भारतीय मानक

Indian Standard

IS 16960 (Part 2) : 2023
IEC 62446-2 : 2020

फोटोवोल्टिक (पीवी) सिस्टम — परीक्षण, प्रलेखन और रखरखाव के लिए आवश्यकताएँ

भाग 2 ग्रिड कनेक्टेड सिस्टम — पीवी सिस्टम का रखरखाव

Photovoltaic (PV) Systems — Requirements for Testing, Documentation and Maintenance

Part 2 Grid Connected Systems — Maintenance of PV Systems

ICS 27.160

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NATIONAL FOREWORD

This Indian Standard (Part 2) which is identical with IEC 62446-2 : 2020 'Photovoltaic (PV) systems — Requirements for testing, documentation and maintenance — Part 2: Grid connected systems — Maintenance of PV systems' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on recommendation of the Solar Photovoltaic Energy Systems Sectional Committee and approval of the Electrotechnical Division Council.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following :

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 62446-1 : 2016 Photovoltaic PV systems — Requirements for testing documentation and maintenance — Part 1: Grid connected systems — Documentation commissioning tests and inspection	IS 16960 (Part 1) : 2018 Photovoltaic PV systems — Requirements for testing documentation and maintenance: Part 1 Grid connected systems — Documentation commissioning tests and inspection	Identical
IEC 62548 Photovoltaic (PV) arrays — Design requirements	IS/IEC 62548 : 2016 Photovoltaic (PV) arrays — Design requirements	Identical with IEC 62548 : 2016
IEC TS 61724-2 Photovoltaic system performance — Part 2: Capacity evaluation method	IS/IEC/TS 61724-2 Photovoltaic system performance: Part 2 Capacity evaluation method	Identical with IEC/TS 61724-2 : 2016
IEC TS 61724-3 Photovoltaic system performance — Part 3: Energy evaluation method	IS/IEC/TS 61724-3 Photovoltaic system performance: Part 3 Energy evaluation method	Identical with IEC/TS 61724-3 : 2016
IEC TS 61836 : 2016 Solar photovoltaic energy systems — Terms, definitions and symbols	IS 12834 : 2013 Solar photovoltaic energy systems — Terms, definitions and symbols	Identical with IEC TS 61836:2007
IEC TS 62446-3 Photovoltaic (PV) systems — Requirements for testing, documentation, and maintenance — Part 3: Photovoltaic modules and plants — Outdoor infrared thermography	IS 16960 (Part 3) : 2020 Photovoltaic (PV) systems — Requirements for testing, documentation, and maintenance — Part 3: Photovoltaic modules and plants — Outdoor infrared thermography	Identical with IEC TS 62446-3:2017

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INTRODUCTION

This Part 2 of IEC 62446 gives requirements and recommendations for the maintenance of PV systems, including periodic inspections, safety and performance related preventive maintenance, corrective maintenance and troubleshooting. Grid connected PV systems are generally considered to be a very low maintenance means of power generation. While this is true relative to conventional generation sources that utilize fuel and/or rotating machinery, PV systems do require some level of preventive and corrective maintenance to perform as anticipated over lifetimes that can exceed 20 years. The level of maintenance required or recommended for performance can vary considerably based on the owner’s preference or contractual obligations for power production; however, a minimum level of monitoring or maintenance is critical for safety and reducing the risk of fire. Adherence to a minimum set of maintenance requirements is also integral to the goals of the IECRE Conformity Assessment system, which is intended to drive the licensing and certification of PV systems and plants from the design to the operations stage.

Indian Standard

PHOTOVOLTAIC (PV) SYSTEMS — REQUIREMENTS FOR TESTING, DOCUMENTATION AND MAINTENANCE

PART 2 GRID CONNECTED SYSTEMS — MAINTENANCE OF PV SYSTEMS

1 Scope

This clause of IEC 62446-1:2016 is applicable with the following exception:

Addition:

This Part 2 of IEC 62446 describes basic preventive, corrective, and performance related maintenance requirements and recommendations for grid-connected PV systems. The maintenance procedures cover:

- Basic maintenance of the system components and connections for reliability, safety and fire prevention
- Measures for corrective maintenance and troubleshooting
- Worker safety

This document also addresses maintenance activities for maximizing anticipated performance such as module cleaning and upkeep of vegetation. Special considerations unique to rooftop or ground-mounted systems are summarized. This document does not cover off-grid systems or systems that include batteries or other energy storage technologies; however, parts may be applicable to the PV circuits of those systems.

This document also does not cover maintenance of medium and high voltage a.c. equipment that are sometimes integral to larger scale systems, as those requirements are not specific to PV systems.

Maintenance of PV systems is often lumped into the catch-all term operations and maintenance (O&M.) This document does not address business or management operational processes (e.g. forecasting, utility pricing incentives, etc.) or other considerations driven by factors outside of basic system working condition, safety and performance.

The confirmation of a system's compliance with the appropriate design and installation standards is covered in Part 1 and takes place during initial project commissioning.

The objectives of this document are to:

- Identify a baseline set of maintenance requirements which may differ by system type (residential, commercial, utility scale), owner, or financing requirements.
- Identify additional maintenance steps that are recommended or optional.
- Identify factors to be used to determine appropriate maintenance intervals.
- Ensure that remote diagnostic methods are allowed as means for periodic verification, problem identification and early failure detection.
- Ensure that alternate means of achieving maintenance related requirements are allowed to accommodate for innovation, manufacturer specific methods, evolving customer requirements, etc.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

This clause of IEC 62446-1:2016 is applicable, with the following exception:

Addition

IEC TS 61724-2, *Photovoltaic system performance – Part 2: Capacity evaluation method*

IEC TS 61724-3, *Photovoltaic system performance – Part 3: Energy evaluation method*

IEC TS 61836:2016 , *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62020, *Electrical accessories – Residual current monitors for household and similar uses (RCMs)*

IEC 62446-1:2016, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 1: Grid connected systems – Documentation, commissioning tests and inspection*

IEC TS 62446-3:2017, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 3: Photovoltaic modules and plants – Outdoor infrared thermography*

IEC 62548, *Photovoltaic (PV) arrays – Design requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 as well as those in Clause 3 of IEC 62446-1:2016 are applicable, with the following additions:

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

Addition:

3.17
support structure
equipment (also known as “racking”) used to physically support modules or groups of modules and position them in a fixed or moving orientation relative to the path of the sun

3.18
equipment pad
foundation typically (but not exclusively) made of concrete or cement used for mounting and securing inverters, disconnectors, transformers, or other equipment associated with a PV system

Note 1 to entry: Equipment pads are typically installed in ground-mount systems, or adjacent to buildings for large rooftop systems where equipment is too large to be wall-mounted.

3.19
combiner box
junction box in which the parallel connections for PV strings, subarrays or arrays are made

3.20
qualified person
person, who has acquired, through training, qualification or experience or a combination of these, the knowledge and skill enabling that person to perform the required task correctly

[SOURCE: IEC 62548:2016, 3.1.7 “competent person”]

3.21
PV array combiner box
junction box where PV sub-arrays are connected and which may also contain overcurrent protection and/or switch-disconnection devices

Note 1 to entry: Small arrays generally do not contain sub-arrays but are simply made up of strings whereas large arrays are generally made up of multiple sub-arrays.

[SOURCE: IEC 62548:2016, 3.1.36]

3.22
balance of system
in a renewable energy system, all components other than the mechanism used to harvest the resource (such as photovoltaic panels or modules)

3.23
lockout/tagout
LOTO
safety procedure used to ensure equipment is properly de-energized and prevented from being re-energized by a locking mechanism until service personnel deems it safe to do so

Note 1 to entry: LOTO is a practice applying to some countries. Different safety procedures, such as the “five safety rules” of EN 50110-1 for Europe, apply in different parts of the world.

3.24
personal protective equipment
PPE
any device or appliance designed to be worn or held by an individual for protection against one or more health and safety hazards whilst performing live working

[SOURCE: IEC 60050-651:2014, 651-23-01]

3.25
authorized personnel
persons approved or assigned by the system owner/operator to perform a specific type of duty or duties for which they are qualified, or to be at a specific location or locations at the installation site

3.26
wiring harness
cable assembly that aggregates the output of multiple PV string conductors along a single main conductor. The harness may or may not include fuse components on the individual string conductors

3.27
central inverter
inverter which has multiple sub-array or array circuits as inputs

Note 1 to entry: Central inverters are large in capacity relative to string inverters. Typical sizes range from 100 kW to 4 MW.

3.28
module-level monitoring
MLM
device or equipment used to monitor power and voltage at the PV module level

Note 1 to entry: Some microinverters and module level d.c.to d.c. converters include such a functionality.

3.29
micro-crack
pressure or stress induced crack in a crystalline PV module cell that is not generally visible to the naked eye

Note 1 to entry: One visible manifestation of micro-cracks is a discoloration effect known in the PV industry as "snail trails." Snail trails result from moisture diffusion through the micro-crack to the cell surface. Subsequent corrosive or chemical reactions cause very noticeable discoloration along the paths of the cracks. Not all micro-cracks result in snail trails, but all snail trails are caused by cracks or micro-cracks.

3.30
data acquisition system
DAS
system for monitoring various PV system parameters, e.g. inverter status, power output, voltages and currents (at array, sub-array, string and/or module level), solar irradiance, temperatures, wind speed, etc.

3.31
shutdown control
automated de-energization of targeted PV array d.c. circuits by either isolation, disconnection, or attenuation of voltage to safe limits

Note 1 to entry: In some countries such equipment is available as "rapid shutdown" equipment for emergency services and is activated by a.c. side system disconnection or other remote control means.

4 System documentation requirements

This clause of IEC 62446-1:2016 is applicable with the following exceptions:

4.1 General

Addition:

Additional documentation should be maintained in support of maintenance measures and activities and should be recorded by maintenance personnel following any inspection, maintenance or repair activity. The date, description of the activity, and any findings should be included in the record.

4.8 Operation and maintenance information

Addition:

h) Monitoring system alarm settings.

i) Schedule of verification and maintenance intervals as determined in 10.2.

j) Evolving site-specific recommendations for periodic or follow-up testing based on findings during maintenance activities, tests, or inspections.

k) As-built construction drawings and an accurate major components list, noting any substitutions, damaged and/or replaced components.

l) A spare-parts list and schedule of replacement for applicable components.

m) Any site-specific recommendations for periodic monitoring and testing for novel experimental components or sub-systems.

n) Schedule of component calibrations, including power and weather monitoring devices.

o) Certificates and dates of component calibrations, or a history of their replacement dates, as applicable.

O&M personnel shall work with the system owner or responsible operator to locate or re-create any missing documentation covered by this list while keeping documentation in a safe and secured place.

Addition:

4.10 Performance benchmarking

System performance benchmarks shall be maintained from test reports conducted according to one or more of the following:

a) Performance related clauses of IEC 62446-1:2016,

b) IEC TS 61724-2,

c) IEC TS 61724-3, and,

d) Any additional performance related testing.

The benchmarking shall be used for comparison with repeated performance checks taken during maintenance procedures called out in IEC 62446-2. Benchmarking information should at a minimum include parameters and information covered by the model PV array test report provided in informative Annex C of IEC 62446-1:2016.

4.11 Documentation of records

Test data and results from the maintenance procedures detailed in Clause 9 of IEC 62446-1:2016 shall be maintained. These records should be used for reference, trending of performance and corrective actions, and for general record keeping in the case of warranty claims or a change of ownership of the system.

5 Verification

This clause and the subclauses of IEC 62446-1:2016 are applicable where specifically called out by the requirements in IEC 62446-2.

6 Test procedures – Category 1

This clause and the subclauses of IEC 62446-1:2016 are applicable where specifically called out by the requirements in IEC 62446-2.

7 Test procedures – Category 2

This clause and the subclauses of IEC 62446-1:2016 are applicable where specifically called out by the requirements in IEC 62446-2.

8 Test procedures – Additional tests

This clause and the subclauses of IEC 62446-1:2016 are applicable where specifically called out by the requirements in IEC 62446-2.

9 Verification reports

This clause of IEC 62446-1:2016 is applicable for specific instances, such as a condition for re-sale or valuation, but is not required on a regular basis.

Addition:

10 Maintenance protocols

10.1 General

This clause describes various maintenance protocols for grid-connected PV systems. These include:

- Periodic verification to determine, as far as reasonably practical, whether the installation and all its constituent equipment remain in a satisfactory condition for safe use. The periodic verification includes inspections and safety-related maintenance testing.
- Recommended periodic performance related maintenance.
- Conditional or condition-based maintenance activities, performed in response to issues or problems detected through monitoring, inspections or testing.
- Administrative maintenance activities – those required by contracts and warranties. This includes preventive maintenance, typically used to describe procedures carried out on a periodic basis to support component life targets.
- Corrective maintenance procedures – the specific mitigating or restorative procedures carried out in response to identified issues.
- Troubleshooting, including generalized measures described in this document, as well as manufacturer specific procedures for individual equipment components.

The intention is that these protocols will be inherently flexible to:

- Allow remote diagnostic methods as means for periodic verification, problem identification and early failure detection.
- Ensure that alternate means of achieving maintenance related requirements are allowed to accommodate for innovation, manufacturer specific methods, evolving customer requirements, etc.

