SANDIA REPORT
SAND2014-19432
Unlimited Release
Printed November 2014

Solar PV O&M Standards and Best Practices – Existing Gaps and Improvement Efforts

Geoffrey T. Klise – Sandia National Laboratories
John R. Balfour – High Performance PV
T.J. Keating – SunSpec Alliance

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.osti.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd.
Springfield, VA 22161

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/help/ordermethods.asp?loc=7-4-0#online

SAND2014-19432
Unlimited Release
Printed November 2014

Solar PV O&M Standards and Best Practices – Existing Gaps and Improvement Efforts

Geoffrey T. Klise
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-MS1137

John R. Balfour
High Performance PV
9436 N. Arroya Vista Dr. East
Phoenix, AZ 85028

T.J. Keating
SunSpec Alliance
4030 Moorpark Ave., Suite 109
San Jose, CA 95117

Abstract

As greater numbers of photovoltaic (PV) systems are being installed, operations & maintenance (O&M) activities will need to be performed to ensure the PV system is operating as designed over its useful lifetime. To mitigate risks to PV system availability and performance, *standardized procedures* for O&M activities are needed to ensure high reliability and long-term system bankability. Efforts are just getting underway to address the need for standard O&M procedures as PV gains a larger share of U.S. generation capacity. Due to the existing landscape of how and where PV is installed, including distributed generation from small and medium PV systems, as well as large, centralized utility-scale PV, O&M activities will require different levels of expertise and reporting, making standards even more important. This report summarizes recent efforts made by solar industry stakeholders to identify the existing standards and best practices applied to solar PV O&M activities, and determine the gaps that have yet to be, or are currently being addressed by industry.

ACKNOWLEDGMENTS

The authors would like to acknowledge the significant contributions from Sarah Kurtz at the National Renewable Energy Laboratory, Rob Andrews of Calama Consulting, George Kelly from Sunset Technology, Inc., Gary Buchanan of Borrego Solar Systems, Tom Tansy from the SunSpec Alliance, as well as contributions made by the Sandia Technical O&M working group, participants in a March, 24 2014 meeting at K&L Gates in San Francisco, CA and a post conference workshop held March 26, 2014 at the SolarPlaza O&M Workshop in San Francisco, CA. See Appendix A for a list of participants from the two meetings. Special thanks also go to Pramod Krishnani and Jamie Mordarski for their review of this paper. This work was funded by the U.S. Department of Energy's SunShot Initiative.

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

CONTENTS

FIGURES

NOMENCLATURE

ac	alternating current
ASTM	American Society for Testing and Materials
dc	direct current
DAS	data acquisition system
DOE	Department of Energy
EPRI	Electric Power Research Institute
GADS	generating availability data system
ICOMP	Installation Commissioning Operation & Maintenance of Photovoltaic Systems
IEC	International Electrotechnical Commission
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IR	infrared
IREC	Interstate Renewable Energy Council
IV	current-voltage
KPI	key performance indicator
kW	kilowatt
kWh	kilowatt-hour
LV	low voltage
MV	medium voltage
MW	megawatt
MWh	megawatt-hour
NEC	National Electric Code
NECA	National Electrical Contractors Association
NERC	North American Electric Reliability Corporation
NFPA	National Fire Protection Association
NREL	National Renewable Energy Laboratory
NABCEP	North American Board of Certified Energy Practitioners
NWIP	new work item proposal
oSPARC	Open Solar Performance and Reliability Clearinghouse
O&M	operations and maintenance
OSHA	Occupational Safety and Health Administration
PID	potential induced degradation
PPE	personal protective equipment
PV	photovoltaic
PVROM	Photovoltaic Reliability Operations Maintenance
PV-RPM	Photovoltaic Reliability Performance Model
QA	quality assurance
RSCM	risk scoring criteria & methodology
SAPC	Solar Access to Public Capital
SDO	Standards Developing Organization
SEIA	Solar Energy Industries Association
SNL	Sandia National Laboratories
STC	standard test conditions
UV	Ultraviolet

