



Digitize O&M Procedure Guidelines for Illu Workflows

Cooperative Research and Development Final Report

CRADA Number: CRD-22-23180

NREL Technical Contact: Andy Walker

**NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
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**Technical Report
NREL/TP-8A00-92856
June 2025**

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Cooperative Research and Development Agreement Report

Report Date: 1/10/2025

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the CRADA final report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Illu Global

CRADA Number: CRD-22-23180

CRADA Title: Digitize O&M Procedure Guidelines for Illu Workflows

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Sponsoring DOE Program Office(s):

Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office

Joint Work Statement Funding Table showing DOE commitment:

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	\$50,000.00
TOTALS	\$50,000.00

Executive Summary of CRADA Work:

NREL will provide technical assistance to help digitize best practice operations and maintenance (“O&M”) procedure guidelines utilizing the Illu platform for specific distributed solar-storage system configurations. NREL shall test Illu workflows in a real inspection environment for clarity of instruction and ease of documentation.

CRADA benefit to DOE, Participant, and US Taxpayer:

- Assists laboratory in achieving programmatic scope,
- Enhances U.S. competitiveness by utilizing DOE developed intellectual property and/or capabilities.

Summary of Research Results:

The objective of this CRADA is to digitize and make more accessible best practice methodology for distributed solar-storage O&M utilizing Illu's workflow platform. In addition, this CRADA aims to quantify the impact of the digital workflows compared to traditional pen-and-paper on the quality and speed of standard system O&M activities, including in-field inspection, testing, and associated documentation. Overall, this CRADA seeks to provide the tools and expertise to help the project succeed by providing technical insight, testing resources, and strategic support to this team within the context of the American Made Solar Prize competition.

Statement of Work: Task Descriptions, Deliverables, and Estimated Completion Dates

Task 1: Review Illu workflows

Illu will supply NREL with and NREL shall review and edit up to 20 Illu workflows for inspection and testing of direct current ("DC") arrays and energy storage systems (specific system configurations to be confirmed and agreed upon by Illu and NREL). At the end of the review, NREL will confirm if the workflows align with the industry best practices, referencing documents including NREL guidelines for Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems, existing inspection checklists, relevant IEC codes, and published standard methods.

NREL provided DRAFT workflows for: PV Array Cleaning, PV Array Visual Inspection; PV Array Electrical Testing; Infrared Camera Inspection, and PV Array Inspection with Microinverters.

NREL: PV Array Inspection with Microinverters

Add a workflow description

The screenshot displays a 20-step workflow for PV Array Inspection with Microinverters. Each step is represented by a card with a thumbnail image, a title, and a description. The steps are as follows:

- 1**: This workflow walks through the testing & inspection of systems with microinverters. The DC voltage generated by the PV modules is directly fed into the microinverters, which convert the DC power to AC power, so the voltage and current measurements typical of a DC string are not possible.
- 2**: Safety Precautions: Before starting any inspection, ensure that you follow safety guidelines and use appropriate personal protective equipment (PPE) as required.
- 3**: Instruments required: Digital Multimeter (1000 V, 10 A), Clamp current meter (1000A), Insulation tester (200 mA continuity test and 4000 Mohm resistance test). Shows in PV Circuit Tester that performs all tests. Instruments must be rated for
- 4**: Instruments required: In order to calculate reference voltage and current to compare with measured values, solar insulation (W/m²) and PV module temperature (C) are recorded by a granometer, or the instrument shown provides both insulation and temperature measurements.
- 5**: Prior to each use of a DC current meter the "zero adjustment" must be set to zero current.
- 6**: Before you go: Install the most recent version of any apps or software by the microinverter manufacturer used for system inspection and ensure that you have the log-in credentials if necessary. Find or prepare a map showing position of individual microinverters in the array.
- 7**: Microinverters are typically integrated with a monitoring system. Use the monitoring platform to access the system's performance data, including energy production, individual microinverter status, and any error messages or alerts. Verify that the monitoring
- 8**: Communication: The microinverters communicate with a device that collects and transmits data to the monitoring system. Check the connection between the microinverters and the data collection system to ensure it is secure and functioning properly.
- 9**: Visual Inspection: Inspect the solar panels for any visible damage, such as cracks, delamination, or hotspots. Check the wiring and connections between the panels and microinverters for loose or damaged wires, corrosion, or signs of
- 10**: Continuity of equipment frame or chassis ground. Ensure continuity (no resistance) from PV frame elements, through W/EB (Weather, Electrical Equipment Bonding) parts, ground conductors, to grounding electrode. Connect lead (red) to module frame and other
- 11**: Branch Circuit Voltage. At the AC combiner boxes, measure the operating voltage (V) of each microinverter branch circuit. Voltage is measured between line 1 and line 2 of the branch circuit and should be 240 V or as specified in the design. Record voltage the following format: _____
- 12**: If there were any issues found in the previous step (Voltage other than specified or difference between branch circuits), document them here and include photos as needed. If not, proceed to the next step.
- 13**: Calculate reference current. Reference Current=PV module operating current(measured insulation)/reference insulation)
- 14**: The microinverter is provided with a current transducer (CT) for the production meter. It is located inside the AC combiner box. Check the production CT is in good condition and installed correctly.
- 15**: Branch Circuit Current. On the same conductor as the production CT in the AC combiner box(es), clamp current clamp of hand-held current meter around loose area of conductor (do not pull on wires) and measure operating current of each branch circuit. Record
- 16**: Functionally check the operation of switches and breakers. Check operation of DC disconnect. All power from microinverters should automatically stop upon shutdown of power.
- 17**: Insulation Resistance Check. Use insulation tester (Megohm meter, or "megger"). Connect one lead to current-carrying conductor and other lead to ground. For 1000 V system, resistance should be 1 Mohm or greater to PASS. Record insulation resistance _____ ohms. There
- 18**: Documentation and Compliance: Review the documentation provided by the microinverter manufacturer, including warranties, operation manuals, and maintenance guidelines. Ensure that the installation and components comply with
- 19**: Also see Workflows related to: 1) Infrared Thermography Inspection PV Array and AC switchgear.
- 20**: Conduct a thermal scan of the modules, array cabling & module junction boxes for hot spots and bypass diode failure. Document the location of any identified issues here.