Personnel performing inspections or maintenance of electrical equipment should be qualified and skilled in the procedures and should follow the general guidelines described in Annex E.

10.2 Verification intervals and triggers

Based on the recommendations or warranty requirements of component manufacturers and system integrators, it may be necessary to schedule preventive maintenance activities in advance of detecting a failure in the field, instead of allowing parts to fail. This keeps equipment in superior operating condition while minimizing downtime by scheduling maintenance, ideally during non-production hours, as well as avoiding longer downtime for unplanned repairs. For larger commercial and utility scale power plant systems it is recommended that replacement parts for key components be stored in order to minimize response time. Depending on the manufacturer recommendations and owner/operator preferences, activities may include cleaning/replacing inverter filters, replacing plastic module cable ties, cycling switches, replacing fuses, etc. Replacements made during periodic or corrective maintenance activities shall be made with the same parts or equivalent parts that are pre-approved by the equipment manufacturer or responsible system operator.

Periodic verification and maintenance should be performed at intervals throughout the life of a PV system, and in response to specific triggers. These intervals can vary considerably based on:

– Type of system (ground mount power plant, commercial, residential, etc.).
– Extent of remote monitoring capabilities.
– Contractual requirements or performance guarantees.
– Manufacturer recommended practices for maintenance of specific components.
– Site specific considerations.
– Cost benefit analyses.

NOTE Two IEC publications support the linkage between maintenance activities, system availability, and life-cycle costs, and provide a basis for gathering data in a format to support the various metrices and analyses. See IEC 60300-3-3 and IEC TS 63019.

This document does not specify verification or maintenance intervals given the extensive set of factors that vary by application, site, and owner or operator obligations. However, Table 3 identifies verification tasks at the system and component level and provides guidance for determining verification intervals. The Interval basis column describes specific examples of issues that would justify more frequent verification intervals. For example, systems located at sites prone to flooding or lightning storms should have more frequent inspections or performance verification of particular components.

Table 3 also identifies the relevant clause or subclause in this document describing each of the verification tasks or procedures. Columns “P” and “I” indicate whether the conditional verification tasks are commonly triggered by detected performance issues (“P”), such as low measured output, or specific incidents (I), such as faults or component failures.

Table 3 – Verification and maintenance tasks and basis for determining task intervals

Component/Task		Relevant Clause/ subclause	P	I	Interval basis
Modules					
	Inspect for cracks, delamination, breakage, burn marks	11.3.3	X	X	Areas with high lightning or wind activity, nearby construction activity, aging systems (in case of delamination).
	Inspect for micro-cracks or "snail trails"				Products with history of micro-cracks. Sites with snow and wind driven forces on modules, etc. Impacts may be greater in high humidity areas.
	Inspect for excessive build-up of soil or droppings			X	Where site is susceptible to high levels of soiling, bird droppings, etc.
	Thermal imaging for junction box, cell variations, internal connections, partial operation.	11.3.3	X	X	Can be the default method for large plants (e.g. using aerial imaging). Locations susceptible to lightning e.g. for bypass diode diagnostics, Seasonal bias for testing to ensure high irradiance, e.g. summer.
	Connector checks – visual damage, sample tightness	11.3.4	X	X	Where connectors are aging or exposed to high winds or other sources of movement or strain. Where dissimilar connector manufacturers are used. For sites with atypically high use of field-assembled connectors, or history of issues with field-assembled connectors.
	Imaging of module connectors for resistive, cracked or compromised connections	11.3.4	X	X	Only conditional based, unless system has history of connector problems, and arc-fault connection and/or sensitive ground fault detection is not included.
Array					
	Debris or stored items under array	11.2.1		X	For ground-mounted power plants following construction or substantial maintenance activities. Consider other types of debris that comes from wind or another source.

Component/Task		Relevant Clause/ subclause	P	I	Interval basis
	Animal or pest activity under array	11.2.1			Dependent on site conditions, and whether there is a potential impact on wiring or equipment. May be seasonal depending on the animal, for example nesting in the spring.
	Periodic insulation resistance testing	IEC 62446-1:2016, 6.7	X	X	For systems with functionally earthed arrays, periodic tests at sites where wiring has history or is susceptible to damage, or where testing can be done in conjunction with periodic inverter checks.
	Track shading sources against baseline during commissioning	11.4.3	X		As needed for diagnosing performance problems. Can be useful as preventive measure at sites with adjacent growing trees, and/or with contractual performance, etc.
	String or wiring harness V_{oc} measurements for baseline comparisons	11.4.4.2	X	X	As needed for performance or troubleshooting; or where contractual performance base lining is required.
	String or wiring harness current measurements for baseline comparisons	11.4.4.3	X	X	
	String or wiring harness I-V curve performance baseline comparisons, ID failures	11.4.4.4	X	X	Alternative to string V/I checks; particularly useful for advanced diagnosis of string performance.
	Vegetation management – cutting, removing, control	11.4.5	X	X	Highly site and season dependent, if needed at all. Base on site review or first year(s) operation; for ensuring performance, protecting equipment, or both.
Inverter					
	Visual cues from inverter lights and displays	N/A	X	X	Useful for checking small systems, including by non-qualified personnel, or for troubleshooting
	Inverter enclosure inspection – exterior	11.4.1			Infrequent, or as part of inverter mfg specified intervals. More frequent at sites with corrosive environments.
	Inverter interior (water, dust, rodent)	11.3.1	X	X	Infrequent, except at sites with rodent issues, or with heavy rains, high humidity, flooding, dust exposure, or history of condensation in connecting conduits.
	Inverter interior – torque marks, burn marks on field terminals	11.3.1	X	X	For troubleshooting, and/or as part of inverter mfg specified intervals. May have more frequent intervals in first 1-2 years.
	Periodic maintenance – manufacturer specified	13.4.1			As specified.
Enclosures					
	Electrical enclosure accessibility (secured)	11.2.1			Periodic checks recommended at sites with high exposure or access; schools, public buildings or parks, etc.
	Enclosure corrosion	11.3.2.2			Infrequent, except at sites with corrosive environments.
CBs/Switch disconnectors					
	Check torque marks on field terminations	11.3.2.1	X		Per manufacturer/supplier recommendations. May only be in first year.
	Look for debris, signs of water	11.3.2.3, 11.3.2.4	X	X	At sites where heavy rain or flooding occurs, or considerable wind blown debris. Where conduits are susceptible to high condensation.
	Burn/arc discoloration on terminals, boards, fuse holders	11.3.2.1	X	X	Locations with high lightning activity, or history of similar issues.

Component/Task		Relevant Clause/ subclause	P	I	Interval basis
	Dust deposits on contact surfaces	11.3.2.1		X	Sites susceptible to wind driven dust or other particulates.
	Thermal image inspection for resistive connections	11.3.2.1	X		Climate considerations, where site have high thermal cycling, material expansion properties. If there is a history of issues at the site that warrant inspection.
	Re-torque field or factory terminals as needed	11.3.2.1	X		Per manufacturer/supplier recommendations. May only be in first year. Access to terminations and connections.
	Enclosure corrosion or deterioration, including cabinet, earth connections, hinges and locking mechanisms, etc.	11.3.2.2		X	Locations with high humidity, salt content (by sea), corrosive environments (e.g. chemical or agricultural industries).
	Water intrusion: Seal off or divert source, drain fittings	11.3.2.3		X	At sites where heavy rain or flooding occurs
	Water intrusion: Replace gaskets			X	
	Debris/Rodent: Remove and seal off	11.3.2.4			Sites susceptible to wind-blown debris, or sites with rodent and other pest activity.
	Switch disconnector operation, grease mechanisms, per mfg inst.	11.3.2.5			Per manufacturers recommendations, or based on field performance data.
	Fuse replacement	13.5.2	X	X	Possible replacement due to aging in advance of failure.
Wiring					
	Module/string wiring secure, free of chafing, sharp abrasive surfaces	11.3.5.2		X	Where wiring is exposed to high winds or other sources of movement or strain.
	Module/string wiring no sharp, abrasive surfaces, pinch points	11.3.5.2		X	Where wiring is exposed to sources of movement or strain and is installed along structures and trackers and less in wiring systems.
	String wire tie breakage or damage, impact on conductors	11.3.5.2		X	Where wire ties are highly relied upon for support, loading of cable bundles, or where installed in corrosive or highly humid environments, etc.
	Sub-array cable signs of wear at enclosures, transitions, exposed locations.	11.3.5.3	X		Where sub-array cable bends are tight and/or unusually exposed. (Note outside the table the issue that some intervals should be determined after construction to address installation issues, not necessarily determined in design stage. Also adjustments in the plan due to plant aging.)
	Periodic insulation resistance testing	IEC 62446-1:2016, 6.7		X	For systems that are functionally grounded where the inverter does not provide regular insulation resistance checks: Sites where direct burial cable is deemed more susceptible due to rocky or less filtered soils, where there is history of ground faults, etc.
Wiring systems					
	Conduit/tray support, bushings, gaskets, joints, wear, corrosion	11.3.7		X	Systems with evidence of stress from high loading, choice of materials, margin of design. Systems in high corrosive areas.
	Trays: remove tray covers to inspect arrangements, integrity, rodent/ingress	11.3.7			Systems susceptible to rodent intrusion or excessive movement from thermal expansion or lack of bracing.
	Expansion joints intact (as applicable)	11.3.7		X	Where use of expansion joints is critical to the integrity of the mechanical connections to electrical enclosures. With long runs of conduit or tray without separations.

Component/Task		Relevant Clause/ subclause	P	I	Interval basis
Earthing					
	Earth connections- enclosures, structures, frames, wiring systems, equipment pads,	11.3.5.4			Where connections are susceptible to weakening from wind, corrosion, rodents, dissimilar material degradation, high storm activity, etc.
	Earth system continuity test	12.4			
	Earth connections – retighten or replace	11.3.5.4			
	Conduit or tray fittings and connection strength if used for earth path.	11.3.7			
Mounting system					
	Support structure rust, corrosion, sagging, deformation, breakage, bolt tightness	11.3.6		X	Systems with evidence of stress from high loading, choice of materials. Systems in high wind or corrosive areas.
	Movement due to settling, expansive soils, frost heave, erosion, etc.	11.3.6	X	X	Ground-mounted systems installed at sites with variable soil conditions, or with incomplete structural / soil analysis, or without consideration of the frost line, especially during the first year of operation or a year with extreme weather conditions.
	Corrosion of pier footings	11.3.6		X	Relevant at sites with higher levels of corrosive chemical content in soils, as determined in analyses of soil samples.
	Vegetation interfering with system	11.4.5	X	X	Sites with significant vegetation growth and management requirements.
Tracker					
	Trackers oriented incorrectly	11.2.3	X	X	Performance triggered generally unless there is product or site specific history of issues.
	Periodic maintenance – manufacturer specified	13.4.2			Manufacturer specified, or as deemed necessary due to field history.
Equipment pad					
	Inverter/electrical equipment pad cracking / wear / undermining	11.3.1		X	Most relevant at sites with less stable soils, heavy rain and flood zones, or seismic activity. settling, expansive soils, frost heave, etc.
	Inverter/equipment pad bolts intact (not loose/damaged)	11.3.1			
Roof					
	Adequate drainage, no blockage or pooling	11.2.2			Degree to which rooftops are adequately sloped and consistent for drainage, level of windblown debris from trees or other sources,
	Vegetation growth in roof array	11.2.2	X		Generally dependent on system (product or roof) type and climate.
	Roof penetrations water tight	11.2.2		X	Generally incident triggered but possibly dependent on roof age and strength, or prior history of issues.
	New shade items or maintenance obstacles – e.g. satellite dish	11.2.2 11.4.3	X		Most relevant where tree trimming is required to prevent excessive shading. Satellite or other equipment additions to commercial and sometimes residential systems
Miscellaneous					
	Debris or stored items at inverter location	11.2			Sites with above average construction, upgrade, or other maintenance activity.
	Identify missing, faded or otherwise unusable signs or placards	11.2			High heat and insolation areas, use of lower-quality sign materials, etc.

Component/Task		Relevant Clause/ subclause	P	I	Interval basis
Weather/Data components					
	Sensor alignment, cleanliness, airflow	13.4.3	X		Dependent on performance tracking requirements, site conditions of soiling, debris, etc.
	Periodic maintenance for DAS	13.4.3			Manufacturer specified or based on field history.
	Periodic calibration	13.4.3	X		Manufacturer specified and as required for performance tracking objectives.
Array cleaning					
	Array / module cleaning	11.3.6	X		Cost/Benefit analysis driven, considering site conditions, levels and types of soiling, seasonal impact on performance, cost of cleaning, etc.

Annex F provides an example maintenance interval table for a site with multiple issues that drive an increased frequency of verification tasks. The example provides additional guidance for determining intervals but should be considered rather extreme. Most systems should not require such frequent intervals for many of the tasks.