1. INTRODUCTION

Sandia National Laboratories (SNL) is working with photovoltaic (PV) industry experts to improve Operation & Maintenance (O&M) activities through regular working group meetings intended to elicit best practices that can be shared with the rest of the industry. This document was developed to inform stakeholders interested in O&M standards and best practices for commercial and utility scale photovoltaic (PV) systems and larger. A need has been identified to try and capture all of the activities focused on standardizing O&M to ensure that any working groups or standards development efforts effectively coordinate and share information, as well as reduce potential overlap. This should be considered a foundational and living document, meant to foster collaboration through ongoing standards development around PV O&M.

Optimal performance of a PV system is dependent on many factors, which include:

1) Enhanced and improved "quality" of planning, specification, design, component selection, construction/installation, and commissioning encompassing O&M considerations and activities,

2) Environmental factors that impact the optimal production of the system, such as temperature, shading, cloudy days, degradation, aging, soiling, lightning, and biotas,

3) Grid availability and curtailment beyond the control of the PV system operator that may reduce a PV system's optimal output, and

4) The established short and long term project goals and objectives, system delivery approach and project team education and experience.

Specifically, this paper focuses on the O&M impact on performance as it is an area of concern among large project developers, owners, financial backers, insurers and energy users. However, the value of O&M to whole system performance, viability and cost is a bellwether and as such, a fiscal and energy production metric over time indicating how well a particular system is specified, designed, constructed and maintained. That information can drive down costs and disruptions to yield. O&M activities can also mitigate some of the environmental effects that can curtail output and viability while reducing performance.

The O&M budget is small when compared to the overall PV system cost, though exact values are difficult to obtain. Estimates include 1% of "capital investment per year" (IEA, 2014) and \$20-\$40/kW$_{AC}$-year or \$10-20/MWh for utility-scale PV (Bolinger and Weaver, 2013). A 2010 report, projecting O&M costs to 2015 estimated fixed utility scale PV O&M costs having the highest variance compared to other energy generating technologies (Tidball et al., 2010). An Electric Power Research Institute (EPRI) report from 2010 estimates O&M costs for PV systems 1 MW and less at \$6/kW to \$27/kW which was around <1% to 5% of the "all in" costs of a PV system, and for larger PV systems, depending on technology and mounting, the cost ranges from \$47/kW-yr. to 60/kW-yr (EPRI, 2010). These estimates span a 4-year time period, and may not reflect current operational and maintenance costs. NREL has compiled additional O&M cost

information in their forthcoming paper on O&M Best Practices (Walker et al., In Preparation) with the most recent reference to an O&M cost range updated in 2013.[1]

As the first cost of a PV system goes down, the ratio of O&M to project first cost rises where O&M becomes a larger percentage of the total system life budget. Without effective standards and best practices, there is a high probability that O&M costs may increase at a far higher rate than anticipated; these costs may further undermine the ability to estimate and control costs over the life of the system. This widening gap must be recognized and addressed during specification, and during the design and implementation phases of PV system delivery.

O&M is a critically necessary activity to keep the PV plant operating as designed with minimal downtime and loss of yield. Currently, O&M represents a growing amount of uncertainty in costs borne by the project owner due to a variety of system effectiveness limiting factors, including the above listed factors and others such as ownership insurance and financing structure (e.g., flip ownership within the first 5-7 years).

Standardizing many of the processes and procedures within O&M as a focus, from specification, contract language, through implementing O&M activities and throughout the system life, can increase PV system performance and reduce costs by:

1) Reducing event and failure uncertainty using root cause analysis methodology,

2) Reduce the cost of labor and component replacement,

3) Improve performance and yield using standard key performance indicators and performance evaluation methodology (Kurtz et al., 2013),

4) Provide an effective process for reporting issues, including lessons learned that will positively impact the specification and design of future systems, and

5) Identifying and understanding financial tradeoffs of O&M event response, both of which will reduce the uncertainty over O&M costs incurred over the PV system's lifetime.

