



Sustainable Integration of Renewable Energy Sources (Solar PV) with SEC Distribution Network Low Voltage and Medium Voltage

Manual for the Maintenance of Solar PV systems (>100kWp)

Version 2

Table of contents

1	SCOPE.....	3
1.1	Notice to users	3
1.2	Consumer undertakings	3
2	REFERENCE DOCUMENTS	4
3	COMPANION DOCUMENTS.....	5
4	TERMS AND DEFINITIONS.....	6
5	GLOSSARY.....	7
6	SAFETY ISSUES	8
6.1	Preface.....	8
6.2	Lockout/Tagout	8
6.3	PPE and other Safety Equipment	8
6.4	Safe Operation of Electrical Disconnects	9
6.5	PV-Specific Signage and Warnings	9
7	O&M OF SOLAR PV SYSTEMS.....	11
8	MAINTENANCE OF THE SOLAR PV SYSTEMS	12
8.1	Preface.....	12
8.2	Maintenance approaches.....	12
8.2.1	Preventative Maintenance	12
8.2.2	Condition-based Maintenance	13
8.2.3	Corrective Maintenance	13
8.2.4	Extraordinary Maintenance.....	14
8.2.5	Additional Services	14
9	PREVENTATIVE MAINTENANCE ACTIVITIES FOR THE SOLAR PV SYSTEMS EXCEEDING 100 KW ..	16
9.1	Preface.....	16
9.1.1	PV modules.....	16
9.1.2	Cleaning the PV modules.....	16
9.1.3	PV array and DC wirings	17
9.1.4	Inverters	18
9.1.5	AC section and wirings	18
10	SPARE PARTS MANAGEMENT	19
11	KEY PERFORMANCE INDICATORS	21
11.1	Solar PV system KPIs.....	21
11.2	O&M Contractor KPIs	21

1 SCOPE

The PV Systems are generally considered to be very low maintenance means of power generation. However, Solar PV systems do require some level of preventative and corrective maintenance to perform over a lifetime that can exceed 20 years. Additionally, the level of maintenance required or recommended for a correct performance can vary considerably based on the Customer's preference or contractual obligations for power production.

This document has been developed with particular regards to the Solar PV systems exceeding 100 kW, however Consultants and Contractors can also apply these recommendations in order to assure the optimal operation and performance of the PV systems of smaller capacity.

Finally, the end-of-life phase of PV Systems is addressed in order to summarize the newest trends in PV recycling, especially for PV modules.

1.1 Notice to users

This document is for use of employees of SEC, Consumers, Consultants and Contractors. Users of this guideline should consult all applicable laws and regulations. Users are responsible for observing or referring to the applicable regulatory requirements and specific Standards. SEC does not, by the publication of these Guidelines, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Users should be aware that this document may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. These Guidelines at any point in time consist of the current edition of the document together with any amendments, corrigenda, or errata then in effect. All users should ensure that they have the latest edition of this document, uploaded on SEC website.

Finally, the user shall refer to Saudi Building Code – Section 401 - Chapter 712, as well as to applicable SASO Standards or International Standards mentioned in these SEC documents, unless differently indicated in other SEC documents related to Small-Scale Solar PV Systems Regulations.

1.2 Consumer undertakings

As stated by the Article 14 of the *Small-Scale Solar PV Systems Regulations - Electricity & Cogeneration Regulatory Authority (ECRA) – ERD-TA-012 (v.02/19)* (ECRA Regulations):

- It is the responsibility of the Eligible Consumer to ensure that regular and routine maintenance of the PV Systems and its corresponding components is undertaken.
- It is the responsibility of the Eligible Consumer to ensure that the frequency of the required maintenance and corresponding tests are conducted.

Further responsibilities are specified in the *Guidelines for Consumers, Consultants and Contractors to connect a Small-Scale Solar PV System to SEC distribution networks* (Connection Guidelines).

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

In particular the Consumer shall be responsible for:

- the installation, operation and maintenance of all the equipment forming the PV system;
- the protection and safety of the generating facility or the generating units, respectively;
- applying for an insurance against damages to the PV System caused by storm, hail, lightning, over voltage, theft, fire or any other external hazards.