10.3 Other considerations for determining specific verification intervals

There are a number of other factors that influence how verification tasks are scheduled or prescribed:

a) Some verification tasks can be performed by non-qualified personnel, such as system owners (and homeowners) who have routine access to monitoring systems or can visually identify an issue without physically interacting with the system. In such cases, this ability can reduce the need for proactive involvement by professional or otherwise qualified maintenance personnel.

b) Task intervals can be coordinated or adjusted to coincide with other activities, for example if qualified personnel are on-site already for other troubleshooting or inspection tasks.

c) The presence or degree of electrical protection devices can influence verification intervals. For example, systems with functioning arc-fault detectors may require fewer inspections of wiring connections and terminations. Similarly, systems that are not functionally earthed and that are continuously monitored by an RCM in accordance with IEC 62020 or an IMD in accordance with IEC 61557-8 do not require periodic insulation resistance measurements.

11 Verification tasks

11.1 General

This clause describes visual and hands-on inspection tasks for a PV system and its components. Personnel should use checklists to ensure that the inspections are thorough and complete. For very large systems, these verification tasks can be performed on a representative sample of the equipment. Where conditions vary throughout a site, the sample should include sub-samples from the various locations. For low voltage installations, inspection shall precede electrical testing and should be done to the requirements of IEC 60364-6.

11.2 General site visual inspection

11.2.1 All systems

a) confirm electrical enclosures are only accessible to authorized personnel, are secured from opening by tools or locks, and have restricted access signage;

b) check for corrosion on the outside of enclosures and the support structures;
c) check for cleanliness throughout the site—there should be no debris under the arrays, in the inverter equipment pad area or elsewhere; there should be no stored items under arrays. These obstructions can impede airflow and associated cooling of the equipment. No flammable items should be stored on or around inverters, to minimize fire risks.
d) check for signs of excessive vegetation, and animal or pest activity under the array.
e) check for robustness of wire management means in critical locations of the system where wire management failure can result in outages.
f) inspect for warning placards including arc flash or PPE requirements for accessing equipment. Comply with all warning placards. Document any missing, faded or otherwise unusable placards.

11.2.2 Rooftop systems

a) check for vegetation growth or other new shade items, such as a satellite dish on rooftop systems;
b) inspect roof penetrations for signs of water ingress, if applicable;
c) ensure drainage is adequate, drains are not clogged, and confirm that there are no signs of excessive water pooling in the vicinity of the array;
d) confirm expansion joints in long conduit runs are meeting design expectations and conduit joints are not showing signs of wear or stress.

11.2.3 Ground-mount systems

a) check for ground erosion near the footings of a ground mount system, or structural corrosion;
b) check for weeds or vegetation adjacent to or beneath ground-mounted systems that are interfering with the modules, wiring, or enclosures;
c) for systems employing trackers, look for any individual trackers that are not oriented in the general direction of the surrounding trackers.

11.3 Component inspection and safety related maintenance

11.3.1 Inverter and main electrical equipment pad

Inspect the inverter/electrical equipment pad in outdoor installations to make sure it does not show excessive cracking or signs of wear or undermining through erosion or animal activities. The inverter should be bolted to the pad at all mounting points per the manufacturer installation requirements. Check for loose or damaged bolts. Depending on the size, location, and accessibility of the system to unqualified personnel, the inverters, combiner boxes, and disconnect switches should require tools or have locks to prevent unauthorized access to the equipment.

Perform a visual inspection of the interior and exterior of the inverter. Look for signs of water, rodent, or dust intrusion into the inverter. Check that fans and ventilation passages are unobstructed and clear. Check for torque marks on the field terminations. See 13.4.1 for inverter manufacturer specific inspection instructions.

11.3.2 Combiner boxes, disconnects and isolators

11.3.2.1 Electrical connections

Open combiner boxes and accessible disconnector enclosures and check that any torque marks on the connections are aligned. Look for debris inside the boxes and any evidence of damaging water intrusion. Look for potential arcing discoloration on the terminals, boards, and fuse holders. If the torque-mark line between the lug and the housing is separated, the lug has moved and needs to be re-torqued. Connections shall always be torqued according to manufacturer specifications using a torque wrench or torque screwdriver which provides indication of the torque force applied.

Combiner box fuse holders often use screw terminals for connections to the field string wiring (performed by installers) and to internal busbars (performed in manufacturing). The integrity of both the field and factory connections should be checked and periodically tightened. Factory connections may be jarred during shipping or installation, and therefore are equally susceptible to loosening over time.

Other connections using small lugs or screws are not practical for torque-marking. These or a sample thereof should also be periodically checked with torque wrenches or torque screwdrivers.

Look for deposits of fine dust on contact surfaces that could reduce the effective electrical spacing. Thermal imaging may also be used to look for heated (resistive) connections caused, for example, by loose terminations, poor switch contacts, or inadequate spacing between components.

11.3.2.2 Corrosion or deterioration

Enclosures should be checked for signs of corrosion or deterioration. Metal enclosures with corrosion may have their earth-system connection compromised over time or may lead to excessive water, debris or rodent ingress. Non-metallic enclosures may deteriorate over time due to exposures to the elements resulting in ingress issues or loss of mechanical or structural integrity. Hinges, locking mechanisms and interfaces may require additional scrutiny. These issues can subsequently lead to electrical failures of the equipment inside.

Low levels of corrosion may be contained with cleaning and an application of sealants that prevent further oxidation. Other measures may be employed to patch trouble spots in different enclosure types. Significantly degraded enclosures should be replaced.

Check for significant degradation of polymeric based handles or knobs used with disconnectors, switch disconnectors or isolators.

11.3.2.3 Water intrusion

Water intrusion may occur due to cabinet integrity failure, cabinet condensation, or condensation from connected conduits. The path of collected water/humidity can reduce spacing or introduce new conduction paths. Cabinets should be checked for the existence of water or water line marks at the bottom of enclosures. If present, the source of the water should be identified, sealed off, or diverted. One or more additional weep holes may be used with proper fittings and manufacturer approval to drain any subsequent water intrusion. Maintaining the integrity of the intended enclosure IP rating while preventing water accumulation is a critical step for preventing faults and fires.

Check for robustness of door gaskets, which can be vulnerable to premature wear-out in outdoor environments. If significantly degraded, the gaskets should be replaced.

11.3.2.4 Debris or rodent intrusion

Cabinets may also have debris build up over time or rodent and insect intrusion depending on field conditions. Checks should be made to identify and seal off any entry points, and any existing debris should be removed.

11.3.2.5 Electromechanical mechanisms

Disconnectors, isolators, circuit breakers, and other electromechanical protection and control components may need maintenance (e.g. annual opening/closing operations, greasing of the operating mechanism, etc.). Component checks, verification, maintenance and any applicable corrective actions shall be performed according to the device manufacturers' instructions.

11.3.3 Modules

Inspect PV modules or sample PV modules for defects that can appear in the form of burn marks, distortions, micro fracturing (“snail trails”), discontinuity or separation between glass and frame, discoloration, delamination, or broken glass. Check modules for excessive soiling from dirt build-up or animal droppings.

Thermal imaging may indicate problems within the modules, such as reverse-bias cells, bypass diode failure, solder bond failure, loose terminal connections, or other poor internal connections. Temperature variations may be evident in operating, partially operating and non-operating PV modules. Recommended procedures for thermal imaging as well as guidance on the magnitude of temperature variations are found in IEC TS 62446-3.

Where available MLM may be used to detect under-performing modules. Deviations in power and voltage indicate problems that should be investigated further, for example with thermal imaging. Some module problems are intermittent. Where MLM is available, the data history (warnings, alerts) may also be checked.

Modules should be replaced if they have broken glass, separated components, signs of arcing or burning, cracked cells (i.e. significant visible cracks with associated corrosion or obscuration of the cell), pinched pigtail cables, or if they show signs of leakage paths into structure, or exhibit signs of heat damage on the backskin, junction box, or terminations.

Modules should also potentially be replaced under manufacturer’s guidance for the following conditions: Significant cell or busbar discoloration that stands out from neighbouring cells and modules, visible delamination creating a moisture path or shading the cell, cracks removing significant active area from a cell or cells, or suspected low power from other causes.

NOTE See IEA PVPS Task 13 publications for useful information on module failure checklists, documenting and reporting.

11.3.4 PV connectors

Properly specified and installed PV connectors generally do not lose connection integrity but failures in these connections are one of the leading causes of series-arc related failures and fires in PV systems.

Connector failures occur due to a variety of reasons:

a) imperfect matching of different connector manufacturers or parts;
b) improper installation (e.g. improper clamping of field-assembled connectors);
c) improper connection with mating connector, e.g., not fully engaged;
d) excessive pull or bending stress on the wire-connector connection, leading to loosening connection or water ingress into the protective jacket (e.g. from loose-hanging wires, from taut wires, from wires exceeding recommended bend radius);
e) the presence of dirt, oil or other debris that compromises the connection which may not immediately be apparent without close inspection;
f) temperature cycling;
g) frost;
h) presence of lichens or fungus;
i) manufacturing defects and excessive current cycling due to shading;
j) corrosion due to wet conditions prior to initial connection.

Periodic inspections on a sample of connectors should include tightness checks and visual checks for any signs of thermal damage, corrosion, or ingress. Thermal imaging devices can also be employed to scan across connections in an array to look for overly resistive connections.

11.3.5 Wiring

11.3.5.1 General

PV system wiring typically involves multiple sections of cable run within arrays outside of conduit, cable trays or other enclosed wiring systems. It may also involve transitions between moving (tracking) mounting systems and fixed trays or support structures. Careful attention therefore shall be paid to the inspection and maintenance of the wiring. Any degrading labels or markings required for future maintenance should be replaced.

11.3.5.2 PV string, sub-array and array conductor integrity

PV string conductors between modules and routed to combiner boxes should be inspected for signs of insulation wear and nicks along the routing path. Special attention should be paid to areas where single or bundled conductors encounter corners or edges of support structures, cable management assemblies, or moving members on tracking systems. Look for pinched cables and route away from pinch points. Look for abnormal twist in cable and relieve the twist. Attention should also be paid to abrasion from surfaces such as roofing shingles.

The integrity of array cable securement should be inspected and corrected as well if needed. For example, non-metallic wire ties that have broken, show significant aging, or are otherwise approaching end-of-life should be replaced. Metallic wire ties may move over time and become sharp, thereby causing insulation damage. Wire clips or guides should be checked for integrity and also to ensure they are not causing any insulation damage. Further check for any conductors that are improperly secured and susceptible to rubbing, chaffing or unintended movement from wind, snow, ice, rain or thermal expansion or contraction. Verify that there is not excessive sagging or movement of cables that could lead to failures.

11.3.5.3 Sub-array and array conductor integrity

Conductor sheaths should be inspected at conduit and enclosure transitions for signs of movement wear, stress against the conduit or fittings, or damage from rodents. Additional conductor protection or replacement should be considered if there is evidence of excessive or increasing wear over time. Verify critical spacing between wiring of different voltage classes (including a.c and d.c.) and spacing created by use of wire ties or other wire management are maintained.

11.3.5.4 Equipment earthing and bonding

Equipment earthing (grounding) connections in or on enclosures, mounting structures, conduits or trays, module frames, equipment pads, etc., should be visually inspected for signs of deterioration, corrosion, torque-mark slip, etc. Connections should be re-tightened with proper torque wrenches or replaced as needed.

11.3.6 Mounting system

Inspect support structures for defects including rust, corrosion, sagging, geometric distortion, and missing or broken clips or bolts. It may be desirable to verify the torque of a sample of bolts to confirm tightness, especially if shifting is suspected. In roof-mounted systems, check the integrity of the penetrations, or movement of ballasts. In ground-mounted systems, look for signs of corrosion of metal, fatigue or deterioration of wood or other materials, especially where earth contact is made and where moisture, snow or ice can back up or have their flow impeded. In tracking systems, additionally check the alignment and any other manufacturer-recommended items.

For locations where the ground can freeze, the depth of the frost line relative to the depth of foundations for ground-mounted systems may result in movement of the structural supports. Soil studies conducted prior to the PV installation may be useful for determining whether frost heave was considered during the design stage. In some locations with variable soil conditions or topography, multiple samples may have been required. During the initial year of operation, it is valuable to verify the study was conducted and the recommendations implemented.

Especially after the first freeze-thaw cycle, it is recommended that the site be examined for evidence of moment of the structural supports due to ground movement. Similarly, it is recommended to examine the system for settling of the structural supports due to uneven soil conditions and/or expansive soils. This is especially important for warranty claims and to avoid further damage to the system.

11.3.7 Conduits and cable trays

Inspect conduits and cable trays for proper support, bushings, damaged gaskets, and expansion joints, where needed. Inspect for excessive wear, cracking, corrosion or other deterioration that could reduce the mechanical protection to the cables. Inspect for excessive sag of the cable tray and address with additional supports if necessary. Inspect for loose fittings, particularly if used as an earthing path. Remove lid from cable trays and inspect cable arrangements, cable integrity, excessive ingress of plant or other material, and for any evidence of rodent activity. Infrared imaging may be useful if the cables are not directly accessible.

11.3.8 Weather station

If a weather station is present, ensure that the sensors are in the correct location and alignment (tilt and azimuth). A global horizontal irradiance sensor should be flat, and a plane of array irradiance sensor should be installed to the same pitch and orientation as the array. Irradiance sensors should be cleaned periodically to remove dirt, bird droppings or other sources of soiling. Ambient temperature radiation shields may also need cleaning to ensure adequate airflow for the temperature sensor. Routine sensor calibration, verification, or replacement ensures accurate readings.

