Humid / Low-Tilt Roofs: Rainwater washes upper surfaces, but lower frame edges collect water and mud belts. Increase cleaning frequency along bottom edges or install automatic drainage/desilting clips.



3.1.6 Post-Cleaning Inspection Checklist

1. Visual inspection confirms clean, bright surfaces free of dirt or water spots.
2. No visible scratches on glass surfaces.
3. No human-induced cracks or glass breakage.
4. Mounting structures are firm without tilting or bending.
5. No component damage (broken glass, cracked backsheet, distorted frame, damaged cables, loose connectors, or damaged junction boxes).

3.2 Clearing Obstructions on PV Modules

3.2.1 Clearing Requirements

1. Prevent environmental shadows (trees, weeds, crops, poles) on working modules to avoid hot spots and power loss. Trim shading vegetation promptly.



2. Comply with local electrical, building, and environmental regulations during vegetation clearing to protect personnel safety and site infrastructure.
3. Avoid clearing operations during severe weather conditions.
4. Remove all cleared branches, weeds, and debris outside the PV array area.
5. Avoid disturbing pile foundations or mounting post stability during vegetation clearing.

3.2.2 Post-Clearing Inspection Checklist

1. Visual check confirms zero shading on front light-receiving surfaces (and minimal rear shading for bifacial modules).
2. Surrounding vegetation height remains lower than the module bottom frame edge.
3. Obstructions are completely cleared from the site and modules remain undamaged.

Chapter 4 Module Fault Handling

4.1 Module Defect Faults

If module defects occur during operational lifetime, refer to the *"Tongwei Photovoltaic Module Limited Warranty"* to request after-sales support. Tongwei will provide technical evaluations and resolution plans according to warranty commitments.

Document download center: <https://www.tongwei.cn/download.html>

4.2 Non-Module Defect Faults

When modules become unusable due to external forces or non-manufacturing factors, decommission them immediately and consult system integration engineers. Scrapping and recycling options include:

- Entrusting licensed e-waste/hazardous waste recycling institutions in compliance with local environmental laws.
- Contacting PV CYCLE for collection if operating within their service territory.

Chapter 5 Safety Management

5.1 Safety Operating Procedures

1. All O&M personnel must wear full personal protective equipment (PPE), including insulating gloves, safety shoes, hard hats, and flame-retardant workwear.
2. A minimum of two operators is required on-site during operations.
3. Ensure electrical equipment is de-energized, isolated, tagged out, and grounded prior to performing electrical O&M.
4. Outdoor high-voltage inspections and operations are strictly prohibited during thunderstorms or extreme weather conditions.

5.2 Fire Emergency Response Procedures

1. In the event of a module fire, immediately switch off the inverter DC-side switch to open-circuit the affected string.
2. On-site personnel must maintain a safe distance to prevent personal injury.
3. **STRICTLY PROHIBIT THE USE OF WATER-BASED FIRE EXTINGUISHERS!**
4. Call the fire department immediately in emergencies and await professional firefighting personnel.

Chapter 6 Spare Parts Management and Tool List

5.1 Spare Parts Management

- Periodically audit spare parts inventory to ensure adequate stock of essential components (modules, junction boxes, connectors, cables, inverters).
- Establish a spare parts management system to track usage logs and ensure timely inventory replenishment.

5.2 Common Tools List

Tool Name	Photos
PV Module I-V Curve Tracer	

EL Tester	
AC/DC Clamp Meter	
Digital Multimeter	
Insulation Resistance Tester	
Grounding Resistance Tester	
Infrared Thermal Imager	

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