Whereas the O&M Contractor appointed by the Consumer shall be responsible for:

- providing operation and maintenance services.

2 REFERENCE DOCUMENTS

- [1] Small-Scale Solar PV Systems Regulations - Electricity & Cogeneration Regulatory Authority (ECRA) – ERD-TA-012 (v.02/19)
- [2] Guidelines for Consumers, Consultants and Contractors to connect a Small-Scale Solar PV System to SEC distribution networks
- [3] Inspection and Testing Guidelines
- [4] Inspection and Testing Checklists
- [5] NREL – Best Practices in PV System Operations and Maintenance (2015)
- [6] Solar Power Europe – O&M Best Practices Guidelines / Version 1.0 (2016)
- [7] Solar ABC – PV System Operations and Maintenance Fundamentals (2013)
- [8] IRENA-IEA/PVPS – End-of-Life management Solar Photovoltaic Panels (2016)
- [9] CENELEC - European Standards for Waste Electrical and Electronic Equipment (2017) - <https://www.cenelec.eu/news/publications/publications/weee-brochure.pdf>

3 COMPANION DOCUMENTS

The documents listed hereinafter have to be considered a compendium of the current document. Therefore, they should be carefully read in addition to this.

- a) Technical Standards for the Connection of Small-Scale Solar PV Systems to the LV and MV Distribution Networks of SEC
- b) Guidelines for Consumers, Consultants and Contractors to connect a Small-Scale Solar PV System to SEC distribution network
- c) Inspection and Testing Guidelines
- d) Inspection and Testing Checklists
- e) Safety related to the installation of the Solar PV systems
- f) PV on buildings and safety
- g) Best Practice for Designing a PV system

4 TERMS AND DEFINITIONS

AC module – PV module with an integrated inverter in which the electrical terminals are AC only

Connection Point - The location at which a solar PV generating system is connected to the distribution network and where the main electricity meter is installed.

Data sheet – Basic product description and specification (Note: Typically, one or two pages, not a full product manual)

In – The nominal rating of an overcurrent protection device

Inspection – Examination of an electrical installation using all the senses in order to ascertain correct selection and proper erection of electrical equipment

Interface Protection (IP) - The electrical protection required to ensure that either the generating plant and/or any generating unit is disconnected for any event that could impair the integrity or degrade the safety and reliability of the distribution network.

Inverter – Electric energy converter that changes direct electric current to single-phase or polyphase alternating current

Irradiance (G) – Incident flux of radiant power per unit area expressed in W/m^2

Irradiation (H) – Irradiance integrated over a specified time interval expressed in kWh/m^2

PV array – Assembly of electrically interconnected PV modules, PV strings or PV sub-arrays.

PV cell – The most elementary device that exhibits the photovoltaic effect, i.e. the direct non-thermal conversion of radiant energy into electrical energy

PV module – Smallest complete environmentally protected assembly of interconnected PV cells

PV string – Circuit of one or more series-connected PV modules

PV string combiner box – Junction box where PV strings are connected which may also contain overcurrent protection devices, electronics and/or switch-disconnectors

PV sub-array – A subset of a PV array formed by parallel-connected PV strings.

Small-Scale Solar PV System – As per ECRA Regulations, a solar PV installation of not more than 2MW and not less than 1kW capacity that is installed in one Premises and connected in parallel to the Distribution Network. From the purposes of this document, and in line with the definition DCD40 of the Distribution Code, this System is to be considered as a power station with one or more Small-Scale Solar PV Units. Besides, circuits and auxiliary services are also to be considered part of a Small-Scale Solar PV System. For avoidance of doubt, in this document the generic term Solar PV System will be considered equivalent to Small-Scale Solar PV System.

Switch – Mechanical device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions. In addition, it is able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions.