11.4 Performance related maintenance

11.4.1 General

Performance related maintenance refers to specific testing or maintenance procedures used to ensure the system is generating the maximum possible energy for its design, installation conditions, location, and age.

NOTE O&M organizations may have financial incentives to not only ensure baseline performance expectations but to improve performance beyond those of baseline expectations.

11.4.2 Wiring connection resistance

The safety related verification steps described in 11.3.2 are relevant also to performance related maintenance since excessive resistance in connections results in unnecessary electrical losses that detract from the overall system production.

11.4.3 Shade evaluation

A verification of the as-built shade conditions is critical to assessing the ongoing performance of a PV system relative to expectations. Where sites are impacted by trees, vegetation or other shade sources that may vary over time, a shading record should be created during commissioning (according to IEC 62446-1:2016) and used as a baseline for comparison to conditions assessed during maintenance visits. More commonly, such an evaluation will be triggered by a measured reduction in performance. Follow the procedure described in 8.4 of IEC 62446-1:2016 to record existing shade conditions for comparison.

11.4.4 Module string or wiring harness testing

11.4.4.1 General

Module string or wiring harness voltage and current tests are made during commissioning and baseline values are recorded for future comparisons. String or harness testing is mostly predicated by performance reduction triggers. Periodic string testing may be conducted if needed for performance tracking. Testing may be performed on all strings (or harnesses), or a subset sample.

Systems incorporating MLM may use the module level recorded data as a substitute for the string or wiring harness testing described in this subclause.

NOTE Data that is continuously tracked via MLM can provide immediate indication of performance deviations during system operation, whether caused by the modules or the module level power electronics themselves.

11.4.4.2 Voltage check

Perform open circuit voltage (V_{OC}) measurements to check that module strings or harnesses are still correctly wired and balanced or to identify loss of a module due to shorted bypass diode or other problem. Tests should be conducted according to 6.4 of IEC 62446-1:2016, or as part of I-V curve testing described in 7.2 of IEC 62446-1:2016.

Where available, MLM capable of recording module open circuit voltages may be used in place of the tests described in 6.4 of IEC 62446-1:2016.

11.4.4.3 Operational current check

Perform string or wiring harness operational current tests according to 6.5.3 of IEC 62446-1:2016.

Measured values should be compared with the expected value from baseline measurements. Where there are stable irradiance conditions, measurements of currents in individual strings or wiring harnesses shall be compared. These values should be the same (typically within 5 % of the average for stable irradiance conditions).

Where available, data recorded from MLM to compare the power of individual modules during normal operation may be used in place of the tests described in 6.5.3 of IEC 62446-1:2016. Where a performance deviation is detected, check the performance of both the electronics and the modules. Where MLM data is used for comparisons, consistent time-stamp information is needed to ensure the stable irradiance condition requirements are met.

NOTE MLM may reveal individual underperforming modules in a string that may otherwise be undetected by string current measurements alone.

11.4.4.4 I-V curve testing

String or wiring harness I-V curve testing is recommended for systems that do not incorporate module level electronics (microinverters or d.c. to d.c. converters). I-V curve tests can provide the following information:

- Measurements of open circuit voltage (V_{oc}) and short circuit current (I_{sc})
- Measurements of max power voltage (V_{mpp}), current (I_{mpp}), max power (P_{max}), and Fill Factor (FF)
- Measurement of string / harness / array performance
- Identification of module / array defects or shading issues

I-V curve tests should be periodically conducted as part of performance related maintenance to identify module component failures or excessive production degradation.

I-V curves should be taken according to the procedures described in 7.2 of IEC 62446-1:2016.

String I-V curve testing should not be performed on systems with module level electronics unless approved by the manufacturer. Where approved, manufacturer instructions should be followed to ensure proper procedures and interpretation of results. I-V curve recordings on modules with power electronics may differ substantially depending on the direction of the measurement (e.g. from V_{oc} to I_{sc} or from I_{sc} to V_{oc}) or depending on the type of load used by the I-V curve device.

Where available, MLM can be used in place of I-V curve tests to reveal most of the issues that would ordinarily be revealed in an I-V curve test.

11.4.5 Vegetation management

Vegetation management is particularly important in ground mount systems but is a consideration for all PV systems. Vegetation can grow into and cause problems with trackers, can cause problems with array wiring, and can cause shading, which will impact production but could also cause damage to the system. Vegetation should also be controlled around the inverter equipment pad and other areas where electrical equipment is present.

a) Mowing or weed trimming vegetation around a ground mount can lead to problems if the mowing or weed trimming kicks up debris that can break the glass or cause general soiling that result in underperformance. Wiring shall be protected from damage.
b) Poisoning weeds can lead to environmental and health problems.
c) Permanent control at the time of installation is an ideal way to deal with vegetation management, by denying plants access to nutrients, water, or light. Some measures may be taken after the fact, such as adding a thick layer of gravel or mulch on the ground to deny sprouting seeds access to light.
d) During inspections, note the amount of vegetation growth and document it through pictures.
e) Work with the site owners to come up with a specific vegetation management plan that involves carefully removing or cutting back vegetation that is currently shading or will eventually grow to shade parts of the array.
f) Many non-toxically treated forms of vegetation can be controlled by the use of grazing animals as an alternative to herbicides. However, animals may damage modules or wiring if not properly anticipated.
g) Large rooftop systems can experience a build-up of dust or detritus which can support plant growth. This should be considered in any vegetation management plan. Birds are the primary vector for seeds and organic material, so addressing the issue of bird populations as described in 11.4.6 is contributory to reducing vegetation in the nooks of rooftop arrays.

Personnel performing vegetation management should be alert to the possible presence of snakes, spiders, bees, and other venomous animals.

11.4.6 Soiling and array cleaning

Soiling reduces the energy output of the PV array, and can lead to localized hot-spot failures if the soiling is uneven. Care shall be taken with array cleaning to avoid damaging the components. Follow the PV module manufacturer's recommendations with any array cleaning.

In the case of uniform soiling, a local, site-specific cost-benefit analysis should be performed to determine whether routine cleaning of the array is warranted. A cleaning regime may not be required at all if the climate and rainfall at the site adequately prevents accumulation. Where cleaning is determined valuable, the frequency determined may be seasonal, depending on local rainfall and dust characteristics.

Efforts should be taken to reduce uneven soiling, for example from bird droppings or the accumulation of material at the lower edge of tilted modules.

Cleaning may be on a defined interval or "condition based," and the impact of soiling can be measured by instruments to trigger a cleaning (for example a sensor with and without a shutter of soiled glass).

Soiling and resulting cleaning regimen depend on local sources of matter. A sample swabbed from the PV module surface can be taken to an analytical laboratory to ascertain its origin. Sources of soiling that may indicate the need for a cleaning regimen include:

a) Agricultural dust: cleaning can be scheduled following plowing. In parts of the world without active soil conservation, persistent dust can require frequent cleaning.
b) Construction dust: cleaning can be scheduled after completion of nearby construction. Encourage construction manager to implement dust suppression.
c) Pollen: schedule cleaning after end of pollen season.
d) Organic matter: growth such as lichen or algae in wetter climates may require more frequent and/or specialized cleaning approaches.
e) Bird droppings: Cleaning may be required where significant bird populations exist. Additional mitigation measures may be taken to reduce droppings, such as use of bird-slides, netting, spikes, or plastic owls or falcons.
f) Diesel soot: present in cities and concentrations such as bus depot and may require frequent cleaning.
g) Industrial sources: Processes such as cooking or manufacturing can be sources of array soiling. This can be identified by testing samples of the dirt.

Clean PV modules and array equipment using cleaning solutions, tools, and methods that comply with specific requirements and instructions provided by module and component manufacturers, including for racking, wiring and wire-ties. Where guidance is not provided by module manufacturer instructions, the following guidelines should be considered:

h) Use plain water, with detergents, oxidants or surfactants used only if needed to remove oily or organic dirt. Bleach or environmentally damaging chemicals should be avoided to minimize environmental impact.
i) Minimize water consumption and chemical overspray and run-off.
j) Sprayers are recommended to be low pressure, e.g. < 1 $MP_{a.}$
k) The cleaning solution used should be documented either by chemical formula and concentration or manufacture and product name.
l) Where possible, avoid acidic cleaning agents or water with pH levels outside of the range from 6 to 9.
m) Dissolved minerals such as calcium and magnesium increase the hardness of water, reducing the effectiveness of the detergent and leaving spots. Consumption of detergent is minimized if the hardness is less than 20 mg $CaCO_3$ per litre.
n) Use only brushes or strip washers specified by the PV module manufacturer for manual and robotic cleaning systems. If not specified, choose a soft material (such as split microfiber) and consult the module manufacturer to ensure the material is safe for the PV module glass coatings. Make sure that dirt held by the cleaning brush does not go on to scratch modules.
o) Cleaning should occur in low irradiance conditions to avoid possible damage to hot modules or from partial shading, and to avoid lost production.

NOTE Machine-mounted or robotic cleaning systems are available for large systems.

Array design can increase or decrease snow accumulation. Clearance avoids wind-driven drifts and allows snow to slide off. Snow generally slides off steep arrays, but does not slide off low-sloped arrays. Snow removal is generally not recommended, but it is sometimes required to reduce snow weight on a roof or to remove ice-dams. Snow removal by use of a powerful turbo-fan is effective for powder or dry snow, and in such cases preferable to a shovel or other mechanical means.

Unexpected localized snow accumulation caused by wind or other factors can occur over time. Check modules for breakage and PV structure deformation in these areas. In some cases structural reinforcement may be required.

12 Troubleshooting and corrective maintenance

12.1 General

Failures in a PV system generally give some indication of a cause or source. If the symptom of a problem is known but not the root cause, troubleshooting steps shall be taken to identify the problem. Once determined, corrective maintenance procedures can be performed to mitigate the problem or failure and prevent re-occurrence. The appropriate mitigating procedure contained in this document or from specific component user manuals should be followed.

Corrective maintenance may take place during regularly scheduled maintenance visits or, depending on the importance, may take place as an unscheduled procedure. Safety related failures may pose a persistent or critical danger and demand an immediate response. Repair times for performance or non-critical issues (posing no danger or reduction of safety) are conditional with respect to owner requirements, contractual requirements, etc., and may largely be driven by cost-benefit analyses such as those recommended for array cleaning,

12.2 Shutdown of equipment in response to hazardous failures

In the event that any corrective action is in response to a safety or fire-related hazard that is on-going, personnel shall follow emergency shut-down procedures. Project specific emergency shut-down procedures shall be developed and maintained at the project site. General procedures or steps for emergency shutdown are described in 13.3.1.

Once emergency conditions are cleared, the normal isolation locking (e.g. lock-out, tag-out or LOTO) procedures shall be followed prior to work on the electrical equipment. Depending on the failure mode, it should be noted that equipment may still present a hazard.

12.3 Troubleshooting non-hazardous failures

When failures do not create hazardous conditions, corrective maintenance procedures may involve working on, testing, or inspecting components where there are live parts. For all such procedures, the normal isolation procedures described in 13.3.2 should be followed, and all appropriate safety procedures (e.g. lock-out, tag-out or LOTO) as defined in 13.2.1 and Annex E should be carried out before work is performed.

12.4 Troubleshooting incident or event-triggered issues

Issues or failures triggered by an event may be indicated by a monitoring system, and shown as the loss of a specific power processing component, such as an inverter, combiner box, string, transformer, circuit breaker, etc.

In the event of an inverter fault, follow the general diagnostic steps outlined in 13.6.2, as well as isolation and safety procedures (e.g. LOTO) as applicable.

Inverter trips may not be the result of a problem with the inverter, but rather an appropriate response to failures in the array. Inverter diagnostic information may point to array-related issues (such as earth faults) that need further investigation before corrective maintenance can be performed. The following procedures may be warranted as appropriate:

a) Earth fault testing according to 13.5.1.
b) String testing according to 11.4.4.
c) Fuse testing according to 13.5.2.
d) PV insulation resistance testing according to 6.7 of IEC 62446-1:2016.
e) Earthing system continuity test according to 6.1 of IEC 62446-1:2016.
f) DAS diagnostic tests according to 12.5.

g) IR imaging tests according to 7.3 of IEC 62446-1:2016, specific procedures found in manufacturers' operating manuals, and/or as recommended in IEC TS 62446-3.

12.5 Diagnosing performance related issues

System operators or owners may become aware of a PV installation's underperformance through one of the following means:

a) a predefined DAS alert corresponding to weather adjusted expected performance, a result of comparison with other systems in a system portfolio, or a result of comparison with other monitored parts of the system at a site (e.g. a site with multiple inverters and/or sub-arrays, or with string and/or MLM);
b) a manual review of the DAS data through an online portal that indicates performance anomalies;
c) a comparison of present performance with performance test results from previous maintenance visits; and
d) customer or external entity reports of a potential problem, e.g. because of an unexpected increase in a monthly bill.

