36 Maplewood Avenue
Portsmouth, New Hampshire 03801

September 23, 2020

TOWN OF SANBORNTON
PO BOX 124
SANBORNTON, NH 03269

Attn: Stephen Laurin – Zoning Enforcement Officer/Planning Board Assistant

RE: RESPONSE TO PLANNING BOARD MEMO
TAX MAP 22 LOTS 14, 19-4&5
TOWER HILL RD SANBORTON, NH

Dear Stephen:
New England Solar Garden Corp. (NESG) prepared this letter in response to the comments and recommendations outlined in your memo dated July 23, 2020. Below please find your comments in bold and initialized with our response following.

Revised plans to be submitted by Wednesday, September 23, 2020
Nobis submitted an updated plan set on September 23, 2020.

Replenishment of the engineering escrow balance sufficient to allow for the Town's review of revised plans prior to plan submission (the current escrow balance is $1,411.50)
A check for $3,600 was provided with the updated plans, submitted by Nobis.

A representative of NE Solar Garden to be physically present at the meeting
Michael Redding, P.E. the Director of Engineering and Operations for New England Solar Garden will be present at the October 15, 2020 planning board meeting.

Report on progress regarding the Eversource Interconnection agreement
Due to the Governor's third veto in September 2020 and the failed attempt for a third year in a row by the representatives to overturn the veto, we are required to re-submit so we can plan for this project to fall into the Community Choice Aggregate (CCA) program versus the General Net Metering (GNM) program. Due to the size of this project we are not eligible for the GNM, as this is limited to 1 MW AC maximum project size. The CCA program was passed in November 2019 and allows for municipalities to aggregate its resident's power usage into a power purchase agreement with a supplier. There is no project limit under the CCA program.

Proposed mitigation of visual impacts (Zoning Ordinance – Art. 4.Z.5(a))
The revised plans show the greater than 50-foot undisturbed buffer along all property lines that abut Old Range Road and Parcels 22-13 (the Jacksons) and 22-15 (the Whitemores). The narrowest undisturbed buffer is 65 ft along the property line shared with Parcel 22-13. Additional buffering will be provided by the addition of 30 evergreen trees in an area along Old Range Road (see Sheet C-2.1) to

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mitigate visual impacts potentially Parcel 15-102 (the Judds). Similarly, 30 evergreen trees will be placed along the shared property line with Parcel 22-13 where the existing undisturbed buffer requires mitigation, as determined by the Town of Sanbornton Planning Board in conjunction with the property owners of Parcel 22-13 (see note on Sheet C-2.1). Furthermore, a green, woven polypropylene mesh will be placed over the fencing mesh to provide even further mitigation of visual impacts. A detail has been provided in the revised plans depicting the plantings with and without the mesh. We feel these mitigation measures are sufficient to reduce the visual impacts significantly and address the comments received from abutters.

Provision of adequate screening (Zoning Ordinance – Art. 4.Z.5(b & g); also Site Plan Review Regulations – Section V.K)
See above response regarding mitigation of visual impacts.

Submission of application for proposed Lot Line Adjustment between lots 19-2 and 19-5 (Tax Map 22)
The proposed southern array has reduced in size since our last plan submittal. The lot line adjustment is no longer required.

Discussion with Fire Chief/Emergency Management Director regarding access, cul-desacs, and training of emergency responders, etc.
NESG met with Chief Dexter on September 16, 2020. We shared our preliminary plans showing the access, solar array layout and electrical connections. Chief Dexter expressed concern about accessing the eastern array if a technician or construction worker needs emergency medical services (e.g., broken ankle). NESG offered to gift to the department a Utility Terrain Vehicle (UTV) with an EMS slide in skid unit similar to ones manufactured by Kimtek Corporation of Orleans, Vermont. This gift would be provided upon completion of construction. Additionally, Chief Dexter expressed concern over training needs for his staff to manage a fire inside the solar array area. NESG is prepared to support the fire department with this training, upon completion of construction.

Access easements across properties to allow for service/maintenance of arrays, etc.
An access easement will be required from the Giunta's to access the northern and southern solar arrays. We received a verbal approval from the Giunta's for the access shown on the plans. Additionally, an access easement from Jon and Nancy Sanborn is required for access to the eastern solar array. We have received verbal approval from the Sanborns for the access shown on the plans. We will finalize and record these easements upon approval of the plan by the planning board. We request the Planning Board make this a condition of approval.

Verification of driveways and dwellings within 100 feet of project boundaries
Nobis has performed the verification of driveways and dwellings within 100 feet of the project boundaries. Documentation has provided to support this effort.

36 Maplewood Avenue
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Interconnection agreement with Eversource (Zoning Ordinance – Art. 4.Z.4(a)(13))
As mentioned above, we are in the process of submitting a new interconnection application to Eversource for inclusion in the CCA program. We will provide the Planning Board a copy of this application as soon as completed and after it is submitted.

Stormwater Management Report, and Soil Erosion and Sediment Control Plan (Zoning Ordinance – Art.4.M and 4.Z.4(a)(6))
Nobis provided a Stormwater Management Report and Soil Erosion and Sediment control Plan as part of its September 23, 2020 submittal.

Complete operation, maintenance, and safety plans (Zoning Ordinance – Art. 4.Z.4(a)(13))
Enclosed is a copy of the PV System Operations and Maintenance Fundamentals report prepared by the Solar America Board for Codes and Standards. This report provides a comprehensive summary of the operation, maintenance, and safety requirements for the photovoltaic solar array system. NESG proposes to use this comprehensive summary as our manual until final details of the solar array technology are completed. We will submit a revised plan/manual up completion of the technology selection; or a supplement to this report to address site specific details.

All State and Federal environmental permits (Art.4.Z.4(a)(1)
NESG is working concurrently with the planning board application to obtain state and federal permits. This project will require an Alteration of Terrain permit for disturbing greater than 2.2 acres, a Minor Impact Wetlands permit for the northern array access drive and associated culvert crossings (two). Prior to construction, a Construction General Permit will be obtained from the US Environmental Protection Agency. We request the planning board make these permit a condition of approval.

Sincerely,

NEW ENGLAND SOLAR GARDEN CORP.

Michael J. Redding, P.E., C.P.E.S.C.
Director of Engineering and Operations

PV System Operations and Maintenance Fundamentals

Prepared by

Josh Haney
Adam Burstein
Next Phase Solar. Inc.

August 2013

Solar America Board for Codes and Standards
www.solarabcs.org

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Download a copy of the report:
www.solarabcs.org/O&M

EXECUTIVE SUMMARY

Until recently, the U.S. photovoltaics (PV) Industry has focused on the development of PV module technology, inverters, components, and manufacturing. The United States now has more than 7.4 gigawatts (GW) of installed capacity, comprising more than 300,000 systems (Sherwood, 2013).

In light of this growth and the continued maturation of the PV market, the industry must focus on operating and maintaining systems. PV installation lifetimes are expected to be 25 years or more, so safe and proper maintenance is an integral part of successful and reliable operation. System operations and maintenance (O&M) is a broad area, and is the continuing focus of several industry/government/national laboratory working groups that are working to better define the issues and develop consensus approaches. In the interim, the Solar America Board for Codes and Standards (Solar ABCs) has prepared an O&M introductory report that includes practical guidelines for PV system maintenance and options for inspection practices for grounded PV systems. This report does not cover bi-polar, ungrounded, stand-alone, or battery backup systems.

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 and ROI. This report includes the current, commonly used diagnostic and troubleshooting procedures for inverter malfunctions or failures and associated reduced power production.

The intent of this report is to help qualified individuals maintain and inspect PV systems safely. Qualification to conduct such inspections is earned by direct on-the-job training under qualified supervision or through training programs offered by accredited educational institutions or manufacturers. It should be noted that many testing and maintenance activities require two people to be performed safely and efficiently. Currently, an employee who is being trained for a task, demonstrates the ability to perform duties related to that task safely, and is under the direct supervision of a qualified person is usually considered to be a qualified person.

This report also addresses currently known major safety requirements during PV servicing and repair, including the proper use of lockout/tagout procedures, the use of personal protective equipment, procedures for safely disconnecting live circuits, and appropriate observation of and compliance with all PV-specific system signage and warnings. In addition, it includes information about routine preventive maintenance and emergency shutdown procedures.