These combined with a process to clearly define and document all issues and failures, then feed them back into the specification and design process can reduce this trend towards increased system performance uncertainty through growing unanticipated O&M costs.

[1] http://www.nrel.gov/analysis/tech_lcoe_re_cost_est.html

2. REPORT ORGANIZATION

The first section of the report is focused on existing consensus standards developed through organizations including the Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC), American Society for Testing and Materials (ASTM) International and others. It is a snapshot in time of existing standards and those which are actively in process at the time of this report. Specifically, standards presented here address primary O&M related activities. As this report serves to identify these standards, it does not make a recommendation on which standard to use. Some standards may eventually be updated over time and the reader is encouraged to look at the history of the standard in more detail if additional information is required. The report will then discuss what standards are currently in development that address O&M activities.

The second section identifies current best practices that are utilized by industry along with those currently in development through active working groups. Some of these best practices may mirror existing standards, result in de facto "standards" or may be submitted and adopted by standards organizations through a formal consensus process at a later time. These best practices borrow from the state of the art and are often formed out of necessity as more formally adopted codes and standards may not be current enough to address new and important issues. It should be noted however that they can lack consistency; in part from a lack of uniformity and agreement on industry terms, definitions and metrics. In addition, if not updated regularly, there is a tendency to only address a narrow practice not applicable to the rest of the industry, or if a consensus standard is developed and adopted, that may supersede that practice.

The third section discusses gaps in O&M standards and best practices through an analysis of what is currently used by industry, discussions with industry experts participating in working groups and conference meetings, and what groups or organizations may have the resources and technical expertise to take on coordination and development of the O&M specific gaps.

The standards and best practices described in this paper can be divided up in different ways, either by organization or categories. In Appendix A, we summarize the different standards and best practices into categories such as target market (residential, commercial, utility), field of use (specification, testing, design, installation, commissioning, monitoring, operations, and finance and insurance), focus (technical, finance), and funding (current, completed).

As the contents of this report represent the landscape of O&M activities at the time of publication, it is hoped that other working groups or organizations can continue to update this body of work in the future. This report will serve as a guidepost to stakeholders that need to identify and track specific standards and best practices to improve the overall quality and reliability of PV systems they design, install and operate. In that spirit, it is suggested that the reader consider that the development of best practices and standards for O&M is an important and continually evolving contribution to the continuing growth of the PV industry. PV systems of all sizes will benefit from new innovations that guarantee reliable operation over their useful lifetime, and done in a way that can both minimize expenses and better predict future expenses with an improving degree of accuracy.

3. STANDARDS IN USE & IN DEVELOPMENT ADDRESSING PV O&M

The standards discussed here may cover areas outside the narrow definition of O&M activities for PV systems. There are elements of system specification, design, installation, commissioning, monitoring operations, control, performance and component testing that are linked to O&M as they influence to what degree O&M falls on a spectrum of time spent in pre-emptive maintenance, preventative or proactive maintenance, corrective or reactive maintenance, and condition-based maintenance. A good discussion of these types of maintenance activities is presented by EPRI (2010). If used properly, these standards will provide critical feedback for future system specification, design and installation that will result in PV systems with greater reliability at reduced cost. This section refers to consensus standards from ANSI certified standards developing organizations. Much of this was put together with the help of industry through SNL's PV O&M Working Group. NEC electrical codes and other building codes are not addressed in this document.

3.1. International Electrotechnical Commission (IEC)

The International Electrotechnical Commission (IEC) as applied to photovoltaic systems through IEC Technical Committee TC82, prepares international standards that focus on the electrical aspects of photovoltaic technologies. There are multiple working groups where IEC standards have been developed or are in progress. The ones that pertain to O&M activities as identified and summarized by SNL's working group are presented below.

IEC 60364-7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

This standard was created to more specifically address PV systems, including those that make use of alternating current (ac) modules; it amends some of the original sections of IEC 60364: Low-Voltage Electrical Installations – 2005. The original standard was developed to provide design rules that apply to many types of electrical installations, including PV systems. Definitions are provided in 7-712 that include safety, fault, short-circuit current protection and wiring, among others. Two general 'schemas' are presented for single and multiple arrays.