Once the underperformance is confirmed, personnel shall determine what is causing it. Steps to diagnosing power production deficiencies include:

e) Review of monitored data to identify sub-system performance changes.
f) Aerial images of large systems may identify the problems with reduced labor.
g) Where aerial imaging is not practical or appropriate, dispatch a field technician to the site to do the following:
    1) Check sub-array and string currents in sub-array and array combiner boxes (if not monitored or recorded remotely). Often a performance problem will be related to string(s) with a blown fuse or other issue that is apparent from a string measurement.
    2) Check that on-site performance meters have similar values and have been properly calibrated. Often systems will have revenue grade performance monitoring that can be compared against the inverter display totals. A phase that has a different output than the others could be the result of a bad current transformer (CT) or a blown fuse in the CT circuit (i.e., an instrumentation problem).
    3) Verify that the array maximum power point voltage is within the maximum power point tracking range of the inverter, using an I-V curve tracer on a sample string or group of strings. Modules will degrade over time and an array that begins service at the lower end of the inverter maximum power voltage window may degrade until its maximum power voltage no longer falls within this range, further compounding the effects of module degradation.
    4) Look for external causes of the production drop, such as unexpected shade on the array. Vegetation growth is the most common form of shading, but it is not unusual to find a satellite dish or other object shading the array that was not present when the system was built. Take photographs with usable coordinates of the installation during commissioning and keep a visual record of any noticeable differences during maintenance visits.
    5) Inspect for signs of animals gnawing on insulation, irregular/unanticipated damage or other connectivity issues that may skew output data.
h) Perform general system checks as necessary to identify problems:
    1) Follow the steps for DAS system diagnostics according to 13.6.1.

2) Check all fuses at the inverter and work out to the combiner boxes according to 13.5.2. Whenever a blown fuse is found, investigate the cause and in cases of repetitive failures, address the underlying cause. When replacing fuses, it is essential to source the appropriate size, type, and rating. Do not assume that the fuse being replaced was the correct size, type, and rating, because an incorrect rating or size could be the reason the fuse blew. It may be necessary to consult the product manual and the design specifications and drawings to ensure the correct fuse is sourced. It is common to come across operating systems with incorrect fuses in place.
3) Perform string I-V curve tracing according to 7.2 of IEC 62446-1:2016 to evaluate I_{sc}, V_{oc}, P_{max}, and fill factor. This is the preferable method as any issues with obstructions or soiling, or degradation of fill factor, will show up in the I-V measurements. Alternatively, perform string voltage and current testing according to Clause 6 of IEC 62446-1:2016.
4) Validate weather sensors.
5) Look for soiling. If soiling might be the problem, test an individual string (V_{oc}, I_{mp}, I-V curve) and then clean the string and retest.
6) Take infrared (IR) images of the PV cells according to 7.3 of IEC 62446-1:2016, or through aerial imaging as appropriate.

13 Additional procedures

13.1 General

Procedures defined in this clause are referenced from multiple sections in the technical specification, as needed for the appropriate task.

13.2 Safety procedures

13.2.1 General

Refer to Annex E for basic safety requirements, considerations and useful references addressing local rules.

13.2.2 Safe operation of switch disconnectors

Switching on or off an electrical contactor or disconnector can be one of the more dangerous tasks involved in maintaining a PV system if not performed properly. Workers shall wear proper PPE when operating disconnects, and care should be taken to use the proper technique for operating switch disconnectors.

Before opening a d.c. disconnector, the system should be shut down by turning off the connected inverter, opening a load break rated switch disconnector, and/or initiating shutdown control, where available. Disconnectors used to control the d.c. circuits of PV systems that are not rated for load-break operation shall be labelled as non-load-break-rated and shall never be opened while the system is operating. See Annex E for more detail.

13.3 Isolation procedures

13.3.1 Emergency shutdown

13.3.1.1 Inverter equipment pad equipment

Proceed to the inverter equipment pad or equipment area only if there is safe access and no discernible safety hazard at the equipment itself. If the inverters have emergency stop buttons, push them in on each inverter. If the inverter has an on/off switch, turn it to the off position. Each inverter should be manually turned to the off position. This will immediately open the internal a.c. and d.c. contactors (if present) inside the inverter, and/or initiate shutdown control, where available.

13.3.1.2 Disconnect switches

Some inverters do not have an on/off switch or an emergency stop button. For these inverters, it will be necessary to turn the systems off using the switch disconnectors attached to or located near the inverters. Do not open disconnectors or switches labelled "Do not disconnect under load" until a load-break switch disconnector has been opened and current flow is stopped. Generally, the first available upstream load-break a.c. switch disconnector or circuit breaker is safer to operate first (before the d.c. switch disconnector), because the inverter instantly shuts down the transistor bridge when a.c. voltage is removed. Once the system is off, the remaining d.c. side isolators can be opened and the system can be locked out until the fault condition is repaired or it is safe to turn back on.

NOTE The d.c. side contacts may still be live when disconnect switches or isolators are opened.

If there is any question about the location of a fault or failure, check that there is no voltage on metallic switch cabinets or handles, and check that the enclosure or handle is not overheated, prior to operating the switch disconnector. Once these checks are cleared, follow the switch disconnector opening procedure described in 13.2.1.

13.3.1.3 Combiner boxes

In an emergency situation, it may be important to isolate combiner boxes or sub-arrays from the rest of the array circuits. Proceed to the equipment area only if there is safe access and no discernible safety hazard at the boxes or enclosures themselves. Check that there is no voltage on metallic switch cabinets or handles, and check that the enclosure or handle is not overheated, prior to operating the switch disconnector. Once these checks are cleared, follow the switch disconnector opening procedure described in 13.2.1. Open the combiner box. If it is necessary to isolate individual string circuits, ensure that there is no current flowing in the string using a current clamp meter before attempting to remove or open a string fuse.

13.3.1.4 Module and string wiring

Do not attempt to isolate module or string wiring in an emergency situation. This should only take place once initial steps have been taken to shut off power or fault current flow via the inverter and isolating switches. After these steps are taken, individual string circuits can be isolated by opening the PV connectors at the string or inter-module level. PV connectors are non-load break devices, therefore current checks should always take place first before opening the connector.

13.3.2 Non-emergency shutdown

13.3.2.1 Inverter equipment pad components

Use the following procedures for disconnecting a single inverter from the grid. If applicable, follow the inverter manufacturer guidelines for a controlled shutdown using the interface keypad to navigate and select a shutdown.

a) Check if there is an insulation or earth fault in the PV array at the inverter or DAS. If so, refer to 13.5.1 for diagnostic and remediation steps.
b) If the inverter has an on/off switch, turn it to off.
c) Turn the a.c. disconnect switch disconnector on the inverter off.
d) Turn the d.c. disconnect switch disconnector on the inverter off and/or initiate shutdown control, where available.
e) Turn off any remaining external switch disconnectors or isolators connected to the inverter.
f) Install lockout devices on all switch disconnectors, locking them in the open or off position.
g) Repeat for all inverters and switch disconnectors to completely isolate the entire PV system from the grid and the inverters from the PV power source.

13.3.2.2 Transformer isolation

Use the following procedures for transformer shutdown:

a) For inverters connected to the transformer, turn the on/off switch to off.
b) Turn the a.c. disconnect off for the inverters connected to the transformer.
c) Turn the d.c. disconnect off for the inverters connected to the transformer and/or initiate shutdown control, where available.
d) Install lockout devices on disconnects.
e) Turn off the grid-side transformer switch, which is either a dedicated stand-alone circuit breaker or switch disconnector or is located in the switchgear.
f) Install a lockout device on the transformer switch.
g) Repeat for all transformers to completely isolate them from the switchgear.

13.3.2.3 Combiner box isolation

To isolate field combiner boxes:

a) Turn off the inverters as described above.
b) Operate the switch disconnector of the combiner (if applicable) by turning the handle to the off position. If an isolator is used, verify there is no current flow on the combiner box d.c. output conductors before opening the isolator.
c) Use a d.c. clamp on the meter to confirm there is no current passing through the string conductors in the combiner box, and then open all of the fuses.
d) If further isolation of the box is needed, use the string diagrams to locate the end connectors of the PV strings.
e) Use a clamp-on d.c. current meter to confirm that the string does not have any current passing through it, and then disconnect the string by opening the homerun positive and negative connectors and putting caps on the source circuit connectors.
f) Return to the combiner box and use a voltage detector with a proving unit to confirm that each string has been successfully disconnected.

13.3.2.4 Modules and string wiring isolation

After turning off the inverter and isolating the combiner boxes from the array, disconnect individual modules from the string:

a) Before disconnecting any string, use a d.c. clamp-on meter to confirm there is no current passing through the string.
b) Use the appropriate connector unlocking tool to disengage the module connector.
c) Repeat for each module to be isolated from the system.
d) If modules are removed from a system, even temporarily, technicians shall ensure that the equipment earthing system remains intact for the remaining modules.
e) Technicians need to be aware that a circuit can easily be reenergized inadvertently and that most modules cannot be turned “off”, and will typically generate the rated voltage when exposed to sunlight, regardless of lock out of transformers, inverters, combiner boxes, etc.

13.4 Inspection and preventive maintenance procedures

13.4.1 Inverter manufacturer specific procedures

Each inverter manufacturer will have specific requirements for inspection, testing, services, and documentation to meet its warranty obligations. Typical requirements for inverter inspections include:

a) Record and validate all voltages and production values from the interface display.

b) Record last logged system error.
c) Clean or replace filters.
d) Clean the inside of the cabinet.
e) Test fans for proper operation.
f) Check fuses.
g) Check torque on terminations.
h) Check gasket seal(s).
i) Confirm warning labels are in place.
j) Look for discoloration from excessive heat build-up.
k) Check integrity of surge arrestors.
l) Check continuity of earthing system and connections.
m) Check mechanical connection of the inverter to the wall or ground.
n) Check internal disconnect operation.
o) Verify that the latest or applicable software is installed. Sometimes an older software version may be appropriate for compatibility reasons.
p) Contact installer and/or manufacturer about any issues found.
q) Document findings for all work performed.

13.4.2 Tracker manufacturer specific procedures

Tracker manufacturers will have specific requirements for inspections, testing, service, and documentation to meet their warranty obligations. Typical maintenance or start-up requirements for tracker systems include:

a) Lubricate tracker by inserting grease with grease gun into appropriate grease caps per manufacturer maintenance recommendation.
b) Check voltages inside the controller box.
c) For tracker electronics that utilize a transparent enclosure cover, verify that internal components appear free of defects from sun exposure.
d) Ensure that there is not excessive moisture accumulated in controller enclosures.
e) Use a digital level to check the calibration and positioning of the inclinometers.
f) Check array for signs of parts hitting or rubbing other parts.
g) Check for any metal stress, loose connections or unusual torqueing or distortion of the tracker framing or device interfaces.
h) Remove vegetation that is near the drive shaft or moving components.
i) Check wind-stow operation.
j) Verify communications with applicable weather station components, gateways, and wind sensors.
k) Verify proper function and position of inclinations sensors, if applicable.

13.4.3 Data acquisition system specific procedures

Data acquisition system (DAS) manufacturers will have specific requirements for inspections, testing, service, calibration, and documentation to meet their warranty obligations. Typical maintenance or startup requirements for DASs include:

– taking voltage readings of power supplies,
– validating current transducer readings by comparing to calibrated equipment, and
– validating sensor reading by comparing to calibrated equipment.

To confirm proper functionality of the DAS, the values measured by the DAS should be verified against values from devices with traceable calibration records. Comparing the irradiance, temperature, and power measurements recorded by the DAS to values obtained from calibrated instruments will help identify sensor calibration issues that could result in the DAS data being incorrect. Where time synchronization of data has been required, confirm that the data synchronization is operating properly. Verify DAS has communication with applicable server and that there are no gaps in stored data. Investigate causes if there are frequent gaps in data, such as problems with cabling, or interference from other equipment.

Sensors and monitoring devices requiring calibration shall be calibrated at intervals no longer than the certifications and manufacturer recommendations, unless there is written justification approved by system owners and operators.

Depending upon system granularity, compare equivalent module, string, sub-array or inverter data for inconsistencies and anomalies, as available.

It is common for DAS documentation to be omitted or insufficiently detailed. As a result of such an omission, initial inspections often do not check for errors in the DAS design and inspectors have nothing to compare the as-built with for compliance. If the DAS is tied into the building information technology system, O&M personnel should be aware that building networking upgrades or routine maintenance can cause connectivity issues.

13.5 Electrical test procedures

13.5.1 Earth fault testing

13.5.1.1 General

Earth faults can be difficult to troubleshoot depending on the severity and location of the fault. However, steps can be taken to efficiently troubleshoot earth faults in a PV system.

Testing can be done under any conditions with enough light to produce voltage. However, some faults are only apparent under certain conditions, such as when components are wet or when the array is exposed to higher irradiance levels. These conditions may need to be replicated to adequately troubleshoot the fault.

Systems without functional earthing (or IT systems) monitored by an IMD according to IEC 61557-8 may use insulation fault location systems (IFLS) according to IEC 61557-9 to simplify this process.