Figure 1. Example workflow for PV Array Inspection with Micro-inverters (zoom in with electronic version to see detail).

Task 2: Field Test Direct Current (“DC”) Array Inspection Workflow

Illu will supply NREL with the prototype application and NREL shall test the pilot implementation of, and field test the DC array inspection workflows in a real system environment, comparing the testing experience with and without the Illu application. NREL shall provide metrics for comparison including the following:

Time spent on:

- Preparing for field testing, including communicating expectations,
- Performing field testing, and
- Documenting field testing results; and
- Quality of testing:
- Compliance with safety best practices,
- Compliance with inspection best practices (which may include the percentage of recommended data points captured as measurement or photos), and the
- Number of issues flagged.

In addition, NREL shall provide feedback from users on how easy it is to (1) follow the inspection/testing instructions presented on the Illu app, (2) log inspection and test results using the Illu app, and (3) generate reports using the Illu web platform.

Two field tests of the PV Array workflows were performed as follows:

- 1) July 11, 2023, staff from ProGreen Solar piloted the app on four residential PV systems in the Longmont area of Colorado. This involved three PV-only systems and one system with battery storage.
- 2) August 28, 2023, Staff of Solar Energy International, NREL and Illu piloted the app on multiple systems at the organization’s educational facility in Paonia Colorado

The following observations resulted from the pilot projects:

- 1) Most residential systems are going to have Module Level Power Electronics (MLPE) such as micro-inverters or DC-optimizers, so it is not possible to do the standard electrical testing for a string of PV modules without MLPE. In these cases, it is recommended to rely on the monitoring capabilities built into the MLPE. This requires an app from the manufacturer and log in credentials, which might be available only to service personnel authorized by the manufacturer. These monitoring systems include V AC, V DC, AC frequency, Power, and temperature. These MLPE automatically prevent reverse polarity which is one of the PV Array Electrical Testing items. The existing Array Electrical Testing that performs IEC 62446 tests would still be applicable for legacy systems that do not have MLPE or for large systems that use central inverters rather than MLPE (for example, SMA products). Add to workflow:
 - a. Add “Update MLPE PV system firmware or app using smart phone or tablet computer.”