IEC 61215/61646: Crystalline silicon / thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval - 2005 / 2008

This standard is for qualifying modules to weed out what are considered "infant mortality" design failures that happen early on after a module is placed in service. Some of the tests include performance characterization, testing for outdoor exposure, bypass diodes, damp heat, wet leakage current, hot spots, and hail. For O&M purposes, having modules that have been tested to these standards helps ensure a base level of quality and ideally, lower rates of module failure and degradation. The test is not meant to qualify modules for specific climates, nor does it cover all of the failures modes that may occur over time.

IEC 61724: PV System Performance Monitoring – Guidelines for measurement data exchange and analysis – 1998 (Under Revision)

This standard is focused on evaluating PV array performance to allow for comparisons across different sized installations and climates, mainly for larger systems. Part of the standard speaks

to a specific design for the data output file and QA check on the data. Output "Derived Parameters" are also defined, with key performance indicators such as array yield, performance ratio and PV plant efficiency, to name a few.

At the time of this publication, 61724 is going through a major revision into a two-part standard with the first part addressing PV system performance monitoring and the second part addressing energy rating. Within the standard, there are specific precision levels (A,B,C) that correspond to the size and type of system, and may help to guide practitioners when developing operations or maintenance plans and associated costs. For example, maintenance of irradiance sensors is laid out for the different size and precision levels.

IEC 61730: Photovoltaic (PV) Module Safety Qualification, -1 Requirements for Construction & -2 Requirements for testing – 2011

This two-part standard references both module construction and testing to ensure the module will operate safely. As related to O&M activities, these standards, when tested against, can "assess the prevention of electrical shock, fire hazards, and personal injury due to mechanical and environmental stresses." In the standard, it references IEC 61215/61730 as the same sample module can be used to perform the module qualification along with these safety tests. A module that passes these tests would be expected to operate in a safer manner than those that do not.

IEC 61829: Crystalline silicon photovoltaic (PV) array – On-site measurement of I-V characteristics – 1995 (Updated in 2014)

This standard allows on-site measurements to be extrapolated to "Standard Test Conditions (STC) or other selected temperatures and irradiance values." Two different temperature and irradiance corrections are available for the test, depending on whether the temperature is measured at the back of the module or by using irradiance measurements. This standard can be used to test modules in the field as part of O&M activities that include system commissioning or troubleshooting.

IEC/TS 61836: Solar PV energy systems – terms, definitions and symbols – 2007

This standard has been in place since 1987 to convey to the PV industry the "what do the words mean" according to the IEC's perspective. This is a document that continues to be updated as new technologies appear, which is important for O&M and all related PV activities as it provides a glossary of definitions that apply to the IEC standards listed in this document.

IEC 62446: Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection – 2009

This standard is aimed at defining what is considered the "minimal" information that is given by the installer to the system owner as well as "commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system." This standard also states that it could be used for re-commissioning a PV system.

O&M specific items that are discussed, and should be included "at a minimum" include checklists for failure response, shutdown procedures, maintenance and cleaning, system operating correctly, and any warranty-specific details on the components or workmanship.

Appendices include references on a model verification certificate, inspection report, PV array test report and an infrared camera inspection procedure.

IEC 62548: Photovoltaic (PV) arrays - Design requirements – 2013

According to the IEC, "This Technical Specification sets out design requirements for photovoltaic (PV) arrays including dc array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads." Sections include Array Configuration, safety issues, selection of electrical equipment and building the system. O&M is referenced to IEC 62446 (see above) and there is a discussion on marking and signage.

IEC/TS 62738: Design guidelines and recommendations for photovoltaic power plants (In Development)

This standard addresses design and installation of 1 MW and larger ground mounted "Power Plants." It covers many of the areas specific to larger systems, including transformer siting, bonding, MV and LV connections, interconnection, communication systems as well as the many inverter configurations, including direct current (dc) optimizers, string inverters and ac modules.