13.5.1.2 Test procedure—string inverters

a) Turn inverter off at the on/off switch disconnector, if applicable.
b) Turn off the d.c. and a.c. disconnects (may be the same switch disconnector).
c) For systems with functional earthing:
   1) In many small inverters, the fuse is the path to earth. When the fuse is removed from the system, the normally earthed conductor is no longer earthed. Verify there is no current flowing in the fuse or disconnecting device.
   2) Remove and test the earth fault fuse continuity with an ohmmeter. If the fuse is good, there may not be an earth fault. Verify by testing voltages to earth with the fuse removed. If within specifications, replace fuse and restart inverter. If the fuse fails continuity test, there may be an earth fault.
   3) Verify it is the correct rating type and size fuse.

If the ends of the circuit are isolated, the strings should not have a well-defined open circuit voltage when tested from the conductor to earth. If a well-defined voltage is present, there may be a fault. Small inverters usually have four or fewer inputs, so isolate the string with the fault by removing the fuses from the combiner box.

d) With the fuses removed, test for voltage from the line side of the fuse terminals relative to earth.

e) For systems with functional earthing, if voltage is present on all of the terminals relative to earth, isolate the normally earthed conductors by opening the earth connection (remove earth fault fuse) or by removing them from the bussing.

f) Repeat until the string with the fault is found.

g) Take the isolated string with the fault and record the voltage from the positive pole to earth (V_{pos}) and from the negative pole to earth (V_{neg}). Check to see that $V_{pos} - V_{neg}$ (i.e. the sum of the absolute values) is approximately equal to the full open circuit voltage of the array. If this is not so then other faults may exist. If the voltage in either measurement is low (e.g. equivalent to the open circuit voltage of zero to one or two modules), the fault is likely to be at that end of the string. If the voltage is a different value, then the fault is probably somewhere in the middle of the array or possibly in a module.

h) Determine the precise location of the fault by taking the voltage V_{pos} or V_{neg} that is smaller in magnitude and divide that voltage by the open circuit voltage of one module. i.e. N_x = magnitude of (V_{pos} or V_{neg}/V_{oc} one module). If the fault is in the inter-module wiring the result N_x should be close to an integer number and that number should indicate the number of modules between the pole associated with the measurement and the fault.

   For example, consider 10 modules in a string with a V_{oc} of 50 Vdc each, with module one connected to the negative main cable and module 10 connected to the positive main cable. When testing at the combiner box from the line side of the negative terminal to earth and the result is V_{neg} = -100 Vdc and testing from the positive to earth and the result is V_{pos} = 400 Vdc, then N_x = 2, and the fault is somewhere between the second and third module in the string counting from the negative main connection. Given the same wiring as above but a reading of 0 Vdc from the negative side and 500 Vdc from the positive side, the fault is in the negative cable.

Given the above scenario, it would be wise to use an insulation resistance tester on all of the conductors in the conduit to make sure that the fault is isolated to the one conductor.

Some inverters or systems include fault location functionality. Check the manufacturer manual on how to apply.

13.5.1.3 Test procedure—central type inverters

Due to their relative size, central inverters require additional procedures to narrow down the source of an earth fault.

a) Turn inverter off at the on/off switch, if applicable.

b) Turn off the a.c. and d.c. disconnects connected to the inverter.

c) For functionally earthed systems with a fuse, contactor or circuit breaker in the earthed connection, verify there is no current flowing in the connection. Remove and test the earth fault fuse continuity with an ohmmeter. If the fuse is good, there may not be a earth fault. Verify by testing voltages to earth with the fuse removed. If good, replace fuse. If the fuse fails the continuity test, there may be a earth fault. Verify it is the correct rating type and size fuse.

d) If an earth fault is suspected, remove the fuse for subsequent testing.

e) For functionally earthed systems using a circuit breaker, contactor or other switching device in the earthed connection, open the switching device.

f) At the inverter d.c. input terminals (where cables from the combiner box to the inverter terminate in the inverter enclosure) measure the voltage between each pole and ground. An earth fault probably exists if the voltage between either dc pole and ground is low or zero.

g) Check the incoming circuits from each combiner box one by one to determine which circuit has the fault.

h) DC input configurations in central inverters vary considerably. Consult with the inverter manufacturer for detailed instructions for isolating the individual d.c. input circuits.
i) If the combiner boxes have switch disconnectors on the output cables, open the switch disconnector and recheck the voltage to ground. If the low voltage is still present, the fault is in the cables between the combiner box and inverter. Otherwise, the fault is in the array strings.
j) To identify the location of the earth fault in the strings, follow the string testing procedures in 13.5.1.1.

13.5.2 Fuse tests

Fuses can be checked under any test conditions. Fuses should never be replaced or tested while the circuit is energized. Isolate the array or sub-array prior to servicing fuses.

Fuse testing procedure:

a) Use appropriate safety procedures (e.g. LOTO)
b) Confirm system is de-energized with a voltmeter.
c) Check with clamp meter that there is no current flow through the fuse (space permitting).
d) Set ohmmeter on a sturdy surface.
e) Remove the fuse to be tested from the fuse holder unless it is clear that no alternative continuity paths can exist that would provide a false reading.
f) Use the ohmmeter to test the fuse by connecting a test probe to the terminals at each end of the fuse, making sure that your fingers are not touching the fuse terminals or the test probe tips as this may give a resistance reading for an open fuse that can be confusing. Confirm that the resistance reading is as expected for a good fuse.
g) Look at the fuse and confirm the size, type, and rating of the fuse.
h) If the fuse fails the test or is not the properly rated size or type, replace with the correct fuse.
i) Always test replacement fuses before installing to confirm the fuse was good when it was placed in service.

Additional best practices:

While testing the voltages with the system off and the fuses open, prepare the box for current testing. Cut zip ties if needed and make sure the conductors are tight in their terminals and will not come out when the current clamp is placed around them in the next phase of testing.

Test with a two-person team so one can keep the safety equipment on and take readings while the other records the readings. This will allow for efficient testing, because the person taking the readings can enter them directly into a form. In addition, there is the safety advantage of having two people present when working on live equipment.

13.5.3 Bypass diode tests

13.5.3.1 General

Bypass diodes can fail open circuit or as a short. If a string has below average voltage relative to other strings, that may be an indication of one or more shorted diodes. Open-circuited diodes may not be as noticeable. Consult with the module manufacturer to determine if a failed bypass diode can be replaced, or if the entire module should be removed and replaced. Diodes that have failed open circuit should be replaced or the module removed if that module receives regular shading.

13.5.3.2 Open circuit diode testing

If there is direct access to the diodes in the junction box, they can be tested with continuity measurements. A healthy diode will conduct in the forward direction and appear open circuit in the reverse direction.

If there is no access to the diodes, open circuited diodes can be detected using selected shading of modules and portions of modules in a series string. This test should be done under stable sunlight conditions so that current changes caused by variable sunlight are not interpreted as diode failures.

a) Set up continuous current measurement of the string under test. Isolating the string under test from other parallel connected strings, where practical, such as on small systems with few PV strings, may provide more revealing results.
b) Selectively shade areas of each module that are segmented by the bypass diode. (Use the module data sheet to identify the number of diodes and cell string partitions.)
c) As each area is shaded, look for drops in current. An open-circuited diode will not be able to create a bypass path for the shaded cells, and current will drop significantly as a result.

13.5.3.3 Short-circuited diode testing

A short-circuited diode may be identified by thermal imaging (see 7.2 of IEC 62446-1:2016) or by locating the module(s) in the string with low voltage. This is achieved by isolating (disconnecting) modules and measuring voltage at the module level. For long strings, it is advisable to divide the string into equal sections and determine which section has the low voltage before disconnecting every module. Where available MLM can be used instead of this test. By comparison of the module voltages a shorted bypass can be detected, if not already indicated by the DAS. If a low voltage module is identified, and there is access to the junction box, the failed diode will measure continuity in both the forward and reverse direction.

13.6 Diagnostic procedures

13.6.1 Validation of data acquisition systems (DAS)

13.6.1.1 General

DAS checks are used to validate the existing systems. If any component is not up to specifications, it may be quicker and cheaper to replace it with a new component than to attempt to alter settings. In some cases, the cheapest and best option may be to establish a policy of replacing equipment such as irradiance sensors at defined intervals rather than spend the time validating the data and then replacing when out of calibration. Consider the accuracy of all instruments when determining whether the reading is within acceptable range.

Perform the testing at the equipment involved, which can be installed throughout the system in combiner boxes, switchgear, transformers, and inverters in the array as well as in separate dedicated DAS enclosures. It is ideal to perform measurements under relatively stable outdoor conditions. In the case where it is not possible to log in to the DAS while at the site, it may be possible to synchronize clocks to compare on-site readings with DAS history afterwards. However, this is less desirable, as additional trips may be necessary to make adjustments for different readings.

13.6.1.2 General DAS

The DAS may be an independent system, or for smaller systems integrated within the inverter. In either case, it is important to verify that the system is regularly recording results to ensure a reliable history of system performance.

a) Log in to the DAS program.

b) Look at system history to confirm data is not intermittent. Intermittent data from inverters can be the result of noise induced by the inverter. It may also be from poor communication connections or uplink protocols.

c) Check that the recommended shielded cable is used for communication wiring.

d) Check route of communication wiring to ensure it is away from voltage carrying conductors.

e) Confirm shield is only landed (connected to earth) in one spot; best to do this at the DAS enclosure.

13.6.1.3 Global horizontal irradiance sensor

a) Ensure device has been properly installed.

b) Ensure location is not shaded.

c) Use level to make sure it is level.

d) Clean with a cloth and mild soap solution if necessary, and/or follow manufacturer's cleaning instructions.

e) Log into DAS program.

f) Place cleaned and recently calibrated handheld sensor in same pitch and orientation.

g) Compare and record results, e.g. for future data analysis and/or degradation trends.

h) If outside of acceptable range, replace sensor, noting serial number of the new sensor for as-built updates.

13.6.1.4 Plane of array irradiance sensor

a) Ensure device has been properly installed.

b) Ensure location is not shaded.

c) Use inclinometer and compass to ensure it is in the same pitch and orientation as the array. Large arrays and/or arrays with multiple orientations may have multiple sensors.

d) Clean with a cloth and mild soap solution if necessary, and/or follow manufacturer's cleaning instructions.

e) Log into DAS program.

f) Place cleaned and recently calibrated handheld sensor in same pitch and orientation.

g) Compare and record results.

h) If outside of acceptable range, replace sensor, noting the serial number of the new sensor for as-built updates.

13.6.1.5 Ambient temperature sensor

a) Log into DAS program.

b) Take reading from handheld temperature sensor.

c) Compare and record results.

d) If outside of acceptable range, replace sensor, noting the serial number of the new sensor for as-built updates.

13.6.1.6 Back of module temperature sensor

a) Ensure sensor is correctly adhered to the back of a module in the middle of a cell in the middle of the module.

b) Log into DAS program.

c) Take reading from handheld temperature sensor.

d) Compare and record results.

e) If outside of acceptable range, replace the sensor, noting the serial number of the new sensor for as-built updates.

f) Rather than risk damaging the module, leave the sensor in place and install the new sensor in the middle of the next closest cell.

13.6.1.7 Anemometer

a) Log into DAS Program.

b) For cup anemometers, hold the cups and confirm it is reading 0 km/h.

c) Turn to confirm it is moving.

d) If further testing is needed, and for ultrasound anemometers, use a handheld anemometer and compare the results at a consistent windspeed greater than 3 m per second.

e) If outside of acceptable range, replace the sensor, noting the serial number of the new sensor for as-built updates.

13.6.1.8 Current transducer

a) Log into DAS Program.

b) Compare the current readings to the inverter display current readings.

c) Revenue grade validating involves using a calibrated current meter and placing it around the same conductors with the system running.

d) Compare results.

e) If outside of acceptable range, replace the sensor, noting the serial number of the new sensor for as-built updates.

13.6.1.9 Voltage transducer

a) Log into DAS program.

b) Check fuses with ohmmeter.

c) Use calibrated voltmeter to test circuits.

d) Compare results.

e) If any difference is noted, switch to other phases.

   1) Check if the meter itself is not working properly.

   2) Check if the reference phase is mislabeled.

13.6.1.10 Revenue meter

a) Log into DAS program.

b) Navigate the program to compare programmed current transformer (CT) ratio to the ratio listed on the CTs.

c) Look at power factor of all three phases to confirm it is close to unity with the system operating.

d) Note that power factor may be low at startup or in low light conditions e.g. less than 250 W/m^2.

e) Confirm proper phase rotation with system running.

f) Compare revenue grade data with inverter data, noting differences.

13.6.1.11 Inverter internal sensors

a) Log into DAS program.

b) Confirm system is checking in accurately, confirming readings where possible.

c) Confirm appropriate resistor or termination is installed in the last inverter in the chain (if required).

13.6.1.12 Combiner box level monitoring

a) Log into DAS program.

b) Confirm communication to all devices.

c) Compare results to manual string current measurement results, or a sample thereof.

13.6.1.13 String level monitoring

a) Log into DAS program.
b) Confirm communication to all devices.
c) Compare recorded string currents with other strings in the same box and/or from adjacent boxes, whose modules are mounted in the same orientation. Slight differences may be due to operating temperatures and module variations.
d) Compare string currents recorded from DAS with those of manually measured baseline string currents.

13.6.1.14 Module level monitoring

a) Log into DAS program.
b) Confirm communication to all devices.
c) If desired, shade individual modules to confirm module mapping is accurate.