Newer PV systems may use devices that are not covered in this document, and technicians should contact the manufacturer for instructions on operating and maintaining such devices. This report also does not cover all the variations in equipment and measurement techniques that are available to qualified personnel, and there are suitable substitutes available for the equipment listed here. Readers should also be aware that PV systems are evolving to higher voltages, and voltmeters and other devices must be rated for use at the higher 1,000-volt level.

Conclusions

The conclusions of this introductory report include:

- To maintain quality control and safety standards, it is important that only qualified personnel work on PV installations. The authors suggest minimum skill and knowledge guidelines for PV technicians.
- Safety is a serious concern when servicing PV installations. Early PV systems often had maximum system voltages less than 50 V_{dc}, but 1,000 V_{dc} systems are now allowed by code in commercial and large-scale installations.
- Qualified personnel should always work in teams of two people when working on live equipment, and there should always be at least two qualified persons trained in cardiopulmonary resuscitation on the jobsite.
- Not all installations have appropriate signage, and qualified persons must be trained to recognize potential hazards with or without signage present.
- System uptime and availability is a key objective of O&M, and inverters that are offline can have a dramatic negative impact on the ROI of a PV system.
- Low power production also impacts ROI, and O&M personnel need effective strategies for identifying and correcting problems quickly.

AUTHOR BIOGRAPHIES

Josh Haney
Next Phase Solar, Inc.

Josh Haney is director of technical services at Next Phase Solar, Inc., which provides post-installation solar services focusing on operations and maintenance of existing photovoltaic (PV) arrays. He has more than two decades experience in the renewable energy field, and has installed, serviced, and managed the installation and maintenance of both small- and large-scale solar systems totaling more than 100 megawatts. He has also overseen the daily monitoring and operations of commercial projects through data acquisition systems. In addition to being a North American Board of Certified Energy Practitioners (NABCEP) certified solar PV installer and a certified California journeyman electrician, he holds a Master of Business Administration with an emphasis in management from San Diego State University.

Adam Burstein
Next Phase Solar, Inc.

Adam Burstein is the president of Next Phase Solar, which he founded in September 2009 to bring technical know-how and strong customer service to the photovoltaic operations and maintenance (O&M) industry. Next Phase provides O&M on more than 150 megawatts of commercial PV arrays and more than 10,000 residential systems across the country. Prior to his work at Next Phase Solar, Adam spent eight years leading PowerLight's and then SunPower's O&M efforts.

Solar America Board for Codes and Standards

The Solar America Board for Codes and Standards (Solar ABCs) provides an effective venue for all solar stakeholders. It consists of a collaboration of experts who formally gather and prioritize input from groups such as policy makers, manufacturers, installers, and large and small-scale consumers. Together, these entities make balanced recommendations to codes and standards organizations for existing and new solar technologies. The U.S. Department of Energy funds Solar ABCs as part of its commitment to facilitate widespread adoption of safe, reliable, and cost-effective solar technologies.

For more information, visit the Solar ABCs website:

www.solarabcs.org

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy under Award Number DE-FC36-07GO17034. The authors sincerely thank the following individuals who have provided helpful reviews and comments for this report: Greg Ball (DNV), Ward Bower (Ward Bower Innovations LLC), Bill Brooks (Brooks Engineering), Dave Click (Florida Solar Energy Center), Marv Dargatz, and Andrew Rosenthal (New Mexico State University).

TABLE OF CONTENTS

Introduction

For most of its history, the U.S. photovoltaics (PV) Industry has focused on the development of PV module technology, inverters, components, and manufacturing. These efforts have helped to advance the state of the art for PV systems worldwide. The United States now has more than 7.4 gigawatts (GW) of installed capacity, comprising more than 300,000 systems (Sherwood, 2013).

In light of this growth and the continued maturation of the PV market, the industry must focus on operating and maintaining systems. PV installation lifetimes are expected to be 25 years or more, so safe and proper maintenance is an integral part of successful and reliable operation. System operations and maintenance (O&M) is a broad area, and is the continuing focus of several industry/government/national laboratory working groups. These groups will better define the issues and develop consensus O&M approaches over the next few years. In the interim, Solar ABCs has prepared an O&M introductory report that includes practical guidelines for PV system maintenance and options for inspection practices for grounded PV systems. It is intended for mono-polar, grid-connected PV systems, and does not explicitly cover bi-polar, ungrounded, stand-alone, or battery backup systems. Off-grid systems have many of the same components, however, and portions of the guidelines can be used for inspection or maintenance of off-grid systems.

Qualified Personnel

This report is intended to help qualified individuals maintain and inspect PV systems safely. The U.S. Department of Labor's Occupational Safety and Health Administration (OSHA) defines a qualified person as one who has received training and has demonstrated skills and knowledge in the construction and operation of electrical equipment and installations and the hazards involved. The definition supplied in Article 100 of the National Electrical Code® *(NEC)* is very similar (NFPA, 2011a): "One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved."

Technicians can be qualified for some maintenance and service tasks but still be unqualified for others. Whether someone is a "qualified person" often depends on the specifics of the task at hand.

Qualification is earned by either direct on-the-job training under qualified supervision or through training programs offered by accredited educational institutions or manufacturers. Many testing and maintenance activities require two people to be completed safely and efficiently. An employee who is being trained for a task, demonstrates the ability to perform duties related to that task safely, and is under the direct supervision of a qualified person is usually considered to be a qualified person.

Additionally, in order to be considered a qualified person for PV service and maintenance, a person must be trained in and familiar with:

- the skills and techniques necessary to identify exposed live parts from other parts of electrical equipment,
- the skills and techniques necessary to determine the nominal voltage of exposed live parts,
- the clearance distances specified by OSHA in the Code of Federal Regulations (CFR) Part 1910.333(c) ("Working on or near energized parts") and the corresponding voltages to which the qualified person will be exposed,
- the pertinent sections of the *NEC*,
- the characteristics of PV sources and hardware typically used in PV systems, and
- the characteristics of the hardware used in the PV system the person is working on.

It is strongly recommended that anyone working around energized PV systems complete a minimum of the 10-hour OSHA-10 Construction Industry Training Program. Local jurisdictions may specify the necessary training, skills, certifications, or licenses required to perform the work discussed in this report. One indicator that a person may be qualified to work on many types of PV systems is to confirm that the person is a certified energy practitioner who has met the qualifications for and passed a certification exam.

SAFETY REQUIREMENTS

Safety begins with adequate planning and preparation. 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.

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 covered by CFR, under 29 CFR 1910.147.

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. OSHA provides variations of LOTO that may be used depending on an approved energy control program. Safety protocols need to be followed when re-energizing equipment, including notifying others that the system is about to be energized.

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 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.

Rubber-insulating gloves, often referred to as "hot 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, OSHA requires the gloves 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.

As PV systems get larger and direct current (dc) operating voltages up to 1,000 volts (V) become increasingly common, arc flash requirements are a growing concern and it is more common to see arc flash warning labels on combiner boxes and disconnects. Unfortunately for maintenance personnel, 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. 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. Lastly, at least two qualified people trained in cardiopulmonary resuscitation (CPR) should be on site at all times.

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 disconnects, and care should be taken to use the proper technique for throwing 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.

The proper technique for safely throwing an electrical disconnect includes:

- wear proper PPE,
- shut the system off at the inverter,
- stand to the right of the switch,
- grab the handle with the left hand,
- turn body and face away from the switch,
- close eyes,
- take a deep breath and hold it (to avoid breathing in flames if an arc flash occurs),
- throw (operate) the disconnect lever,
- use a properly rated voltmeter to confirm that no voltage is present on the disconnected circuit, and
- use LOTO methods to ensure the switch remains off.

PV-Specific Signage and Warnings

Article 690 of the *NEC* (NFPA, 2011b) covers the requirements for PV-specific signage and warnings that must be present on every PV system. Additional signage may also be required by the local jurisdiction or utility. These placards and warnings need to be visible to those working on or near the systems and should never be covered or painted over.

Early PV systems often operated with maximum system voltages less than 50 V_{dc}. Today, 600 V_{dc} systems are common and 1,000 V_{dc} systems are allowed by code in commercial and large-scale installations. 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, disconnects, 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.