Testing – implementation of measures in an electrical installation by means of which its effectiveness is proved (Note: It includes ascertaining values by means of appropriate measuring instruments, said values not being detectable by inspection)

Verification – all measures by means of which compliance of the electrical installation to the relevant standards are checked

5 GLOSSARY

In addition to those in 4 which need a definition, the following acronyms and symbols are used throughout the document:

c-Si	crystalline silicon
CENELEC	European Committee for Electrotechnical Standardization
ECRA	Electricity and Co-Generation Regulatory Authority
IEC	International Electromechanical Commission
kWp, Wp	kW peak, W peak (units usually adopted to refer to the size of PV modules)
LV	Low Voltage (namely 220/127 V or 380/220 V or 400/230 V)
MV	Medium Voltage (namely 13.8kV or 33 kV)
O&M	Operation and maintenance
PV	(Solar) PhotoVoltaic
SEC	Saudi Electricity Company
V	Voltage
WEEE	Waste Electrical and Electronic Equipment

6 SAFETY ISSUES

6.1 Preface

Safety begins with adequate planning, preparation and training. Effective safety policies must be in place and employees and contractors must be familiar with — and committed to following — safety procedures in order to prevent accident or injury.

Major safety requirements during PV servicing include the proper use of lockout/tagout procedures, the use of personal protective equipment (PPE), procedures for safely disconnecting live circuits, and appropriate observation of and compliance with all PV-specific system signage and warnings.

6.2 Lockout/Tagout

Lockout/Tagout (LOTO) procedures are designed to ensure safe working practices and must be strictly followed whenever systems are de-energized prior to servicing.

LOTO is required when energized equipment is serviced or maintained, safety guards are removed or bypassed, a worker has to place any part of his or her body in the equipment's point of operation, or hazardous energy sources are present.

Lockout/tagout steps include:

- notify others that the equipment will be shut down,
- perform a controlled shutdown to power down the equipment,
- open all of the energy isolating devices identified on the equipment's specific LOTO procedure,
- lock and tag all energy isolating devices,
- dissipate or restrain stored or residual energy,
- verify that the equipment is completely de-energized by attempting to cycle it, and
- verify that the equipment is completely de-energized by testing for voltage with a voltmeter.

Proper LOTO labeling includes:

- name of the person placing the LOTO and the date placed,
- details regarding the shutdown procedure for specific equipment,
- a list of all of the energy sources and isolating devices, and
- 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. The lockout devices, such as padlocks, shall be approved for LOTO applications. Safety protocols need to be followed when re-energizing equipment, including notifying others that the system is about to be energized.

6.3 PPE and other Safety Equipment

Service personnel must know what PPE is required for a specific task and wear it while completing the task. PPE includes fall protection, arc flash protection, fire-rated clothing, hot gloves, boots, and

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

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 in 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.

Rubber-insulating gloves are the first line of defense against electric shock. They should always be worn with protective leather gloves over them and inspected before each use. Additionally, gloves need to be re-certified or replaced at regular intervals, beginning six months after they are placed in service. Insulated hand tools provide an additional layer of shock protection. 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. Tasks such as performing thermal imaging on operating inverters with opened coverings or doors or verifying voltages in switchgear commonly require arc flash rated PPE.

Even when not required by statute or regulations, general industrial safety equipment such as hardhats, safety glasses, boots, fire-rated clothing, and safety vests are strongly recommended when working on construction sites or around live electrical equipment. The jobsite also must be equipped with appropriate fire extinguishers and first aid supplies and all personnel must have proper training in their use. Finally, at least two qualified people trained in cardiopulmonary resuscitation (CPR) should be on site at all times.

6.4 Safe Operation of Electrical Disconnects

Switching on or off an electrical contactor or disconnect is a process often taken for granted as safe but it can be one of the more dangerous tasks involved in maintaining a PV system. Workers must wear proper PPE when operating disconnectors, and care should be taken to use the proper technique for maneuvering switches.

Some of the switches used to control the DC circuits of PV systems are not rated for load-break operation. Non-load-break-rated switches, which must be labeled as non-load-break-rated, must never be opened while the system is operating. Before opening a DC switch that is not rated for load break, the system should be shut down by turning off the connected inverter.