There are sections that discuss both commissioning/acceptance testing as well as O&M activities. This standard references many other IEC standards that should be followed in both the design and installation phases.

IEC 60364-9-1: Installation, design and safety requirements for Photovoltaic systems (In Development)

According to the IEC, this standard is currently in development, and is a product of both Working Groups TC 64 and TC 82, which will result in a combination of 62548 (presented above) and 60364-7-712 (presented above). As stated in the documentation, "This Standard sets out design requirements for photovoltaic (PV) arrays including dc array wiring, electrical protection devices, switching and earthing provisions. This standard covers dc equipment associated with the PV array including power conditioning equipment connected to the array and includes and special requirements on the output side of the power conditioning equipment (either dc or ac.) that is unique to the source i.e. the PV array and its associated topology and connection arrangement." Sections include Array Configuration, safety issues, selection of electrical equipment and building the system. O&M is referenced to IEC 62446 (see above) and there is a discussion on marking and signage.

IECRE Solar PV Rules of Procedure (In Development)

This new conformity assessment for IEC sets a process by which PV systems can be assessed by "Certifying Bodies" which look at how standards are followed from initial testing and qualification of PV components all the way to operating PV systems in the field. For O&M, this process is intended to focus on the entire spectrum of a PV system's lifecycle, including design, installation, commissioning, and O&M. Many standards and best practices have not yet been developed in the installation and O&M space, though this conformity assessment is intended to reference those as they become available.

IEC Maintenance of PV Systems - WG 3 NWIP (In Development)
There is an effort underway to develop an IEC standard on "Maintenance of PV Systems." The initial outline of this draft was taken from the Solar ABC's document on PV System O&M Fundamentals, which is discussed in more detail below. This document covers both rooftop and ground mount PV systems and addresses safety, performance indicators, reliability, diagnostics, troubleshooting and documentation from a maintenance perspective. Operational aspects beyond system status, battery backup or off-grid systems are not covered.

3.2. ASTM International

The American Society for Testing and Materials develops international consensus standards for solar that focus on test procedures for components and PV systems. Subcommittee E44.09 on Photovoltaic Electric Power Conversion oversees most of the PV related standards development, with the exception of E44.01, which developed the standard terminology in E772-13 and E44.44 (safety standard for preventing fires with PV modules and systems). Relevant to O&M, the five presented below are currently available for practitioners to use with the sixth currently under development.

ASTM E772-13/E1328-05: Standard terminology relating to solar energy conversion
This includes definitions on PV systems, including solar radiation measurements. The second standard listed is tailored to PV performance measurements though it was withdrawn in 2012 and replaced with 772.

ASTM E2047-10: Standard test method for wet insulation integrity testing of photovoltaic arrays
This safety standard presents a test procedure to ensure that electrical components of an entire PV array are properly insulated from the environment. The test looks to find whether there are any insulation flaws in the array that can be identified through a user-defined leakage resistance.

ASTM E2848-13: Standard test method for reporting photovoltaic non-concentrator system performance
Specifically, this standard addresses overall PV system "performance" for acceptance testing, reporting performance and monitoring system performance. The results of this test are designed to assess the performance of the system being measured; not to be used for comparing the performance of different PV systems. Specific annexes discuss the use of a calibrated reference cell for measuring irradiance as well as how to determine a spectral irradiance at a reference condition.

ASTM E2908-12: Standard guide for fire prevention for photovoltaic panels, modules and systems
This standard addresses fire safety for PV modules and systems along with design and installation instructions to reduce any fire-related risks. It only covers generally accepted practices at the time the standard was developed, and also does not discuss ways to put out a fire on a PV system.

ASTM E2939-13: Standard practice for determining reporting conditions and expected capacity for photovoltaic non-concentrator systems

This is used to develop modeled PV system performance for a specific PV system over a specific time period. Power plant acceptance is one of the purposes of this standard, and it can be used with 2848 (discussed above) to compare measured power output, with what is predicted (in 2939). With respect to O&M, using both 2848 and 2939 can serve as a way to track PV plant performance over time.