Although it is impossible to compile a list of universally applicable safety guidelines, the authors 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 1,000 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 alternating current (ac) and dc voltages up to 1,000 V (or 600 V, when applicable) 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 (30 V_{dc}) 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 (also known as a source circuit) 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.

ROUTINE SCHEDULED PREVENTIVE MAINTENANCE

One of the most valuable techniques for identifying existing problems and preventing future problems is to walk the site and conduct a thorough visual and hands-on inspection of the PV system components. These inspections should be conducted at regular intervals, and personnel should use checklists developed for these periodic maintenance activities to ensure that the inspections are thorough and complete.

General Site Annual Inspection

At least once a year, O&M personnel should conduct a general inspection of the PV installation site. During this inspection, technicians should:

- ensure roof penetrations are watertight, if applicable;
- ensure roof drainage is adequate, roof drains are not clogged, and confirm that there are no signs of water pooling in the vicinity of the array;
- check for vegetation growth or other new shade items such as a satellite dish;
- check for ground erosion near the footings of a ground mount system;
- confirm proper system signage is in place;
- confirm appropriate expansion joints are used where needed in long conduit runs;
- confirm electrical enclosures are only accessible to authorized personnel, are secured with padlocks or combination locks, and have restricted access signage;
- check for corrosion on the outside of enclosures and the racking system;
- check for cleanliness throughout the site—there should be no debris in the inverter pad area or elsewhere;
- check for loose hanging wires in the array; and
- check for signs of animal infestation under the array.

Detailed Visual Inspection

The installation should be inspected regularly for issues that impact the physical integrity or performance of the PV system. A visual inspection should include the following actions:

- Inspect the inverter/electrical pad to make sure it does not show excessive cracking or signs of wear. The inverter should be bolted to the pad at all mounting points per the manufacturer installation requirements. 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.

- Look for warning placards including arc flash or PPE requirements for accessing equipment. Be sure to comply with all warning placards. If no placards are present, or if some placards are missing, make a note of it and install the missing placards during the maintenance visit. Consult the *NEC* and Underwriters Laboratories (UL) standards as well as the site host to determine signage requirements.

- Inspect PV modules for defects that can appear in the form of burn marks, discoloration, delamination, or broken glass.
- Check modules for excessive soiling from dirt buildup or animal droppings. (See Array Washing Procedure for proper procedures for cleaning an array.)
- Ensure that the module wiring is secure and not resting on the roof, hanging loose and exposed to potential damage, bent to an unapproved radius, or stretched across sharp or abrasive surfaces.
- Inspect racking system for defects including rust, corrosion, sagging, and missing or broken clips or bolts.
- If sprinklers are used to spray the array, check that the water is free of minerals (demineralized) as these minerals can cause gradual performance degradation.
- Inspect conduits for proper support, bushings, and expansion joints, where needed.
- In roof-mounted systems, check the integrity of the penetrations.
- In ground-mounted systems, look for signs of corrosion near the supports.
- Open combiner boxes and check for torque marks on the connections. Torque marks are made when lugs have been tightened to the proper torque value. Ideally they are applied during initial installation, but if not, the technician can mark the lug after torquing during a maintenance visit. A proper torque mark is made with a specialized torque marking pen. The mark is a straight line through the lug and the housing. Over time, if the line separates between the lug and the housing, it shows that the lug has moved and needs to be re-torqued. Look for debris inside the boxes and any evidence of damaging water intrusion. Look for discoloration on the terminals, boards, and fuse holders.
- Open the door to the disconnect(s) and look for signs of corrosion or damage. Check to make sure the cabinet penetrations are properly sealed and there is no evidence of water ingress. Check for torque marks on the terminals.
- 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 for torque marks on the field terminations.
- If a weather station is present, ensure that the sensors are in the correct location and at the correct 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 to remove dirt and bird droppings.

Manufacturer-Specific Inverter Inspection

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

- Record and validate all voltages and production values from the human-machine interface (HMI) display.
- Record last logged system error.
- Clean filters.
- Clean the inside of the cabinet.
- Test fans for proper operation.

- Check fuses.
- Check torque on terminations.
- Check gasket seal.
- Confirm warning labels are in place.
- Look for discoloration from excessive heat buildup.
- Check integrity of lightning arrestors.
- Check continuity of system ground and equipment grounding.
- Check mechanical connection of the inverter to the wall or ground.
- Check internal disconnect operation.
- Verify that current software is installed.
- Contact installer and/or manufacturer about any issues found.
- Document findings for all work performed.

Manufacturer-Specific Tracker Inspection

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

- Lubricate tracker by inserting grease with grease gun into appropriate grease caps per manufacturer maintenance recommendation.
- Check voltages inside the controller box.
- Use a digital level to check the calibration and positioning of the inclinometers.
- Check array for signs of parts hitting or rubbing other parts.
- Remove vegetation that is near the drive shaft or moving components.
- Check wind-stow operation.

Use appropriate (volt, ohm, dc clamp-on) meters to test:

- continuity of the equipment grounding at the inverter, combiner boxes, and disconnects;
- continuity of all system fuses at the combiner boxes, disconnects, and inside the inverter(s);
- open-circuit voltage (V_{oc}) of all strings with the inverter off; and
- maximum power current (I_{mp}) of all strings with the inverter on and at specified or recorded levels of power.

Additional testing (used when problems are identified or required by contract terms) may include:

- thermal images of combiner boxes (opened and closed), disconnects, inverters (external and internal at a specified operating point for a specified period of time), and modules;
- short circuit (I_{sc}) testing of strings;
- current-voltage (IV) curve testing of strings;
- insulation resistance tests (also known as “megger” tests) of conductors at specified voltage; and
- comparison of a weather-corrected performance calculation of expected output to actual output of the system.

Manufacturer-Specific Data Acquisition System Inspection

Data acquisition system (DAS) manufacturers will have specific requirements for inspections, testing, service, 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 must 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.

The PV industry as a whole is getting better at DAS installation and documentation, but it is still typical for DAS plans to be omitted or insufficiently detailed. As a result of such an omission, plan checkers 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 will be tied into the building information technology system, O&M personnel should be aware that building networking upgrades or routine maintenance can cause connectivity issues.

GENERAL ISOLATION PROCEDURES

Energized Components

Some testing and maintenance activities may require the system to be energized while workers are working on or near the equipment—string current testing is one example. Another common testing practice discussed in Megohmmeter Testing (megger testing) is to use an insulation resistance meter to induce voltage to wiring or other components in an effort to identify signs of damage to insulation or resistance/leakage from other sources such as loose connections.

OSHA provides guidance for what must be done in order to work safely on energized systems:

- Only qualified employees can work on electric circuits or equipment that has not been de-energized using LOTO procedures.
- Qualified employees must be able to work safely on energized circuits.
- The qualified employee must be familiar with the proper use of special precautionary techniques, PPE, insulating and shielding materials, and insulated tools.
- Employees working in areas where there are potential electrical hazards must be provided with and use electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.

Inverter Pad Equipment

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 HMI keypad to navigate and select a shutdown.
- If the inverter has an on/off switch, turn it to off.
- Turn the ac disconnect switch on the inverter off.
- Turn the dc disconnect switch on the inverter off.
- Turn any remaining external disconnect switches connected to the inverter off.
- Install lockout devices on all disconnects, locking them in the open or off position.
- Repeat for all inverters and switches to completely isolate the entire PV system from the grid and the inverters from the PV power source.

Transformer Isolation

Use the following procedures for transformer shutdown:

- For inverters connected to the transformer, turn the on/off switch to off.
- Turn the ac disconnect off for the inverters connected to the tranformer.
- Turn the dc disconnect off for the inverters connected to the transformer.
- Install lockout devices on the disconnects.
- Turn off the transformer switch, which is either a dedicated stand-alone switch or is located in the switchgear.
- Install a lockout device on the transformer switch.
- Repeat for all transformers to completely isolate them from the switchgear.

FAILURE RESPONSE

Emergency Shutdown

In an emergency situation:

- 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 (this may require a key). Each inverter should be manually turned to the off position. This will immediately open the internal ac and dc contactors (if present) inside the inverter.

Note that 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 disconnect switches attached to or located near the inverters. Do not open switches that are specifically labeled "Do not disconnect under load" until a load-break switch has been opened and current flow is stopped. Generally, the first available upstream load-break ac switch or circuit breaker is safer to operate first (before the dc switch), because the inverter instantly shuts down the transistor bridge when ac voltage is removed. Once the system is off, the remaining switches can be opened and the system can be locked out until the fault condition is repaired or it is safe to turn it back on.