The hinges of most disconnect switches are on the left side of the switch and the handles are on the right. A recommended safety protocol is to follow the left-hand rule, which involves standing to the right side of the switch and using the left hand to throw the switch. This ensures that the worker's body is not in front of the switch should an arc flash occur.

6.5 PV-Specific Signage and Warnings

Qualified personnel must use properly rated equipment and be trained for servicing the higher voltage systems. Particular care must be taken to observe and follow warning labels reading "DO NOT DISCONNECT UNDER LOAD" located on module connections, combiner boxes, disconnectors, and some inverter switches not designed as a load-break switch. Failure to heed these warning labels can lead to instrument malfunction, arcing, fires, and personnel injuries.

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

Although it is impossible to compile a list of universally applicable safety guidelines, we suggest the following steps as crucial to safe work:

- Before operating the PV system, read all instructions for each product.
- All system components must be assumed to be energized with maximum dc voltages (up to 1500 V) until personnel verify that the voltage has been removed.
- All enclosure doors should remain closed with latches tightened, except when they must be open for maintenance or testing.
- Only qualified personnel who meet all local and governmental code requirements for licensing and training for the installation of electrical power systems with AC and DC voltages up to 1500 V should perform PV system servicing.
- To reduce the risk of electric shock, only qualified persons should perform servicing other than that specified in the installation instructions.
- In order to remove all sources of voltage from the inverter, the incoming power must be de-energized at the source. This may be done by opening the AC disconnect and the DC disconnect. Follow manufacturer guidelines for specifics of how to de-energize the inverter. In addition, allow a minimum of five minutes for the dc bus capacitors to discharge after disconnecting the power, always testing that voltage is reduced to touch-safe levels before working on the system.
- Always follow LOTO procedures.
- Always check for ground faults. If there is a ground fault, there may be a voltage potential between the inverter and ground. Further, check that the normally grounded pole is properly grounded and has not been energized by a fault.
- Do not work alone when servicing PV equipment. A team of two is required until the equipment is properly de-energized, locked-out, and tagged-out. Verify with a meter that the equipment is de-energized.
- Do not open a string combiner fuse holder without first confirming that there is no current flowing on the circuit.
- Do not disconnect (unplug) module leads, jumpers, or homerun wires under load.

7 O&M OF SOLAR PV SYSTEMS

An effective O&M Program is necessary to assure the optimal performance of the Solar PV systems regardless their capacity. However the higher the capacity the more important is the definition and implementation of a proper Maintenance Program suitably tailored to the characteristics of the Solar PV system, such as the location and layout of the PV arrays, the technology of the PV modules, the characteristics of the inverters, etc.

The Consultants and Contractors need to prepare and submit adequate documentation regarding the O&M program of the Solar PV system. The requirements and the information that shall be submitted in the frame of the connection process are specified by the *Small-Scale Solar PV Systems Regulations - Electricity & Cogeneration Regulatory Authority (ECRA) – ERD-TA-012 (v.02/19)* (ECRA Regulations) and the *Guidelines for Consumers, Consultants and Contractors to connect a Small-Scale Solar PV System to SEC distribution networks* (Connection Guidelines).

The Connection Guidelines provide the Consultants and Contractors with a detailed specification of the design documentation they are supposed to deliver when applying for “Design Evaluation and Approval”. This design documentation shall include the O&M Manual that shall cover as a minimum the following topics:

- Shutdown/isolation procedure
- PPE and other safety equipment
- Spare parts management
- Preventative maintenance activities
- Warranty documentation

Throughout the duration of its contract, the provider of the maintenance service is required to commit itself in order to implement the procedures and measures defined by this operation and maintenance manual.

In addition to the documentation requirements set by the Connection Guidelines that apply to any Solar PV systems, an O&M Program shall be submitted when applying for “Inspection and Energization”, in case of PV Systems with capacity exceeding 100kW.

The present document provides Consultants and Contractors with proper recommendations in order to issue this detailed O&M Program covering all the necessities of the Solar PV equipment, focusing the topics that are highlighted in the next chapters.