13.6.2 Inverter diagnostics

When an inverter goes offline, technicians should determine the cause and address errors if applicable. The inverter may be checked remotely or via the local interface for the reported error(s). Recommended follow-up actions are listed in Table 4. These are common examples; specific recommendations and requirements should be provided by the inverter manufacturer.

Table 4 – Common reported inverter errors

Inverter error	Action
DC undervoltage	Steps to diagnosing underperforming systems
DC overvoltage	V_{DC} string testing
DC earth fault	Earth fault detection procedure
Gating fault	Check connections Contact manufacturer
AC undervoltage	Confirm all breakers are on (closed) Check AC voltage with voltmeter If within range, perform a manual restart If outside of range, contact utility
AC overvoltage	Check AC voltage with voltmeter If within range, perform a manual restart If outside of range, contact utility
Low power	System is probably just shutting down because of lack of sun; if it is sunny, perform steps to diagnose underperforming systems
Over temperature – fan not operating	Check power supply to fan – if good, replace fan; if bad, replace power supply
Over temperature – fan is operating	Check to confirm sensor readings – if bad, replace sensor; if good, check intake and exhaust filters for excessive build-up, and clean or replace if necessary

Some inverter faults will clear automatically when the fault condition returns to normal, but some fault conditions require a manual reset of the inverter. The earth fault fuse and even a.c. fuses can be non-standard items that are difficult to purchase. Keep replacements on hand, especially if there are multiple inverters of the same size on site or in the portfolio. Having qualified technicians available and properly equipped with common replacement parts helps maximize system uptime.

Some inverter service actions require that the system be shut down for safe inspection. Always begin with a visual inspection of the equipment, and further inspect subassemblies, wiring harnesses, contacts, and major components.

The following sample inverter service checklist applies to larger central inverters (not residential scale) and is not intended to be complete for all models from all manufacturers:

a) Check major device and control boards for discoloration. Use inspection mirror if necessary.
b) Check input d.c. and output a.c. capacitors for signs of damage from overheating.
c) Record all voltage and current readings from the front display panel.
d) Check appearance/cleanliness of the cabinet, ventilation system, and insulated surfaces.
e) Check for corrosion/overheating on terminals and cables.
f) Torque terminals, connectors, and bolts as needed.
g) Record ambient weather conditions, including the temperature and whether the day is cloudy or sunny.
h) Check the appearance of both the a.c. and d.c. surge suppressors for damage or burn marks.
i) Check the operation of all safety devices (emergency stop devices, door switches, earth fault detector interrupter).
j) Inspect (clean or replace) air filter elements.
k) Correct any detected deficiencies.
l) Complete maintenance schedule card.
m) Complete written inspection report.
n) If manufacturer-trained personnel are available on-site, install and perform any recommended engineering field modifications, including software upgrades.

Annex E
(normative)

Safety considerations

E.1 Qualified persons

Because of the shock and arc flash hazards present in PV systems, it is essential that personnel interacting with the system have appropriate training, use appropriate personal protective equipment, and follow safe procedures. Personnel need to be trained to:

a) Identify exposed live parts from other parts of electrical equipment.
b) Determine the nominal voltage of exposed live parts.
c) Determine safe working distances depending on the voltage to which the person will be exposed.
d) Be familiar with access and safe area exit routes in case of emergency.
e) Be familiar with pertinent sections of local electrical and fire codes and standards.
f) Be familiar with characteristics of PV sources and hardware typically used in PV systems.
g) Be familiar with the characteristics of the hardware used in the PV system.
h) Verify that test and inspection equipment is appropriately rated for the conditions of the tests.
i) Operate the test and inspection equipment.
j) Be familiar with other site-specific hazards.

Note that personnel who are not qualified to perform work directly on the system but who may be onsite for other purposes shall be made aware of any hazards they may encounter and the appropriate precautions.

E.2 General safety considerations

Qualified persons shall use properly rated equipment and be trained for servicing systems. They shall also be aware of the normal expected conditions, voltages and currents of a particular system, so that they are better able to identify abnormal or unsafe conditions.

Particular care shall be taken to observe and follow warning labels reading "DO NOT DISCONNECT UNDER LOAD" located on module connections, combiner boxes, and some d.c. isolators not designed for load-break operation. Failure to heed these warning labels can lead to instrument malfunction, arcing, fires, and personnel injuries. The following steps should be followed as a minimum to ensure safe operating conditions:

a) Before operating the PV system, read system documentation and instructions for each product or component.
b) The presence of an insulation fault or earth fault should be checked before performing any task at a PV system. If an insulation fault is present, the relevant exposed-conductive-parts of the PV array should be considered live.

   NOTE Insulation fault indication is typically available at the DAS and/or the inverter.

c) All system components shall be assumed to be energized with maximum d.c. voltages (up to 1 500 V or more) until personnel verify that the voltage has been removed.
d) For a.c. circuits, use a suitable voltage detector or voltmeter to prove the circuit is dead. A contactless voltage detector shall not be used for proving dead as they can indicate a false safe condition. A suitable proving unit should be used to verify the correct operation of the voltage detector or voltmeter before and after proving dead. Use a voltage detector with a contact-less proving unit before using multi-meters to test for dead circuits.

e) All enclosure doors should remain closed with latches tightened, except when they are open for maintenance or testing.

f) In order to remove all sources of voltage from an inverter, the incoming power should be de-energized at both the d.c. and a.c. source. In most inverters d.c. voltage will remain for 5 min or more while the d.c. bus capacitors discharge.

g) Always follow isolation safety procedures (e.g LOTO).

h) Do not work alone when servicing PV equipment. A team of two is recommended until the equipment is properly de-energized, locked-out, and tagged-out.

i) Do not remove a fuse without first confirming that there is no current flowing on the circuit.

E.3 Personal protective equipment

Service personnel shall be aware of the specific PPE required to perform various tasks on the electrical equipment. PPE includes fall protection gear, arc flash and fire-rated clothing, rubber (hot) gloves with protectors, boots, and protective eyewear, among other items. PPE is designed to help minimize exposure to inherent system hazards. Identification of potential hazards is crucial to the process of selecting the appropriate PPE for the task at hand. All personnel working on or near PV systems should be trained to recognize hazards and choose the appropriate PPE to eliminate or reduce those hazards.

Many existing PV systems have been installed without labels warning of arc flash hazard. Service personnel need to be able to perform on-site evaluations to determine when a higher category of PPE is required to perform the work.

The jobsite should be equipped with appropriate fire extinguishers and first aid supplies and personnel should have proper training in their use. People trained in cardiopulmonary resuscitation (CPR) should be on site at all times.

PV arrays are often home to snakes, spiders, bees, and other venomous animals. Wear protective clothing and be alert for possible encounters.

E.4 Isolation procedures

Maintenance personnel shall be aware of isolation procedures specific to all of the major components of a PV system. Many d.c. components are energized from multiple sources and therefore may require additional steps to remove hazardous voltages in comparison to more typical a.c. power installations. Isolation procedures are common to most all O&M operations, and specific procedures are defined in Clause 13. A separate set of isolation procedures and considerations is described generally for emergency conditions.

Some testing and maintenance activities may require the system to be energized while workers are working on or near the equipment. String voltage and current testing are but two examples. In such cases, isolation of the equipment from other sources with appropriate safety procedures (e.g. LOTO) is still important to reduce safety hazards, and the appropriate PPE requirements shall be followed.

E.5 Lock-out tag-out

Lockout/tagout (LOTO) or similar procedures are designed to ensure safe working practices and shall be strictly followed whenever systems are de-energized prior to servicing. LOTO is required in some locations when energized equipment is serviced or maintained, safety guards are removed or bypassed, or where hazardous energy sources are present. However, the presence of a lock does not ensure that no voltage will be present on some components since the voltage on a PV module appears when placed in the sun.

LOTO steps include:

a) Notify others that the equipment will be shut down,
b) Perform a controlled shutdown to power down the equipment,
c) Open all energy isolating devices identified on the equipment's specific LOTO procedure,
d) Lock and tag all energy isolating devices,
e) Dissipate or restrain stored or residual energy,
f) Verify that the equipment is completely de-energized by attempting to cycle it, and
g) Verify that the equipment is completely de-energized by testing for voltage with a voltmeter.

NOTE Some shutdown control systems use a safe low voltage for indicating that shutdown has occurred and is distinct from a physical break in the circuit conductor.

An additional recommended measure for systems is to place temporary portable signage indicating that work is taking place. This is especially useful when others are on the project site yet are not aware that there is a LOTO procedure in effect.

Proper LOTO labelling includes:

a) Name of the person placing the LOTO and the date placed,
b) Details regarding the shutdown procedure for specific equipment,
c) A list of all of the energy sources and isolating devices, and,
d) Labels indicating the nature and magnitude of stored potential or residual energy within the equipment.

The lock placed on equipment during servicing should be removed only by the person who placed it. Safety protocols need to be followed when re-energizing equipment, including notifying others on site that the system is about to be re-energized.

E.6 PV specific signs and labelling

All circuits, protective devices, disconnects and terminals should already be suitably labelled to the requirements of IEC 60364 in general and IEC 62548 in particular. Personnel shall heed requirements and instructions provided by the signs and labelling. Signs shall also be maintained or replaced if weathering or exposure has led to a deteriorated or unreadable condition and should never be covered or painted over.

Annex F
(informative)

Example preventive maintenance schedule

F.1 General

This annex describes an example preventive maintenance schedule using the model from Table 3 in Clause 10. The purpose of the example is to demonstrate the considerations that drive development of a thoughtful maintenance program by highlighting the site and system-specific nature of the process. The purpose is not to describe a default maintenance schedule for systems, and should not be considered as such. The example is in fact representative of an outlier case in several aspects to illustrate how some unusual circumstances can be addressed. See Table F.1.

F.2 Example system description

The example project is a large, utility scale system located in an area (such as northern North America) that is subject to hot and humid summers but also severe winter temperatures. Winter low temperatures are often less than -25°C. The site is also subject to heavy spring rains which can cause flash flooding conditions given the terrain. It is located in an agricultural area with both farms and industrial processes, and there has been evidence of corrosive chemicals in the soils. The site is not located in a high seismic activity zone, or a high wind zone. Lightning activity is expected at the site given the long anticipated project life, but the occurrence probabilities on an annualized basis are not high. There is some question about whether rodents may be an issue at the site, given that a few other PV plants in the area have had issues, but most have not.

The system utilizes N-S axis tracking, and power is collected at standardized 2 MWac equipment pads with outdoor rated central inverters and medium voltage transformers. The d.c. array circuits are functionally earthed, and the inverter ground fault detection does not incorporate regular checks of insulation resistance. There is no notable history of micro-cracks or “snail trails” with the model of PV module used at the site. One short edge of the site is located adjacent to a forest with young trees, and it is anticipated that these trees will cause shading to one or two array segments when they mature.

The plant monitoring system measures the current and voltage from each combiner box (~12-15 strings per combiner box), as well as all of the inverter power parameters. Currents at the string level are not monitored. There are at least 3 weather stations with horizontal and plane of array irradiance measurements, ambient temperatures, wind speed, and sample back-of-module thermocouple measurements. There is no soiling monitoring station. The project has a performance guarantee that drives certain maintenance tasks for the first five years of operation.

Table F.1 – Preventive maintenance schedule for XYZ plant

Component/Task		Maintenance procedure interval	Interval basis
Modules			
	Inspect for cracks, delamination, breakage, burn marks	Lightning storm event driven, 5-year inspection of sample sections of plant	Areas with high lightning or wind activity, nearby construction activity, aging systems (in case of delamination).
	Inspect for micro-cracks or "snail trails"	Check sample arrays after 1 year. 5-year inspections thereafter or adjusted as needed.	Products with history of micro-cracks. Sites with snow and wind driven forces on modules, etc. Impacts may be greater in high humidity areas.
	Inspect for excessive build-up of soil or droppings	Years 1-5 check of soiling due to nearby farm preparation and harvest activities. Determine if rain is sufficient	Where site is susceptible to high levels of soiling, bird droppings, etc.
	Thermal imaging for junction box, cell variations, internal connections, partial operation.	Recommended after lightning storm events where there is evidence of diode failures. Other event driven diagnostics. No periodic requirement.	Can be the default method for large plants (e.g. using aerial imaging). Locations susceptible to lightning e.g. for bypass diode diagnostics, Seasonal bias for testing to ensure high irradiance, e.g. summer.
	Connector checks – visual damage, sample tightness	5-year inspections in sample circuits of arrays	Where connectors are exposed to high winds or other sources of movement or strain. Where dissimilar connector manufacturers are used.
	Imaging of module connectors for resistive, cracked or compromised connections	Triggered by performance issues or other external evidence of failures	Only conditional based, unless system has history of connector problems, and arc-fault connection and/or sensitive ground fault detection is not included.
Array			
	Debris or stored items under array	Annual checks after rainy season.	For ground-mounted power plants following construction or substantial maintenance activities. Consider other types of debris that comes from wind or another source.
	Animal or pest activity under array	Annual checks for years 1-5, modified as needed thereafter.	Dependent on site conditions, and whether there is a potential impact on wiring or equipment. May be seasonal depending on the animal, for example nesting in the spring.
	Periodic insulation resistance testing	Annual insulation resistance testing at the inverter combiner level.	For systems with functionally earthed arrays, periodic tests at sites where wiring has history or is susceptible to damage, or where testing can be done in conjunction with periodic inverter checks.
	Track shading sources against baseline during commissioning	Inspect the arrays impacted by growing trees after 3 years. Performance based checks. No other periodic measures.	As needed for diagnosing performance problems. Can be useful as preventive measure at sites with adjacent growing trees, and/or with contractual performance, etc.