Isolation Procedure—Inverter Pad Equipment

To isolate the inverter pad safely:

- Shut the inverters off through a controlled shutdown.
- Turn off all dc and ac disconnects that feed the pad. Follow the procedure in the LOTO section for opening electrical disconnects.
- Use LOTO procedures to ensure the system remains off.
- Always wear appropriate PPE and test for voltages with a properly rated meter to confirm the system is completely isolated.

Isolation Procedure—Field Combiner Box

To isolate field combiner boxes:

- Turn off the inverters as described above.
- Operate the switch of the combiner (if applicable) by turning the handle to the off position.
- Use a dc clamp on the meter to confirm there is no current passing through the ungrounded conductors in the combiner box, and then open all of the fuses.
- If further isolation of the box is needed, use the string diagrams to locate the homeruns (end connectors of the PV strings).
- Use a clamp-on dc current meter to confirm that the homerun 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.
- Go back to the combiner box and use a voltmeter to confirm that each string has been successfully disconnected.

Isolation Procedure—Modules and String Wiring

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

- Before disconnecting any string, use a dc clamp-on meter to confirm there is no current passing through the string.
- Use the appropriate connector unlocking tool to disengage the module connector.
- Repeat for each module to be isolated from the system.
- If modules are removed from a system, even temporarily, technicians must ensure that the equipment grounding system remains intact for the remaining modules.

INVERTER TROUBLESHOOTING AND SERVICE

There is an understandable focus on maximizing ROI and system production. System uptime and availability is a key objective of O&M. 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 even more important than how often an inverter goes offline is how quickly it can be placed back into service. The type of inverter fault often dictates how quickly it can be placed back into service. Inverters with known failure modes need a failure response procedure. This may include stocking critical parts that have long supply lead times so that the system is not left offline because of a lack of spare parts.

Inverter Troubleshooting

When an inverter goes offline, technicians must determine why and correct the error as quickly as possible. They can check the HMI for reported errors, and then follow the actions noted in the table below.

Common Reported Inverter Errors

Inverter Error	Action
Dc undervoltage	Steps to diagnosing underperforming systems
Dc overvoltage	V_{oc} string testing
Dc ground fault	Ground fault detection procedure
Gating fault	Check connections Contact manufacturer
Ac undervoltage	Confirm all breakers are on 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 likely 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, investigate further
Over temperature—fan is operating, sensors are accurate	Check intake and exhaust filters for excessive buildup, and clean or replace if necessary
Software fault	Contact manufacturer

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 ground fault fuse and even ac 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.

Inverter Service Procedures

Some inverter service actions require that the system be shut down for safe inspection. Always begin with an examination of the equipment as described in the ROUTINE SCHEDULED PREVENTIVE MAINTENANCE chapter, and further inspect subassemblies, wiring harnesses, contacts, and major components.

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

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

DIAGNOSING AND TESTING FOR LOW POWER PRODUCTION

Low power production also impacts ROI, and O&M personnel need effective strategies for identifying and correcting problems quickly. System operators or owners may become aware of a PV installation's underperformance through one of the following means:

- a predefined DAS alert, which may be weather-related, a result of comparison with other systems in the portfolio, or a result of comparison with other monitored parts of the system at a site with multiple inverters;
- a manual review of the DAS data through online portal that indicates performance anomalies;
- a comparison of present performance with performance test results from previous maintenance visits; and
- customer or external entity reports of a potential problem, often because of an unexpected increase in a monthly bill.

Diagnostic Overview

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

- During routine maintenance and when diagnosing an underperforming system, the first and most important components to check are the fuses. Fuses generally must be removed from their holders to determine whether they have blown.
- Perform a system performance data review using the DAS or a program such as the PVWatts calculator (NREL, 2012) to calculate the expected system output based on weather conditions and system size to compare actual to modeled systems production.
- Dispatch a field technician to the site to do the following:
    - o Check that on-site performance meters have similar values. Often systems will have revenue grade performance monitoring that can be compared against the inverter display totals.
    - o If there is a difference in the values, then ideally the technician can log into the DAS system (when available) to investigate.
        - 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).
    - o If there is no difference in recorded values, then use the inverter operator display/interface (if applicable) to identify the inverter error log. See inverter diagnostics for errors that may have caused the inverter to perform at less than 100% power.
    - o Verify that the array maximum power point voltage is in the maximum power point tracking window of the inverter, using an IV 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.

- o 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 of the installation during commissioning and keep a visual record of any noticeable differences during maintenance visits.
- o Perform general system checks as necessary to identify problems:
  - Check all fuses at the inverter and work out to the combiner boxes.
  - Perform V_{oc} string testing.
  - Perform I_{mp} string testing.
  - Validate weather sensors.
  - Look for soiling. If soiling might be the problem, test an individual string (V_{oc}, I_{mp}, IV curve) and then clean the string and retest.
  - Perform IV curve tracing.
  - Take infrared (IR) images of the PV cells.

Diagnostic Testing

O&M personnel can use a number of diagnostic procedures to determine the cause(s) of power deficiencies in a PV installation. The following sections describe these tests in detail.

Infrared (IR) Image Procedure

This procedure describes how to properly perform field diagnostics of a PV installation using an IR camera to detect abnormal heat signatures. Topics include correct camera settings and proper conditions for field inspection.

Test conditions

- IR imaging should be completed with the system operating at peak levels if possible.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, during rainy or wet conditions.

Tools include:

- IR Camera, such as Fluke Ti10, Fluke Ti32, FLIR i40, or FLIR i7; and
- clamp-on ammeter.

Safety considerations

- Ensure all OSHA and environmental health and safety requirements are met, especially if working on angled roofs and/or at heights greater than six feet.
- Safety precautions should also be taken when working near active high voltage systems or near surfaces that may be very hot to the touch.
- Contact local health, security, safety, and environment personnel for questions and access to pertinent documentation.

IR imaging procedure

- Before starting the IR scan, verify that the PV array is operating, because temperature differences in modules are not apparent when the system is not operational.
  - o Check inverter display for instantaneous kilowatt output.
  - o Check current on each string in combiner box to ensure that it is operational.
  - o If the inverter or any of the strings are not operational, these must be corrected before the test can be conducted.

IR camera settings

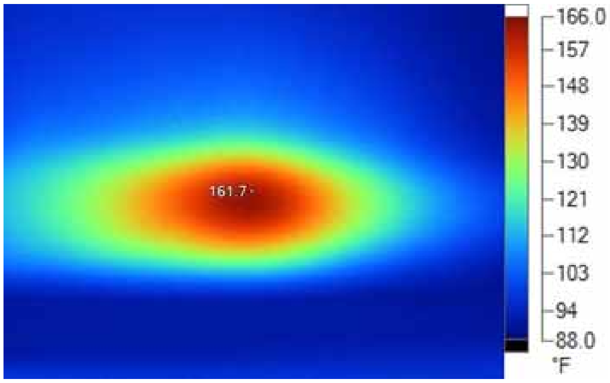
- Set the IR camera to "auto-scaling" rather than manual scaling. This will allow for automatic adjustment of the temperature scale.
- Set emissivity value to 0.95 (usually the camera default). The IR camera does not capture shiny surfaces such as polished metals well due to their low emissivity value. However, for most active components on a solar module such as cells, J-Box, and cables, a value of 0.95 will be sufficient.
- Set temperature units to Celsius.
- Set color palette to Iron or Rainbow. "A thermal imager interprets IR radiated or reflected heat by assigning a visible graduated color or gray scale to a radiated portrait of the scene. The color palette displays hot spots as white with diminishing temperatures through red-orange-yellow-green-blue-indigo-violet to black being cold" (Fluke Corporation, 2006, 2008).