8 MAINTENANCE OF THE SOLAR PV SYSTEMS

8.1 Preface

A professional O&M service package ensures that the photovoltaic system will maintain high levels of technical and consequently economic performance over its lifetime. Nowadays, especially in regard to Solar PV systems of very high power capacity, it is well acknowledged by all stakeholders that high quality of O&M services mitigates the potential risks, improves the levelized cost of electricity (LCOE) and positively impacts the return on investment (ROI). This can be highlighted if taken into account the lifecycle of a PV project which can be broken down into the 4 phases below. The O&M phase is by far the longest phase.]

1. Development (some months)
2. Construction (some months)
3. Operation & Maintenance (typically 20-35 years)
4. Dismantling or repowering (some months)

Therefore, the benefits for increasing the quality and in contrast the risks for neglecting O&M are high. With the understandable focus on maximizing return on investment (ROI) and system production, system uptime is a key O&M objective. For example, inverters that are offline can have a dramatic negative impact on the ROI of a PV system.

Inverter failure rates are important to ROI, but equally or even more important than how often an inverter goes offline is how quickly it can be placed back into service. Diagnosing and correcting power production deficiencies is also important to maximizing availability of system components.

Although defined for Solar PV systems exceeding a power capacity of 100 kW, Consultants and Contractors are warmly suggested to check and exploit these recommendations also for systems of lesser power capacity in order to increase the quality of their service as well as the performance of the Solar PV systems.

8.2 Maintenance approaches

8.2.1 Preventative Maintenance

Preventative Maintenance activities are the core element of the maintenance services to a solar PV system. It comprises regular visual and physical inspections, as well as verification activities with a specific task periodicity of all key components which are necessary to comply with the operating manuals and recommendations issued by the Original Equipment Manufacturers (OEMs). It must also maintain the equipment and component warranties in place and reduce the probability of failure or degradation. The activities should also comply with respective legal issues e.g. national standards for periodic inspection of certain electrical components. Technical experience and relevant track records will optimize the activities further. The O&M contract should include this scope of services and each task periodicity.

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

This maintenance is carried out at predetermined intervals or according to prescribed OEM manuals. These are included in a detailed Annual Maintenance Plan which provides an established time schedule with a specific number of iterations for carrying out the maintenance.

It is under the responsibility of the O&M Contractor to prepare the task plan until the end of the contract, following the periodicities contracted. These activities should be reported to the Client. The reporting of this activity is important to follow up the plan.

The “O&M Program” includes a list of regular inspections per equipment (e.g. module, inverter etc.) and per unit of equipment (e.g. sensors, fuses etc.). Examples of preventative maintenance can also be ad-hoc replacement of parts of inverters or sensors. In general, outside of the equipment warranty terms or after its expiration it is important to follow detailed preventative maintenance procedures, which are agreed upon in the Annual Maintenance Plan.

In cases, where downtime is necessary to perform preventative maintenance, the execution of preventative maintenance activities during the night would be considered best practice as the overall power generation would not be affected.

8.2.2 Condition-based Maintenance

Condition-based maintenance is the practice of using real-time information from data loggers to schedule preventative measures such as cleaning, or to head off corrective maintenance problems by anticipating failures or detecting them early. Because the measures triggered by condition are the same as preventative and corrective measures, they are not listed separately. Rather, condition-based maintenance affects when these measures occur, with the promise of lowering the frequency of preventative measures and reducing the impacts and costs of corrective measures.

8.2.3 Corrective Maintenance

Corrective Maintenance covers the activities performed by the Maintenance team in order to restore the Solar PV system, equipment or component to a status where it can perform the required function. The CM takes place after failure detection either by remote monitoring and supervision or during regular inspections and specific measurement activities.

Corrective Maintenance includes three maintenance activities: 1) Fault Diagnosis also called troubleshooting to identify fault cause and localization, 2) Temporary Repair and 3) Repairs. The last two actions are physical actions taken to restore the required function of a faulty item. After Temporary Repairs the faulty items are able to perform their required function for a limited interval and until a Repair is carried out.

The scope of CM activities and its interaction with preventative maintenance requires specific attention and it should be properly defined in the Maintenance contract. Usually the corrective maintenance is contractually obliged to comply with certain response times and / or minimum repair times.