- b. Check AC and DC voltage (DC voltage will vary according to DC optimizer, but AC voltage should be as specified).
- 2) There is a need to integrate all the apps available to the PV industry practitioner (interoperability, API's, data standards). Software includes: OpenSolar, Aurora, Solargraph, etc. Integrate Illu App to cross reference system description.
 - 3) For safety issues, such as a blown fuse or a tripped breaker have a "Safety Stop" button to indicate need for qualified personnel to troubleshoot and current the safety problem before proceeding.
 - 4) Users like the references to code sections where applicable.
 - 5) Add "Collaborators" that can get the mobile app and assigned workflows.
 - 6) Procedures will have to be very product specific.
 - 7) Add a prompt for a photo wherever a photo would be beneficial in the report.
 - 8) There is a pause after hitting "Done" which makes field techs wonder what they are doing wrong.
 - 9) It would be more efficient for the field tech to set-up the system description because the office personnel would have to go find a design or something whereas the field personnel can just look at it and enter make and model of PV module and inverter. Also, this would be more reliable as-built information.
 - 10) Add "Not Applicable", "Not Accessible" "Unable to Complete" as possible outcomes to most measures in workflow, with a comment box as to "why,"
 - 11) Have an indicator to show how far you are from a workflow (50% done?) and confirm when done with whole workflow.
 - 12) There are too many workflows to choose from. Rather than have office personnel pick and choose workflows, recommend combining into what the person would have to do or what a person is accountable for. Add "sections" of a workflow that can be assigned to people:
 - a. Periodic O&M Inspection: does not repeat all the tests done for new install
 - b. New Install
 - i. Rough Install: structural, footings, flashings.
 - ii. Final Rooftop:
 - iii. Rough Electrical
 - iv. Final Electrical
 - c. Make is so the workflow can be assigned by office personnel to the person doing it.
 - d. An "Inspector" does not do "Testing" and might not have the qualification or equipment for testing.
 - e. Order workflows based on "why am I here":
 - i. New install that hasn't been turned on yet

- ii. Check of existing system with system on
- iii. Troubleshooting existing system that has been turned off

13) To Visual Inspection add:

- a. Do an initial check and document before touching anything, such as: any error codes, any obvious damage or hazards. Check wiring connections for strands of wire that are pushed back and not in the terminal clip or that are cut off. Ensure wires are firmly held by terminal clips using “tug test”.
- b. Most important part of visual inspection is PV module clamps to rail, rail bolts to L foot, and L foot to roof stanchion (structural attachments). Check torque on clamps and bolts.
- c. Can’t inspect the back of a PV module if it is flush mounted on roof, so add “Not Accessible” if that is the case.
- d. Visual inspection of fuses and fuse holders will not be possible with Module Level Power Electronics, where the fuse is inside the units.
- e. Some of the visual inspection items are suitable for new construction or remove/reset, once they have been checked initially, they don’t need to be re-checked in an O&M inspection.
- f. Regarding shading, if an inspector comments on shading it will only be for the time of the inspection (sun moves). So shading inspection should be limited to SunEye, or on-line LIDAR, drone scan, or other established means.
- g. The term “powerhouse” is undefined. Use the term “inverter” instead.
- h. When doing inspection, you might see something that needs to be measured with a meter but there are a lot of steps before you can use a meter such as PPE or system shutdown, and it could even be a different person qualified to use the meter. Make is that “fail” becomes a work order to be fulfilled with the testing workflow.
- i. PV Ground Mount Inspection: #6 “concrete foot” should be “foundation” could be any kind of driven or helical pile instead of concrete.
- j. In #9, some PV modules will not be clamped, rather through bolted. It is not important that the array be level, rather that it is straight and in the same plane.
- k. In #2, change “Locked Position” to “off” or “locked in off position”

14) Changes to PV Array Electrical Testing:

- a. PV Array Electrical Testing of IEC 62446 requires four measurements (Voc, Isc, Rground, Rinsulation) It is not practical to do these tests as part of an O&M inspection. Open circuit voltage is difficult because it is possible to break an old fuse holder to open it and short circuit current is not feasible because the circuit needs to be altered and a special enclosed current interrupter would have to be used (arc). These Voc and Isc tests are suitable as the system is being constructed and before it is energized (commissioning). Resistance of the electrical insulation is also not feasible as O&M inspection because it requires that the system be shut down and

requires a Megger. In #5 and #7, “Polarity” is not a needed test because the original commissioning would catch this, and the operating voltage measurement would catch it too (fuse will be burned).

- b. Move step #8 so that cell temperature and voltage; and current and insolation; are all measured at precisely the same time.
- c. Electrical testing that should be performed is to measure the operating voltage of the string (this will be the same for all strings unless the string fuse is burned). Also measure the operating current of each string. These can be compared to reference voltage calculated as a function of temperature and reference operating current calculated from insolation level. Continuity of the grounding system is also feasible to do and should be retained.
- d. Add “Rapid Shutdown” to electrical testing workflow (voltage of array should throttle down to <30V).
- e. Don’t open Junction Boxes on PV Modules and do not do a bypass diode test.
- f. Have a “check box” next to each inspection item (e.g., “___deformed plastic”)
- g. Checking for missing gasket would be “Not Applicable” for boxes where the gasket is molded into the plastic.
- h. Develop tabular input for inputting testing data. Integrate with other test instruments that record measurements such as Seward PV100, Solmetric PVQ or Fluke IV instruments, so that measurements can just be imported to the report from those tools. However, without these, a handheld multimeter, current clamp, irradiance and temperature measurements are all that are needed to do an inspection.
- i. Every circuit should be checked for complete inspection (rather than sample).
- j. In #9, rather than “input/output branches” say “DC and AC wires to and from Inverter”
- k. In #1 do not specify range of instruments, rather say “appropriate for system” (e.g., 1000 A is way too big a range for PV, should be 10 or 100 A.) A current clamp will always be used for current (will not pass current directly through multi-meter).
- l. Replace “WEEB” with “frame element” (WEEBS not used anymore).
- m. Regarding #7, change the calculation from open circuit voltage and short circuit current to operating voltage and current; change spreadsheet that does calculations.
- n. Add “whole system performance test” as a separate new workflow.
- o. In #12 you can open fuse holder of Voc test but otherwise leave this out.
- p. #14 is optional but nobody will do it anyway.