IR inspection

- When sunlight is present and camera settings are properly set, point the lens at the object of interest. In the case of solar modules in operation, looking through the glass onto the active cells is the most common inspection technique.
- Ensure that the picture is focused, either manually or automatically. For best results, position the camera as close to the module as possible without shading it or creating a reflection in the glass surface. If possible, the distance between the camera and the surface to be measured should not exceed three meters or 10 feet. This will depend on the camera's minimum focal distance and other specifications. Some temperature differences will not be picked up if the camera is too far away from the module.
- For best results, position the camera as perpendicular as possible to the object being measured. Hot spots will be easier to see if the image is taken perpendicular to the module surface. Image quality will degrade at camera angles other than normal (i.e. perpendicular) incidence.
- Care should be taken to avoid shading any part of the module while capturing images.
- Record module serial number, time, date, picture number, and module location in the array for all issues.

Sample Images

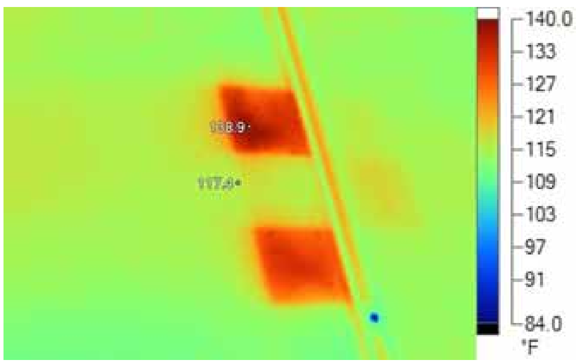
Junction boxes on back surface of a PV module



IR Image

Visible light image

Cells in a module



IR Image

Visible Light Image

Megohmmeter Testing

Megohmmeter or "megger" testing is a valuable way to identify weakened conductor insulation and loose wiring connections. These tests are often used in system acceptance and commissioning procedures but not often used in general maintenance unless a thorough troubleshooting of a fault condition is needed. The insulation resistance tester (IRT) applies a voltage to the circuit under test and measures return current to determine the insulation resistance and integrity. IRTs have various test voltage settings, such as 50 V, 100 V, 250 V, 500 V, and 1,000 V. Generally, the higher voltage settings are better for detecting high impedance shorts in the wiring than lower voltage settings. However, some newer low voltage equipment has sophisticated filtering that enables effective measurements even on circuits with PV modules. All 600 V-rated wire and PV modules should be capable of being tested at 1,000 V_{dc}, because they are factory proof tested at twice the maximum rated voltage plus 1,000 V—this adds up to 2,200 V for 600 V cable and PV modules. This test is short-term and will not damage the wire or module insulation.

To test specific products, including strings of modules, it is best to confirm that the testing (high voltage) will not void the warranties of those materials. It is best to get written permission for testing procedures from the module manufacturer if they do not already have approved megohmmeter testing guidelines. Some manufacturers explicitly disallow megohmmeter testing on their modules. Although it is true that some products may not allow this testing, the most common location of ground faults in PV systems is in the module wiring and modules

Testing using the 500 V_{dc} setting may be appropriate for some modules. Lower voltages are often necessary when the system includes surge protection devices within the combiner boxes. Insulation testers are now available with 50 V_{dc} settings that will not damage the surge protectors. If these are used it is important to ensure that they have filtering capable of compensating for the array capacitance. The added benefit of a low voltage insulation test is that it can detect problems with surge protectors. Leaking surge protectors are a common fault of older PV systems.

Test conditions

- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.

Tools include:

- IRT megohmmeter;
- PPE rated for the appropriate voltages;
- screwdriver or combiner box key, if applicable;
- dc clamp-on meter;
- dc voltmeter;
- electrical tape;
- system drawings—string wiring diagram;
- warning signs: "High Voltage—Testing in progress—Stay clear of photovoltaic array!"; and
- recording device (pen and paper, laptop or tablet preferred).

Safety considerations include:

- shock hazard, live voltages present;
- fall hazard, combiner boxes are often elevated;
- need for proper PPE for electrical voltage testing;
- recognition that normally de-energized circuits may be energized in fault conditions; and
- requirement for two qualified people trained in CPR.

IRT testing procedure

- Turn system off at the inverter.
- Post "High Voltage," Testing in progress," "Stay clear of photovoltaic array!" signs around all entry points to array.
- Use LOTO procedures.
- Record test conditions including ambient temperature and irradiance.
- Open disconnect switch on combiner box, if applicable. If there is no switch at the combiner box, open the applicable disconnect or fuse at the inverter to isolate the combiner box circuit.
- Isolate the output circuit grounded conductor (negative in a negative grounded system, positive in a positive grounded system) by removing the cable from its termination.
- Remove any surge protection devices from circuits being tested (if testing at more than 50 V_{dc}).

- Visually inspect box for signs of damage, including:
    - heat discoloration,
    - corrosion,
    - water intrusion, and
    - conductors rubbing against metal in enclosure or other insulation damage.
- Use dc current meter to confirm there is no current present in the combiner box.
- Open all fuse holders.
- Use ohmmeter to verify continuity of the box enclosure to ground. If enclosure is not metal, verify ground wire connection to ground.
- Test V_{oc} of all strings to confirm proper polarity and voltage of each string.

FOR POSITIVELY GROUNDED SYSTEMS:

First, test all strings in the box simultaneously:

- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the red (positive) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach black (negative) lead from megohmmeter to the positive busbar (unfused side).

If low impedance is detected at the box level, test the individual strings:

- Remove positive string conductors one at a time from the grounded conductor (positive) busbar, capping each with a wire nut before moving to the next. Make sure there is no exposed copper once the wire nut is tight.
- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the red (positive) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach black (negative) lead from megohmmeter to the positive lead of the string.

FOR NEGATIVELY GROUNDED SYSTEMS:

First, test all strings in the box simultaneously:

- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the black (negative) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach the red (positive) lead from megohmmeter to the negative busbar (unfused side).

If low impedance is detected at the box level, test the individual strings:

- Remove negative string conductors one at a time from the grounded conductor busbar, capping each with a wire nut before moving to the next. Make sure there is no exposed copper once the wire nut is tight.
- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the black (negative) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach red (positive) lead from megohmmeter to the negative lead of the string.

FOR UNGROUNDED SYSTEMS:

For ungrounded systems, note there should be two pole switches to completely isolate the positive and negative combiner circuits from the inverter and other combiner boxes, so there should be no need to remove an output circuit cable from its terminal.

First, test all strings in the box simultaneously:

- Open the positive fuse holders only in the combiner box, leaving the negative fuse holders closed in.
- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the black (negative) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach the red (positive) lead from megohmmeter to the negative busbar.

If low impedance is detected at the box level, test the individual strings:

- Open all of the positive and negative fuse holders. The string conductors do not need to be removed from the fuse holders.
- Set megohmmeter on a sturdy surface. Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Attach the black (negative) lead from megohmmeter to the ground busbar in the combiner using an alligator clip. Attach red (positive) lead from megohmmeter to the negative lead of the string, using the array-side screw terminal of the fuseholder.
- After positive leads are tested using the procedure below, repeat the test on the negative leads of the string using the array-side screw terminal of the fuseholder.
- Set meter to the appropriate voltage setting.
- Press and hold the "Test" button for a specific and consistent time period—at least 15 seconds.
- Watch the display of the meter closely during the 15 second tests and look for fluctuations in the readings.
- Record the result after the 15 second interval. Insulation resistance measurements will vary based on system age, moisture, temperature, and the size of the string under test. Because absolute numbers vary based on these and other conditions, typically a string conductor with a value of greater than one to three megaohms is considered passing (Mync & Berdner, 2009). Box level measurements can be lower, as low as 500 kiloohms. Because of the variable conditions stated above, it is important to look for relative differences in the measurements of different boxes.
- Repeat test until all strings are tested.
- If a string fails the test, isolate the conductors from the array and test again.
- Replace or repair all wiring in any failed strings.
- Record all results for future comparison.

Fuse Checks

Fuses blow for a reason. Whenever a blown fuse is found, investigate why the fuse blew. 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 to ensure the correct fuse is sourced. It is common to come across operating systems with incorrect fuses in place.

Test conditions

- Fuses can be checked under any test conditions.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.

Tools include:

- ohmmeter;
- PPE;
- screwdriver or combiner box key, if applicable;
- fuse puller, if applicable; and
- recording device (pen and paper, laptop or tablet preferred).

Safety considerations

- Fuses should never be replaced or tested while the circuit is energized. Shut the system down prior to servicing fuses.
- Wear proper PPE for electrical voltage testing, at least until no voltage has been verified and the source has been locked out, if applicable.