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

Interventions for reconditioning, renewal and technological updating, save for the cases where those actions are directly included in the scope of the contract, should be excluded from CM and included in the Extraordinary Maintenance.

8.2.4 Extraordinary Maintenance

Extraordinary Maintenance actions are necessary when major unpredictable events take place in the plant site, which requires substantial activities and work to restore the previous plant conditions or any maintenance activity generally not covered or excluded from the O&M Contract.

Generally, these activities are being billed separately in the O&M contract and are managed under a separate order. It is advisable that the O&M contract includes the rules agreed among the parties to prepare the quotation and to execute the works. Either a “lump sum turn-key” or a “cost-plus” method can be used for such purpose.

Extraordinary maintenance interventions are required for:

- damages that are a consequence of a Force Majeure event
- damages as a consequence of a robbery or a fire or other occurrences
- serial defects on equipment, occurring suddenly and after months or years from plant start-up
- modifications required by regulatory changes.

Although not necessarily maintenance interventions, also the improvement, revamping (restoring and optimization) activities can be included in the extraordinary maintenance list, or at least managed with the same rules.

8.2.5 Additional Services

The O&M agreement may foresee additional services to be performed by the O&M Contractor upon the Customer’s request. These services are being requested on demand and can either be priced per service action or based on hourly rates applicable to the level of qualification of staff required to perform the works. These hourly rates usually escalate at the same rate as the O&M Service fee. The following non-exhaustive list provides an overview of additional services:

- Module Cleaning
- Vegetation Management (if on ground)
- Road Maintenance
- Snow Removal
- Pest Control
- Waste Disposal
- Maintenance of buildings
- Perimeter fencing and repairs
- Maintenance of Security Equipment
- String Measurements – to the extent exceeding the agreed level of preventative maintenance
- Thermal Inspections – to the extent exceeding the agreed level of preventative maintenance

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

- Handle contract management of contracts with component suppliers.
- Handle contract management of contracts with authorities (ex. Meter weekly/monthly readings and data entry on fiscal registers or in authority web portals for FIT tariff assessment (where applicable)
- Design and execute the disconnection, decommissioning, dismantling, recycling and restoration of the installation site to its original configuration.

It should be noted that some of these items are to be found as a part of the preventive maintenance. This depends on the agreement between the Customer and the O&M Contractor.

9 PREVENTATIVE MAINTENANCE ACTIVITIES FOR THE SOLAR PV SYSTEMS EXCEEDING 100 KW

9.1 Preface

The preventative maintenance activities described here below are to be considered as a generic list that shall be integrated and refined according to the specific needs of the Solar PV system to be maintained.

Many of the listed activities can be carried out as described in the “Inspection and Testing Guidelines”. Contractors may also take advantage of the “Inspection and Testing Checklists” in order to report the outcome of inspection and testing activities.

9.1.1 PV modules

ID	Activity	Interval	Notes
1.1	Infrared inspection	Annual	Use infrared camera to inspect for hot spots and bypass diode failure.
1.2	Inspection: corrosion and encapsulate yellowing	Annual	
1.3	Torque check of bolts and visual inspection	Annual	
1.4	Test output of damaged PV modules	Annual	Only for the followings: – that exhibit cracked glass – bubble formation – oxidation or discoloration of busbars – hot spots (bypass diode failure) – corrosion of ribbons to junction box

9.1.2 Cleaning the PV modules

ID	Activity	Interval	Notes
1.5	Cleaning	Condition or study dependent (1 ÷ 6 months)	– Plain water (with mild dishwashing detergent if necessary) – Compressed air Do not use brushes, any types of solvents, abrasives, or harsh detergents. At all times, the O&M manual of the PV modules manufacturer should be taken into consideration for any O&M actions.