15) Regarding IR Camera workflow: IR camera is now available for iPhone (pilot team used this onsite). Add criteria for when IR inspection will work, like not less than 40% power. Add look at disconnects to IR workflow.

16) Integrate with other maintenance management systems so Illu report can feed up to repair plans, etc.

- 17) Set up the App so there is a “pass/fail” (next/back) on the inspector as well as the system...did the inspector upload the requested photo? Did the inspector enter the required test results? Do the entries pass preliminary quality control? Site deficiencies in the inspection before the inspector leaves the site.
- 18) Add a system description with Make and Model of PV Modules, Inverters, etc., and required parameters such as PV module temperature coefficient. This documentation is hard to hand from person to person. Are the modules as specified? Are they all the same?
- 19) Put “Error Log” as the first item rather than #5 (before you do anything see if there is an error displayed and if it is safe to proceed. Error might be hazardous ground fault or arc fault which should be corrected before any testing.
- 20) Opening enclosures for visual inspection or IR camera would generally require PPE and system shutdown, which is too invasive for O&M inspection.
- 21) Add “voice memo” (note that microphone can already do voice recognition-make available in app).
- 22) Add a check box on PPE to confirm that PPE is on before proceeding.
- 23) There needs to be some way to identify where the observed problems are in the system. Recommend an “array tree” which breaks the system down into numbered strings and modules.
- 24) Add feature to extract text from photos (such as PV module or inverter nameplate). This is possible by exiting the app to the regular camera, then saving and importing the image.
- 25) Use “review” to navigate within a workflow. Make is so users can change order of workflow (eg do all inverter items at the same time).
- 26) Always have two people on-site to help each other with ladder etc., and for safety reasons. Make it less clunky when two users are in the same workflow at the same time.

Task 3: Field Test Energy Storage System Inspection Workflow

NREL shall field test the relevant energy storage inspection and testing workflows in a real system environment.

Two field tests of the PV Array workflows were performed as follows:

- 1) July 11, 2023, staff from ProGreen Solar piloted the app on a battery system consisting of two 16 kWh LG RESU battery systems.
- 2) August 28, 2023, staff of Solar Energy International, NREL and Illu piloted the app on multiple battery systems at the organization’s energy storage system testing and educational facility in Paonia Colorado. “Fortress Power” battery was examined in some detail.

The following recommendations were recorded:

- 1) Add “charge the battery” to workflow, unless battery is fully charged already.

- 2) Communications link is critical to batteries. The communications board is the biggest problem. All the battery systems inspected were sealed, requiring the data link and battery manufacturer protocols to measure parameters internal to the battery unit.
- 3) Add “Capacity Test” of battery to measure remaining battery capacity (fully charge and discharge battery).
- 4) Unlike the PV array, the battery control involves a very large number of setpoints. These setpoints are often the sources of a problem.
- 5) Need to have all the battery specifications and communications protocols/software available.
- 6) People sometimes use equipment from multiple manufacturers (e.g., inverter, charge controller) which makes it hard to be consistent in a single approach to inspecting battery system.

Task 4: Other work at the direction of the Participant, consistent with the scope and subject to the availability of funding.

NREL staff co-authored a publication on how O&M workflows can vary from standard tests based on the needs of a project:

PV Magazine “How to convert IEC standards into actionable procedures for your team

Solar workflow management systems provider Illu provides perspective on best practices and procedures.” December 5, 2023 by Natasha Allen, Illu

Conclusions

NREL has supported the partner through launch of a commercial product available for PV O&M practitioners at <https://help.Illu.works/>.

Recommendations for future work include:

- 1) Solicit equipment-specific O&M workflows from equipment manufacturers and suppliers
- 2) Add ability to estimate cost of each O&M workflow based on entered labor rates, locations, etc.
- 3) Continue testing and improving all workflows.

References: None

Subject Inventions Listing: None

ROI#: None