Fuse testing procedure

- Confirm system is de-energized with a voltmeter.
- Use LOTO procedures.
- Use an ohmmeter to test the continuity of the fuse. It may be possible to get voltage through a fuse that has not completely blown but is about to blow. For this reason, having voltage only on the load side of the fuse is not enough.
- Set ohmmeter on a sturdy surface.
- 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.
- Use meter and test the fuse by placing a lead on each end of the fuse and listening for the meter to beep confirming continuity.
- If the beep continuity reading is not constant while still holding the leads on each end of the fuse, then look at the ohm settings for a measurement of the resistance. Make sure your fingers are not touching each end of the fuse as this will give a resistance reading for an open fuse that can be confusing.
- Look at the fuse and confirm the size, type, and rating of the fuse.
- If the fuse fails the test or is not the properly rated size or type, replace the fuse with the correct fuse.
- Always test replacement fuses before installing to confirm the fuse was good when it was placed in service.

Best practices

While testing the voltages with the system off and the fuses open, prep 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.

DC System V_{oc} Checks

Dc voltage checks are done with the system off, but—depending on the system size—voltages of up to 1,000 V_{dc} may be present.

Test conditions

- Ideally, test in stable sunlight of more than 750 watts per square meter (W/m^2). However, stable conditions more than 200 W/m^2 still allow for simple comparisons among strings.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.
- Perform testing at the combiner boxes.

Tools include:

- dc voltmeter;
- PPE;
- irradiance meter;
- temperature sensor;
- screwdriver or combiner box key, if applicable; and
- recording device (pen and paper, laptop or tablet preferred).

Safety considerations include:

- shock hazard, live voltages present;
- fall hazard, combiner boxes are often elevated;
- proper PPE for electrical voltage testing;
- recognition that normally de-energized circuits may be energized in fault conditions; and
- requirement for two qualified people trained in CPR.

Voltage testing procedure

- Turn system off at the inverter.
- Use LOTO procedures.
- Record test conditions including ambient temperature and irradiance.
- Open disconnect switch on combiner box, if applicable.

- Visually inspect box for signs of damage, including:
    - heat discoloration,
    - corrosion,
    - water intrusion, and
    - conductors rubbing against metal in enclosure or other insulation damage.
- Open all fuse holders.
- Attach red lead to red terminal on tester. Attach black lead to black terminal on tester.
- Use ohmmeter to verify continuity of the box enclosure to ground. If enclosure is not metal, verify ground wire connection to ground.
- Use dc clamp-on ammeter to test for current in the equipment grounding conductor. If current is present, stop this procedure and proceed to the Ground Fault Troubleshooting procedure.
- Use voltmeter to test equipment grounding conductor to ground.
    - If voltage is present, find source of problem before placing combiner box back into service.
    - Test ungrounded conductors one at a time by removing them from the bussing. Wear PPE and use insulated tools to remove ungrounded conductors under a fault condition.
- Ideally, use an alligator clip meter cable for the black lead, connect to ground.
- Take the red lead and individually test from the line side of the open fuse holder for the ungrounded conductor.
- Record results.
    - Note voltage and polarity of each string, and if polarity is incorrect, find the source of problem before placing back into service.
    - If reverse polarity is observed, do not just switch it without further investigation to identify the problem. Re-identify and properly label conductors if a switch is made. A change to the as-built plans may also be necessary.
    - All voltages should be within 10% of each other. If one string is the equivalent of the V_{oc} of one module (roughly 30-40 V depending on the module) less than the average and one string is 30-40 V more than than the average, it is a good indication that the stringing is incorrect for both strings.
    - Given the same example of 40 V_{oc}, if one string is 10-20 V less, then there may be an issue with one of the modules, and further investigation may be necessary (such as performing IV curve tracing).
- If I_{mp} testing is going to be carried out in the same combiner box, it is best to prep the box for the I_{mp} testing.
    - Ensure all terminations are properly torqued.
    - Pull on conductors to ensure a large enough loop for the current meter to attach to. If necessary, cut zip ties.
- Close fuse holders.
- Close disconnect.

DC System I_{mp} Checks

The dc I_{mp} tests are completed with the system running. Full operating voltages and current are present in the combiner boxes.

Test conditions

- Ideally, test in full, stable sunlight. Usually, a minimum stable irradiance of 500 W/m^2 will allow for accurate comparisons among strings.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.
- Do the testing at the combiner boxes. The ambient test conditions should be recorded for each combiner box. This includes the ambient temperature and plane of array irradiance. If a calibrated weather station is installed, a time stamp can be used to pull the data from the weather station or handheld tools can be used to record the real time values.

Tools include:

- dc clamp meter;
- PPE;
- irradiance meter;
- temperature sensor;
- wrench or additional combiner box handle;
- screwdriver or combiner box key, if applicable; and
- recording device (pen and paper, laptop or tablet preferred)

Safety considerations include:

- shock hazard, live voltages and current present;
- fall hazard, combiner boxes are often elevated;
- proper PPE for electrical current testing; and
- requirement for two qualified people trained in CPR.

I_{mp} testing procedure

- With system operating, open dc combiner box.
- It may be necessary to use a wrench or other handle type tool to close the combiner box switch (if the system is so equipped) with the door open. Technicians should wear proper PPE.
- Box should be prepped in advance during the voltage testing process.
  - Fuse holders are not meant to be opened under load.
  - The dc combiner boxes may not be designed to be turned off under load—look for warning labels.
- With a two-person team, an electrician wearing the proper PPE places a dc clamp-on meter around each individual string, calling out the numbers to the helper who records the data.

- Close the combiner box lid.
    - o If the combiner box lid cannot be closed with the switch closed, turn the inverter off and then open the switch rather than shutting off the switch with the door open. This is usually more efficiently done after all combiner boxes are tested rather than individually.
- Compare the I_{mp} results of strings with identical pitch and orientation and similar test conditions to look for low-performing strings.
    - o Low performing strings can be further diagnosed using the steps for diagnosing production issues in the Diagnostic Overview section.

Grounding System Integrity Checks

It is important to verify that the equipment ground is properly installed on all exposed non-current carrying metal parts. That way, the removal of a single piece of equipment—during module replacement, for example—does not impact the integrity of the bonding of the remaining equipment. If removal of any component results in a break in the bond connection, a jumper of suitable ampacity must be used as a temporary connection.

Test conditions

- Tests can be performed in any weather condition.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.

Tools include:

- ohmmeter;
- screwdrivers; and
- keys to open enclosures, if applicable.

Safety considerations include:

- This test presents a fall hazard, because some of the system grounding equipment may be located higher than six feet and will require fall protection per OSHA 1926 Subpart M.

Procedure

- Set ohmmeter to the continuity setting.
- Touch one lead to a metal surface or ground wire.
- Touch the other lead to a nearby metal surface or ground wire.
    - o Confirm continuity between the two surfaces by listening for the beep when the leads touch the surfaces at the same time.
- Repeat this process randomly throughout the array and at every combiner box, disconnect, and inverter.

DAS Check

DAS checks are used to validate the existing systems. If any component is not up to specs, it may be quicker and cheaper to replace it with a new component than to attempt 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.

Test conditions

- Ideally, test in full, stable sunlight.
- Do not open or work in electrical boxes, particularly those with NEMA 4 rating, in wet conditions.
- Do 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.

Tools include:

- ac/dc voltmeter;
- ohmmeter;
- laptop;
- computer software (DAS/manufacturer-specific);
- computer cables (Ethernet, Crossover, RS232 to USB, RS485 to USB);
- PPE;
- irradiance meter;
- temperature sensor;
- level;
- inclinometer;
- compass;
- screwdrivers/sockets; and
- equipment keys, if applicable.

Safety considerations include:

- shock hazard, live voltages present;
- fall hazard—combiner boxes and meteorological stations are often installed at heights of more than six feet and will require fall protection per OSHA requirements;
- proper PPE for electrical voltage testing;
- normally de-energized circuits may be energized in fault conditions; and
- requirement for two qualified people trained in CPR.

Testing procedure

- Global horizontal irradiance:
    - Ensure location is not shaded.
    - Use level to make sure it is level.
    - Clean with a cloth and mild soap solution if necessary.
    - Log in to DAS program.
    - Place cleaned and recently calibrated handheld sensor in same pitch and orientation.
    - Compare results.
    - If outside of acceptable range, replace sensor, noting serial number of the new sensor for as-built updates.