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

9.1.3 PV array and DC wirings

ID	Activity	Interval	Notes
2.1	Test open circuit voltages of strings	2 years	Log measured voltages
2.2	Check corrosion on mounting system	Annual	Check all hardware for signs of corrosion, remove rust and re-paint if necessary.
2.3	Look for damaged PV modules	Annual	Walk through each row of the PV array and check the PV modules for any damage. Report any damage to rack and damaged modules for warranty replacement. Note location and serial number of questionable modules.
2.4	Check mounting system stability	Annual	Inspect ballasted mounting system for abnormal movement
2.5	General cleaning	Annual	Determine if any new objects, such as vegetation growth, are causing shading of the array and move them if possible. Remove any debris from behind collectors and from gutters.
2.6	Remove bird nests from array and rack area	Annual	
2.7	Nesting vermin removal, eventual nesting vermin prevention	Annual	
2.8	Test system grounding	Annual	Check circuit continuity
2.9	Scan combiner boxes with Infrared camera to identify loose or broken connections	Annual	Check also that no fuses have blown and that all electrical connections are tight. Re-torque all electrical connections in combiner box. Check for water incursion and corrosion damage.
2.10	Inspect cabling	Annual	check signs of cracks, defects, pulling out of connections; overheating, arcing, short or open circuits, and ground faults.
2.11	Check proper position of DC disconnect switches.	Annual	
2.12	Look for any signs of intrusion by pests such as insects and rodents	Annual	Remove any nests from electrical boxes (junction boxes, pull boxes, combiner boxes) or around the array. Use safe sanitation practices because pests may carry disease.
2.13	Check grounding braids for wear	Annual	

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

9.1.4 Inverters

ID	Activity	Interval	Notes
3.1	Observe instantaneous operational indicators on the faceplate of the inverter to ensure that the amount of power being generated is typical of the conditions	Monthly	Compare current readings with diagnostic benchmark. Inspect Inverter housing or shelter for physical maintenance required if present. At all times, the O&M manual of the PV inverter manufacturer should be taken into consideration for any O&M actions.
3.2	Replace transient voltage surge suppression devices	As per manufacturer	
3.3	Install any recent software upgrades to inverter programming or data acquisition and monitoring systems	As per manufacturer	Check every 5 years anyway
3.4	Clean (vacuum) dust from heat rejection fins	Annual	
3.5	Replace any air filters on inverters	As needed	
3.6	Test overvoltage surge suppressor devices in inverters	5 years	

9.1.5 AC section and wirings

ID	Activity	Interval	Notes
4.1	Inspect electrical panels for corrosion or intrusion of water or insects.	Annual	Seal boxes if required
4.2	Check position of disconnect switches and breakers.	Annual	
4.3	Exercise operation of all protection devices	Annual	
4.4	Transformer/panel inspection	Annual	Inspect transformer meter, oil and temperature gauges, include housing container, or concrete housing if present

10 SPARE PARTS MANAGEMENT

Spare Parts Management is an inherent and substantial part of the O&M Program. It should ensure that spare parts are available in a timely manner for corrective maintenance in order to minimize the downtime of (a part of) a Solar PV system. As regards to spare part management, the following considerations have to be made:

- Ownership and responsibility of insurance
- Stocking level
- Location of storage (Proximity to the PV system, Security, Environmental conditions)

Depending on the agreement between the Customer and the O&M Contractor, spare parts management may be a responsibility of one of the two. Ownership of spares is with the Customer while normally the storage (and hence insurance) responsibility is on the shoulders of the O&M Contractor. Besides ownership matters, it is above all important to make sure (upon mutual agreement) that one of the parties undertakes the responsibility of insuring the spares.

The O&M Contractor shall act as the main interface for the spare parts management. Access to the spare parts inventory books should be ensured and responsibility to order spare parts and goods for the replenishment of the spare parts inventory should be assumed.

For a new PV system, the initial spare parts are procured by the EPC. However, it is best practice, if the EPC and O&M Contractor have agreed upon the list. The O&M Contractor is free to add additional spares that he deems necessary to meet the contractual obligations (e.g. reaction time, availability guarantees etc.).

Regarding the stocking level, due to the very different configurations and sizes of solar PV systems, it is very difficult to define a hard number for stocking specific spare parts. The determination of spare items and quantity is also driven by the O&M Contractor's contractual commitments on reaction time and/or plant availability and other contractual details.