Component/Task	Maintenance procedure interval	Interval basis
String or wiring harness Voc measurements for baseline comparisons	Annual measurements for 2 % of the plants strings for years 1-5 in compliance with the performance guarantee. Performance or failure triggered only thereafter.	As needed for performance or troubleshooting; or where contractual performance base lining is required.
String or wiring harness current measurements for baseline comparisons	Annual measurements for 2 % of the plants strings for years 1-5 in compliance with the performance guarantee. Performance or failure triggered only thereafter.	
String or wiring harness I-V curve for performance baseline comparisons, or to identify module component failures	Annual measurements for 1 % of the plants strings for years 1-5 in compliance with the performance guarantee. Performance or failure triggered only thereafter.	Alternative to string V/I checks; particularly useful for advanced diagnosis of string performance.
Vegetation management – cutting, removing, control	Annual check in late spring, management as needed.	Highly site and season dependent, if needed at all. Base on site review or first year(s) operation; for ensuring performance, protecting equipment, or both.
Inverter		
Visual cues from inverter lights and displays	N/A due to the remote monitoring system.	Useful for checking small systems, including by non-qualified personnel, or for troubleshooting
Inverter enclosure inspection – exterior	Check annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Infrequent, or as part of inverter mfg specified intervals. More frequent at sites with corrosive environments.
Inverter interior (water, dust, rodent)	Event driven by localized flooding.	Infrequent, except at sites with rodent issues, or with heavy rains, flooding, or history of condensation in connecting conduits.
Inverter interior – torque marks, burn marks on field terminals	Check torque marks after 1 year in every inverter. Event driven thereafter.	For troubleshooting, and/or as part of inverter mfg specified intervals. May have more frequent intervals in first 1-2 years.
Periodic maintenance – manufacturer specified	As specified.	As specified.
Enclosures		
Electrical enclosure accessibility (secured)	N/A at the enclosure level. Plant security routinely checks site access (locking gates)	Periodic checks recommended at sites with high exposure or access; schools, public buildings or parks, etc.
Enclosure corrosion	Check annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Infrequent, except at sites with corrosive environments.
CBs/Switches		
Check torque marks on field terminations	Check torque marks at year 1, then every 5 years thereafter.	Per manufacturer/supplier recommendations. May only be in first year.

Component/Task		Maintenance procedure interval	Interval basis
	Look for debris, signs of water	Event driven by localized flooding.	At sites where heavy rain or flooding occurs, or considerable wind blown debris. Where conduits are susceptible to high condensation.
	Burn/arc discoloration on terminals, boards, fuse holders	Event driven by lightning storms, evidence of fuse or bypass diode failures.	Locations with high lightning activity, or history of similar issues.
	Dust deposits on contact surfaces	Check in spring and fall of first year coinciding with agricultural activity; modify thereafter bases on experience	Sites susceptible to wind driven dust or other particulates.
	Thermal image inspection for resistive connections	Annually on sample boxes in years 1-5. Every 5 years thereafter.	Climate considerations, where site have high thermal cycling, material expansion properties. If there is a history of issues at the site that warrant inspection.
	Re-torque field or factory terminals as needed	At year 1. Event driven thereafter based on results from above thermal imaging.	Per manufacturer/supplier recommendations. May only be in first year. Access to terminations and connections.
	Enclosure corrosion or deterioration	Check annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Locations with high humidity, salt content (by sea), corrosive environments (e.g. chemical or agricultural industries).
	Corrosion/Deterioration: Repairs for enclosure integrity	As needed	
	Corrosion/Deterioration: Repair enclosure earth connections	As needed	
	Corrosion/Deterioration: Repair enclosure hinges, locking mechanisms, etc.	As needed	
	Corrosion/Deterioration: Apply sealants, cleaning, patching	As needed	
	Water intrusion: Seal off or divert source, drain fittings	As needed	At sites where heavy rain or flooding occurs
	Water intrusion: Replace gaskets	As needed	
	Debris/Rodent: Remove and seal off	As needed	Sites susceptible to wind-blown debris, or sites with rodent and other pest activity.
	Disconnector operation, grease mechanisms, per mfg inst.	Every 3 years per manufacturer recommendation	Per manufacturers recommendations, or based on field performance data.
	Fuse replacement	As needed. Check sample resistances relative to baseline after 10 years to gauge need for aging based replacements.	Possible replacement due to aging in advance of failure.
Wiring			
	Module/string wiring secure, free of chafing, sharp abrasive surfaces	Check samples annually in years 1-5. Adjust thereafter based on experience.	Where wiring is exposed to high winds or other sources of movement or strain.
	Module/string wiring no sharp, abrasive surfaces, pinch points	Check samples annually in years 1-5. Adjust thereafter based on experience.	Where wiring is exposed to sources of movement or strain and is installed along structures and trackers and less in wiring systems.

Component/Task		Maintenance procedure interval	Interval basis
	String wire tie breakage or damage, impact on conductors	Every 3 years or as needed more often.	Where wire ties are highly relied upon for support, loading of cable bundles, etc.
	Sub-array cable signs of wear at enclosures, transitions, exposed locations.	Sample checks after year 1.	Where sub-array cable bends are tight and/or unusually exposed. (Note outside the table the issue that some intervals should be determined after construction to address installation issues, not necessarily determined in design stage. Also adjustments in the plan due to plant aging.)
	Periodic insulation resistance testing	Annual insulation resistance testing at the inverter combiner level.	For systems that are functionally grounded where the inverter does not provide regular insulation resistance checks: Sites where direct burial cable is deemed more susceptible due to rocky or less filtered soils, where there is history of ground faults, etc.
Wiring systems			
	Conduit/tray support, bushings, gaskets, joints, wear, corrosion	Check annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Systems with evidence of stress from high loading, choice of materials, margin of design. Systems in high corrosive areas.
	Trays: remove tray covers to inspect arrangements, integrity, rodent/ingress	Annual checks for years 1-5 (to determine rodent impact), modified as needed thereafter.	Systems susceptible to rodent intrusion or excessive movement from thermal expansion or lack of bracing.
	Expansion joints intact (as applicable)	N/A	Where use of expansion joints is critical to the integrity of the mechanical connections to electrical enclosures. With long runs of conduit or tray without separations.
Earthing			
	Earth connections- enclosures, structures, frames, wireways equipment pads,	Check samples annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Where connections are susceptible to weakening from wind, corrosion, rodents, dissimilar material degradation, high storm activity, etc.
	Earth system continuity test	Check samples annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	
	Earth connections – retighten or replace	As needed	
	Conduit or tray fittings and connection strength if used for earth path.	Check samples annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	
Mounting system			
	Support structure rust, corrosion, sagging, deformation, breakage, bolt tightness	Check samples annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Systems with evidence of stress from high loading, choice of materials. Systems in high wind or corrosive areas.

Component/Task		Maintenance procedure interval	Interval basis
	Movement due to settling, expansive soils, frost heave, erosion, etc.	Check frost heave potential annually at beginning of spring for years 1-5, every 3 years thereafter, or event driven	In locations where severe winter temperatures can cause frost heave, or where soil conditions more prone to settling.
	Corrosion of pier footings	Check samples annually in years 1-5 due to corrosive environment. Adjust thereafter based on experience.	Add something here
	Vegetation interfering with system	Annual check in late spring, management as needed.	Sites with significant vegetation growth and management requirements.
Tracker			
	Trackers oriented incorrectly	Performance triggered. Include visual checks with other year 1-5 inspections.	Performance triggered generally unless there is product or site specific history of issues.
	Periodic maintenance – manufacturer specified	Manufacturer specified 3- year checks.	Manufacturer specified, or as deemed necessary due to field history.
Equipment pad			
	Inverter/electrical equipment pad cracking / wear / undermining	Annual checks due to frost heave and heavy rains	Most relevant at sites with less stable soils, heavy rain and flood zones, or seismic activity. settling, expansive soils, frost heave, etc.
	Inverter/pad bolts intact (not loose/damaged)	Annual checks in years 1-5, every 5 years thereafter.	
Roof			
	Adequate drainage, no blockage or pooling	N/A	Degree to which rooftops are adequately sloped and consistent for drainage, level of windblown debris from trees or other sources,
	Vegetation growth in roof array	N/A	Generally dependent on system (product or roof) type and climate.
	Roof penetrations water tight	N/A	Generally incident triggered but possibly dependent on roof age and strength, or prior history of issues.
	New shade items or maintenance obstacles – e.g. satellite dish	N/A	Most relevant where tree trimming is required to prevent excessive shading. Satellite or other equipment additions to commercial and sometimes residential systems
Miscellaneous			
	Debris or stored items at inverter location	Annual checks after rainy season.	Sites with above average construction, upgrade, or other maintenance activity.
	Identify missing, faded or otherwise unusable signs or placards	Annual checks after rainy season at sample inverter equipment pad and combiner locations.	High heat and insolation areas, use of lower-quality sign materials, etc.
	If sprinklers used, check that water is free of corrosion inducing minerals	N/A	Usually not ongoing but needed where filter replacement is necessary.

Component/Task		Maintenance procedure interval	Interval basis
Weather/Data components			
	Sensor alignment, cleanliness, airflow	6-month irradiance sensor cleaning for years 1-5, annual thereafter	Dependent on performance tracking requirements, site conditions of soiling, debris, etc.
	Periodic maintenance for DAS	2 year maintenance protocols as defined by manufacturer	Manufacturer specified or based on field history.
	Periodic calibration	2 year re-calibration/replacement of irradiance. Other devices according to mfg.	
Array cleaning			
	Array / module cleaning	Years 1-5 check of soiling due to nearby farm preparation and harvest activities. Determine if rain is sufficient to keep soiling losses to anticipated 3 % annual.	Cost/Benefit analysis driven, considering site conditions, levels and types of soiling, seasonal impact on performance, cost of cleaning, etc.

Annex G
(informative)

PV system operations

This document does not address the technical and business operational and management process and protocols needed for a complete operations treatment of PV plants or fleets of plants. The operations functions however are important to define.

PV system operations require:

a) Administration. Ensures effective implementation and control of operation and maintenance activities including: archive as-built drawings, equipment inventories, owners and operating manuals, warranties; keep records of performance and O&M measures provided; prepare scopes of work and selection criteria for service providers; contract with suppliers and service providers; prepare budget and secure funding and contingency plans for O&M activities; approve work and process invoices. Integrate physical security with facility security or provide separately, if appropriate.

b) Conduct of operations. Ensure efficient, safe, and reliable process operations including economic NPV/ROI decision support; Maintenance procedures, protocols, indicators, metrics and documentation. Serve as point of contact for personnel regarding operation of PV system and coordinate with others regarding system operation and any required shutdown. Provide instructions regarding defined work tasks scheduled in the morning or evening hours to avoid production losses, electrical hazards, heat stress, and local access. Provide instructions regarding access routes, storage and lay-down areas, and hours when work can be conducted without affecting the mission of the facility.

c) Provisions and directions for the performance of work and to ensure that maintenance is performed safely and efficiently including the formalization and enforcement of safety policy including training for d.c. and a.c. safety, rooftop safety (if rooftop system), minimum number of personnel, (arc flash, lock-out tag-out, etc.). Ensure compliance with any environmental or facility-level policies regarding handling controlled materials such as weed-killer and insecticide.

d) Evaluation and provision on an ongoing basis of sufficient equipment status control – monitor, alarm, analytics to be cognizant of status of all equipment to support operational decision making and optimize monitoring resolution based on economic benefit. Compare results of system monitoring to benchmark expectation and push reports to facility stakeholders.

e) Design and maintenance of operator knowledge, protocols, documentation and training to ensure that operator knowledge and performance will support safe and reliable plant operation. Confirm and enforce qualifications of service providers.

Examples of operations functions that are used to drive maintenance decisions which are beyond the scope of this specification:

f) Operations that relate to forecasting, grid-driven curtailment, and operational considerations driven by factors outside of the system status are not covered in this specification.

g) Services other than energy delivery (voltage regulation; power factor correction; etc.) are not described in this specification.

h) Work control system: control the performance of maintenance in an efficient and safe manner such that economical, safe, and reliable plant operation is optimized.

i) Policy development such as work guidelines preventive maintenance and corrective maintenance optimization and detail planning, budgeting and cost benefit justifications.

j) System design or operational upgrades such as re-programming 1-axis trackers to stay in the horizontal position on overcast days, to better capture the diffuse light.

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(*Continued from second cover*)

The technical committee has reviewed the provisions of the following International Standards referred to in this adopted standard and has decided that they are acceptable for use in conjunction with this standard.

International Standard	*Title*
IEC 62020	Electrical accessories — Residual current monitors for household and similar uses (RCMs)

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding of numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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