- Plane of array irradiance:
  - Ensure location is not shaded.
  - Use inclinometer and compass to ensure it is in the same pitch and orientation as the array.
  - Clean with a cloth and mild soap solution if necessary.
  - Log in to DAS program.
  - Place cleaned and recently calibrated handheld sensor in same pitch and orientation.
  - Compare results.
  - If outside of acceptable range, replace sensor, noting the serial number of the new sensor for as-built updates.
- Ambient temperature sensor:
  - Log in to DAS program.
  - Take reading from handheld temperature sensor.
  - Compare results.
  - If outside of acceptable range, replace sensor, noting the serial number of the new sensor for as-built updates.
- Back of module temperature sensor:
  - Ensure sensor is correctly adhered to the back of a module in the middle of a cell in the middle of the module.
  - Log in to DAS program.
  - Take reading from handheld temperature sensor.
  - Compare results.
  - If outside of acceptable range, replace sensor, noting the serial number of new sensor for as-built updates.
    - Rather than risk damaging the module, leave the sensor in place and install the new sensor in the middle of the next closest cell.
- Anemometer:
  - Log in to DAS Program.
  - Hold the anemometer and confirm it is reading 0 MPH.
  - Turn to confirm it is moving.
  - If further testing is needed, use a handheld anemometer and compare the results at a consistent windspeed greater than three meters per second.
  - If outside of acceptable range, replace sensor, noting the serial number of new sensor for as-built updates.
- Current transducers:
  - Log in to DAS Program.
  - Basic test is to compare the current readings to the inverter display current readings.
  - Revenue grade validating involves using a calibrated current meter and placing it around the same conductors with the system running.
    - Proper PPE must be worn when testing live circuits.
  - Compare results.
  - If outside of acceptable range, replace sensor, noting the serial number of new sensor for as-built updates.

- Voltage reference:
  - Log in to DAS program.
  - Check fuses with ohmmeter.
  - Use calibrated voltmeter to test circuits.
    - Proper PPE must be worn when testing live circuits.
  - Compare results.
  - If any difference is noted, switch to other phases.
    - Meter could be bad.
    - Reference phase could be mislabeled.
- Revenue meter:
  - Log in to DAS program.
  - Navigate program to compare programmed CT ratio to the ratio listed on the CTs.
  - Look at power factor of all three phases to confirm it is close to one with the system operating.
    - Note that power factor may be low at startup or in low light conditions of less than 250 W/m^2.
  - Confirm good phase rotation with system running.
  - Compare revenue grade data with inverter data, noting differences.
- Inverter direct:
  - Log in to DAS program.
  - Confirm system is checking in accurately.
  - Look at system history to confirm data is not intermittent.
    - Intermittent data from inverters can be the result of noise induced by the inverter.
      - Check that the recommended shielded cable is used for communication wiring.
      - Check route of communication wiring to ensure it is away from voltage carrying conductors.
      - Confirm shield is only landed in one spot; best to do this at the DAS enclosure.
      - Confirm appropriate resistor or termination is installed in the last inverter in the chain (if required).
- Combiner box level monitoring:
  - Log in to DAS program.
  - Confirm that all boxes are visible.
  - Compare results to I_{mp} string test results.
- Module level monitoring:
  - Log in to DAS program.
  - Confirm communication to all devices.
  - Shade individual modules to confirm module mapping is accurate.

Ground Fault Troubleshooting

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

Test conditions

- Testing can be done under any conditions with enough light to produce voltage. However, some fault conditions only occur when the system is wet or is moved to a particular angle, and may be difficult to troubleshoot without replicating those conditions.

Tools include:

- dc voltmeter;
- ohmmeter;
- replacement fuses;
- jumper wire USE-2 or PV Wire with male and female connectors compatible with the system;
- megohmmeter;
- PPE;
- screwdriver or combiner box key, if applicable;
- electrical tape;
- system drawings—string wiring diagram; and
- recording device (pen and paper, laptop preferred).

Safety considerations include:

- shock hazard, live voltages present;
- normally un-energized components may become energized under fault condition;
- fall hazard—combiner boxes and meteorological stations are often installed at heights of more than six feet and will require fall protection per OSHA requirements;
- proper PPE for electrical voltage testing;
- normally de-energized circuits may be energized in fault conditions; and
- requirement for two qualified people trained in CPR.

Test procedure—small residential-scale inverters

- Turn inverter off at the on/off switch, if applicable.
- Turn off the dc and ac disconnects (may be the same switch).
- Remove and test the ground fault fuse continuity with an ohmmeter.
    - o If the fuse is good, may not have a ground fault.
    - o Verify by testing voltages to ground with the fuse removed. If within specifications, replace fuse and restart meter.

- If the fuse fails continuity test, there may be a ground fault.
  - o Verify it is the correct rating type and size fuse.
  - o In most small inverters, the fuse is the path to ground. When the fuse is removed from the system, the normally grounded conductor is no longer grounded.
  - o If the ends of the circuit are isolated, neither the ungrounded nor grounded strings should have a well-defined open circuit voltage when tested from the conductor to ground.
  - o 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.
    - With the fuses removed, test for voltage from the line side of the fuse terminals to ground.
    - If voltage is present on all of the terminals to ground, isolate the normally grounded conductors by removing them from the bussing.
    - Repeat until the string with the fault is found.
- Take the isolated string with the fault and record the voltage from the normally grounded conductor to ground and from the normally ungrounded conductor to ground.
  - o If the voltage is equal to the full open circuit voltage of a string, then the fault is likely at the normally grounded end of the string.
  - o If the voltage is a different value, then the fault is likely somewhere in the middle of the array or possibly in a module.
    - Determine the location of the fault by adding the V_{oc} of a single module one after another until it adds up to the voltage of the fault. For example, consider 10 modules in a string with a V_{oc} of 50 V_{dc} each, with module one connected to the ungrounded homerun cable and module 10 connected to the grounded homerun cable. When testing at the combiner box from the line side of the ungrounded fuse holder to ground and the result is 100 V_{dc} and testing from the ungrounded conductor to ground and the result is 400 V_{dc}, then the fault is somewhere between the second and third module in the string. Given the same wiring as above but a reading of 0 V_{dc} from the ungrounded side and 500 V_{dc} from the grounded side, the fault is in the ungrounded homerun.
- Given the above scenario, it would be wise to use a megohmmeter on all of the conductors in the conduit to make sure that the fault is isolated to the one homerun conductor.

Test procedure—central type inverters

- Turn inverter off at the on/off switch, if applicable.
- Turn off the ac and dc disconnects connected to the inverter.
- Remove and test the ground fault fuse continuity with an ohmmeter.
  - o If the fuse is good, there may not be a ground fault.
  - o Verify by testing voltages to ground with the fuse removed. If good, replace fuse.
  - o If the fuse fails the continuity test, there may be a ground fault.
  - o Verify it is the correct rating type and size fuse.

- For central inverters, the only fuse allowed in the grounded conductor is the ground fault interrupter fuse with an accompanying label, so removing the fuse will unground the grounded conductor.
    - o Remove conductors one at a time, test the voltage to ground, and then put a wire nut or electrical tape around the end of the conductor.
    - o Repeat until the string with the fault is identified. (Note: If the combiner box with the fault was not found, the next step is to use a megohmmeter to test the homerun wires from the combiner box back towards the inverter. It is possible to have a fault in the homerun wire from the combiner box to the inverter.)
- Take the isolated string with the fault and record the voltage from the normally grounded conductor to ground and from the normally ungrounded conductor to ground.
    - o If the voltage is equal to the full open circuit voltage of a string, then the fault is likely at the normally grounded end of the circuit.
    - o If the voltage is a different value, then the fault is likely somewhere in the middle of the array or possibly within a module.
        - Determine the location of the fault by adding the V_{oc} of one module after another until it adds up to the voltage of the fault. For example, consider 10 modules in a string, with each module having a V_{oc} of 50 V_{dc}. Module one is normally the ungrounded homerun and module 10 is normally the grounded homerun. If a test at the combiner box from the line side of the ungrounded fuse holder to ground results in 100 V_{dc}, and the test from the ungrounded conductor to ground results in 400 V_{dc}, then the fault is somewhere between the second and third module in the string. Given the same wiring as above but a reading of 0 V_{dc} from the ungrounded side and 500 V_{dc} from the grounded side, the fault is in the ungrounded homerun.
- Given the above scenario, it would be wise to use a megohmmeter on all of the conductors in the conduit to make sure that the fault is isolated to the one homerun conductor.