It is important to differentiate between Consumables and Spare Parts. Consumables are low cost and frequently used spare parts, like for example fuses, that the O&M Contractor should have always on stock and maintenance crews should carry with them, together with the relevant tools, during every site visit.

In an attempt to define the stocking levels of Spare Parts and Consumables, the following parameters should be taken into consideration:

- Frequency of failure
- Impact of failure
- Cost of Spare Part
- Degradation over time
- Possibility of consignment stock with the manufacturer

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

Generally, it is not economically feasible to stock spare parts for every possible failure in the plant. Therefore, the O&M Contractor together with the Customer should define the stocking level of specific spare parts that make economic sense (Cost Benefit Analysis). For example, if a specific part in a solar PV system has a frequency of failure at least of once every year or more and the loss of revenues due to such failure is greater than the spare part cost, such spare is important to have it available.

Normally there are certain spare parts that could be considered as essential to have as those in the list below:

- Fuses for all equipment (combiner boxes, inverters, etc.) and fuse kits
- PV modules
- Inverters (where string inverters are used) or inverter spares (power stacks, circuit breakers, contactor, switches, controller board, etc.)
- Cables and DC connectors
- Harnesses and cables
- Screws and other supplies and tools

Regarding the storage and warehousing, this should be done in locations where the spare parts cannot be damaged (e.g. from humidity or high temperature variations). Additionally, the store sites should have appropriate security measures.

The decision for having either onsite or a warehouse facility or just an agreement with the suppliers to provide the spare parts depends on many factors, including the kind of part, the commercial agreement, and the facilitation of the service provision.

While proximity to the plant is a parameter that needs to be evaluated on a per case basis, Security and Environmental conditions are very important as they could lead to a loss of property either through robbery or damage.

11 KEY PERFORMANCE INDICATORS

Key Performance Indicators (KPIs), provide the Customer with a quick reference on the performance of the PV power plant. The KPIs are divided into the following categories:

- Solar PV system KPIs, which directly reflect the performance of the PV power plant. PV plant KPIs are quantitative indicators.
- O&M contractor KPIs, which reflect the performance of the service provided by the O&M Contractor. O&M Contractor KPIs are both quantitative and qualitative indicators.

The O&M Contractor is generally responsible for the calculation of the KPIs and reporting to the Customer. It is important to underline that the O&M Contractor cannot and is thus not responsible for providing contractual guarantees for all the KPIs listed below.

11.1 Solar PV system KPIs

Solar PV system KPIs can be split into two groups:

- KPIs from raw data measurements. The following list of data (non-exhaustive) can be obtained directly from the PV plant and used to calculate KPIs.
 - AC Power produced (kW)
 - AC Energy produced (kWh)
 - AC Energy metered (kWh)
 - Reactive power (kVar)
 - Irradiation (W/m²)
 - Ambient and module temperature
 - Alarms, status code and duration
 - Outages, unavailability events
- KPIs using the raw data from the Solar PV system. These calculated KPIs give a more balanced overview of the operation of the PV plant and can be calculated over different time periods, but often they are computed on an annual basis. Suggestions for calculated KPIs for a Solar PV system are:
 - Reference Yield
 - Specific Yield
 - Expected Yield
 - Technical Availability or Uptime
 - Contractual Availability
 - Energy-based Availability
 - Performance Ratio
 - Temperature-corrected Performance Ratio

11.2 O&M Contractor KPIs

As opposed to power plant KPIs, which provide the Customer with information about the performance of their asset, O&M Contractor KPIs assess the performance of the O&M service.

Suggestions for O&M Contractor's KPIs are:

- Acknowledgement Time
- Intervention Time

MANUAL FOR THE MAINTENANCE OF THE SOLAR PV SYSTEMS

- Response Time
- Resolution Time
- Reporting

Experience of the O&M Contractor with Solar PV systems in a region, grid environment and/or with Solar PV systems equipped with certain technology or size can play an important role. This is quite relevant for the selection of the O&M Contractor and can be tracked by the owner over time (track record).