Array Washing Procedure

Depending on the site conditions, an annual or even quarterly cleaning may pay for itself in gained production. Some sites have more accumulation of dirt and other buildup than other sites. Depending on the tilt of the array and amount of seasonal rainfall, the soiling can have a dramatic impact on the overall production of the system. Most module manufacturers have specific guidelines about how not to clean modules, such as not using high pressure water, not using harmful chemicals, and even not using cold water when the module glass temperature is hot or using hot water to clean cold modules. Thermal shock from the difference in temperature between the glass surface temperature and the water temperature can result in fracturing or breaking of the glass.

Safety Considerations

- Wear rubber sole shoes with good traction to prevent slips and falls.
- Never walk on the modules. Use non-conductive extended reach broom and hose handles to reach modules
- A lift may be needed to access the array. Follow aerial lift safety procedures, including wearing a harness if required.

Before Washing Modules

- Walk the site to confirm that there are no broken modules (shattered glass). Never spray broken modules with water. Perform a safety evaluation of the site looking for safety hazards such as trip hazards or areas that will become excessively slippery when wet.
- Plan for water runoff. If the site has a storm water prevention plan in place, determine how the used water will be collected and disposed of. If harmful chemicals are not used during the cleaning process, drain guards can be used to filter out sediments.
- Be aware of trip hazards introduced by having hoses spread throughout the property, cone off area if needed.
- Determine whether the module cover glass is too hot and will be damaged by coming into contact with cool water. Depending on the local climate and time of year, it may be best to limit washing activities to the morning or evening hours.
- Identify the water source to be used. Ideally, there will be a source of water near the array. If not, it may be necessary to bring in water from an outside source, which will involve a tank or water truck.
- Determine the best method of getting water to the modules. Typically, a ¾-inch garden hose is used to connect to a spigot near the array.
- Set up hoses and tools.
- If required, block or install drain guards for filtration or water capture purposes.
- Take a baseline production reading of the system, noting both kilowatt-hour (kWh) output of each of the inverters and weather conditions including temperature and irradiance.

Washing Modules

- De-ionized water is preferred to prevent spotting and calcium buildup.
- Normal water pressure of 50 to 70 pounds per square inch is recommended; do not use high pressure washers.
- If high pressure washers are necessary, hold the pressure source far enough away from the modules to prevent damage. As a rule of thumb, if the stream is too strong to comfortably hold one's hand in, it is too much pressure for the modules.
- Spray the modules with water.
- Use a soft-bristled brush to get stubborn dirt off.
- If needed, use a non-damaging soap.
- Use extensions with tools to be able to reach extended distances.
- If needed, squeegee modules dry.

After Washing Modules

- After the system returns to steady-state temperature (i.e., there is no remaining impact from the cooling effect of wash water), take another production reading of the system, noting both kWh output of each of the inverters and weather conditions including temperature and irradiance.
- Clean up tools.
- Remove any drain guards or blocks.

- Record the washing in the maintenance log.
- Compare production of the clean system to the previous production values.

Vegetation Management

Vegetation management is particularly important in ground mount systems, but is a concern 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 definitely impact production but could also cause damage to an operating system. Vegetation should also be controlled around the inverter pad and other areas where electrical equipment is present. Note: PV arrays are often home to snakes, bees, and venomous animals of all kinds. Wear protective clothing and be alert for possible encounters.

Safety Considerations

- Wear rubber soled shoes with good traction to prevent slips and falls.
- Wear PPE to prevent bites and stings from insects, snakes, and vermin.

Vegetation Management

- 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 results in underperformance.
- Poisoning weeds can lead to environmental and health problems.
- Permanent abatement at the time of installation is the ideal way to deal with vegetation management.
- During inspections, note the amount of vegetation growth and document it through pictures.
- 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.

System Warranties

It is important to know and understand the warranty requirements of the specific products used in a PV system. Not all warranties are created equal. Warranty requirements not followed, including documenting regularly conducted preventive maintenance, can result in a voided warranty. Typical warranty requirements are strict regarding the tasks that must be performed. However, the tasks are often simple and serve to protect the products and ensure greater long-term reliability.

CONCLUSIONS

As the number of U.S. PV installations grows, the industry will increasingly focus on O&M. PV systems have multi-decade lifetimes, and regular O&M helps optimize an installation's ROI over its life. There are currently three working groups focused on this issue, and they will develop a more comprehensive O&M approach in the next few years. In the meantime, this report serves as an introduction to O&M for PV installations.

The conclusions of this introductory report include:

- To maintain quality control and safety standards, it is important that only qualified personnel work on PV installations. It is not always easy, however, to identify qualified personnel. The authors suggest skill and knowledge guidelines for PV technicians in the Qualified Personnel section of the INTRODUCTION chapter.
- Safety is a serious concern when servicing PV installations. Early PV systems often had maximum system voltages less than 50 V_{dc}, but 600 V_{dc} systems are now common, and 1,000 V_{dc} systems are allowed by code in commercial and large-scale installations. Safety considerations require that qualified personnel use properly rated equipment and be trained for servicing the higher voltage systems.
- Qualified personnel should always work in teams of two people when working on live equipment. In addition, on a given jobsite, there should always be at least two qualified persons trained in CPR.
- Not all installations have appropriate signage, and qualified persons must be trained to recognize potential hazards with or without signage present.
- System uptime and availability is a key objective of O&M. 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 even more important than how often an inverter goes offline is how quickly it can be placed back into service.
- Low power production also impacts ROI, and O&M personnel need effective strategies for identifying and correcting problems quickly. One specific recommendation is to stock critical parts that have long supply lead times.

ACRONYMS

A	amperes (either ac or dc current)
ac	alternating current or voltage
BOS	balance of system
CFR	Code of Federal Regulations
CPR	cardiopulmonary resuscitation
CT	current transformer
DAS	data acquisition system
dc	direct current or voltage
HMI	human-machine interface
I_{mp}	current at the maximum power
IR	infrared light wavelengths
IRT	insulation resistance tester
I_{sc}	short circuit current
IV	current-voltage designation for PV characteristics
kWh	kilowatt-hour
LOTO	lockout/tagout
NEC	*National Electrical Code*®
OSHA	Occupational Safety and Health Administration
PPE	personal protective equipment
PV	photovoltaic
ROI	return on investment
Solar ABCs	Solar America Board for Codes and Standards
UL	Underwriters Laboratories
V	volt
V_{oc}	open-circuit voltage
W/m^2	watts per square meter

GLOSSARY

balance of system—in a renewable energy system, all components other than the mechanism used to harvest the resource (such as photovoltaic panels or a wind turbine). Balance-of-system costs can include design, land, site preparation, system installation, support structures, power conditioning, operations and maintenance, and storage.

lockout/tagout—safety procedure used to ensure equipment is properly de-energized and, just as importantly, not re-energized until the technician that applied the lock deems it reasonably safe to do so.

megger testing—testing method that uses an insulation resistance meter to induce voltage to wiring or other components in an effort to identify signs of damage to insulation or resistance/leakage from other sources such as loose connections.

PV module connector types—PV modules usually come standard with polarized positive and negative connectors. The connectors are terminations installed by the module manufacturer at the ends of the wires used to couple modules together or in the field to connect the homerun wire back to a combiner box. The connector on the homerun wire needs to be compatible with the connector installed by the module manufacturer. Multi-Contact, Tyco, Amphenol, Wieland, and Radox are five different manufacturers that make different connectors specifically for PV modules.

National Electrical Code—specifically NFPA 70, which is published by the National Fire Protection Association, and is adopted in all 50 states. It is referred to commonly as the *NEC*, and is the benchmark for safe electrical installation and inspection to protect people and property from electrical hazards.

personal protective equipment—equipment designed to protect workers from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards. Besides face shields, safety glasses, hard hats, and safety shoes, protective equipment includes a variety of devices and garments such as goggles, coveralls, gloves, vests, earplugs, and respirators.

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Solar America Board for Codes and Standards

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