ASTM WK43549 – New practice for installation commissioning operation and maintenance process (ICOMP) (In Development)

Specifically geared towards gaps recognized by the ASTM, the ICOMP standard intends to cover areas of installation, commissioning and O&M. This process started in late 2013 with a goal of having a standard developed in this space by 2015. From the ASTM, "This practice details the minimum requirements for installation, commissioning, operations and maintenance process' to ensure safe and reliable power generation for the expected life of the photovoltaic power plant. Specifically dealing with commercial photovoltaic installations, this practice covers a broad spectrum of designs and applications and shall be focused on proper process' to ensure quality." Three key areas identified by this standard include: "1) Design, engineering and construction of the PV plant. Further standards should be developed for building integrated, or building mounted systems, modules with embedded power electronics, lightweight flexible modules, or other specific components. 2) Commissioning, testing and approval for power generation (Utility Witness Testing). Standards for owner acceptance will also be addressed. 3) Operating and Maintenance of the PV plant including performance monitoring, periodic inspection, preventative maintenance and periodic re-commissioning."

3.3. National Electrical Contractors Association

According to NECA, *National Electrical Installation Standards*™ are intended to improve communication among specifiers, purchasers, and suppliers of electrical construction services. They define a minimum baseline of quality and workmanship for installing electrical products and systems. These standards are intended to be referenced in contract documents for electrical construction projects. Essentially, these go beyond NFPA 70E and provide detail on "tricks of the trade."

NECA 412-2012: Standard for Installing and Maintaining Photovoltaic (PV) Power Systems

This is an existing ANSI standard that focuses on all PV system sizes at 1000 volts or less. Specific areas this standard addresses, from an "electrical contractor's perspective" includes, 1) receiving, handling, storing, 2) Pre-Installation considerations, including performance, building codes, structural engineering, utility interactive systems, and interconnection, to name a few, 3) Solar PV power system safety, 4) Installing a PV system, 5) Start-up and commissioning, 6) Site cleanup, and 7) Maintenance. Annexes include sizing PV systems and reference standards. An outline of the report is available here: http://www.techstreet.com/products/preview/1836909

3.4. TUV Rheinland PTL

TUV Rheinland PTL is a testing and certification laboratory that can test photovoltaic system components against IEC, IEEE, and UL standards, including many others. Recently, they have become an ANSI certified standards developing organization, and The North America Group of TUV is currently developing two standards, one of which is germane to O&M presented is below.

TUV-R 71732-01:201X: Qualification PLUS (Q+) Testing for PV Modules - Test and Sampling Requirements

The purpose of Qualification PLUS is to implement testing that goes beyond IEC 61215/61646 and 61730 in a way that can identify potential module defects that may result in faults and failures much later during the lifetime of the module. Much of what is being developed consists of "accelerated testing" meant to simulate multiple cycles of UV exposure, thermal stress, and conditions that lead to potential induced degradation (PID). If these failure methods can be detected using this new testing procedure, it may result in modules that are highly reliable over time and result in fewer failures and lower degradation rates.[2]

[2] http://www.tuv.com/en/usa/about_us/press_1/press_releases/newscontent_usa_205830.html

4. BEST PRACTICES IN USE & IN DEVELOPMENT ADDRESSING PV O&M

In this section, we present different organizations that have developed, and are actively developing best practices that can be used by industry to improve O&M activities, based on demonstrated need. They continue to reflect the need for improvements as the solar market pushes towards greater maturity. Some of these may be used as a foundation for an ANSI recognized consensus standard, such as those presented above.

Not mentioned in this paper, but important to note is the fact that over the past few years, the number of webinars, conferences and industry articles on O&M have increased, with trade publications such as SolarPro offering in-depth technical articles on O&M and reliability topics, for example. This is reflective of the numerous challenges posed as PV systems age and an industry looking for insights and best practices that can be applied.

4.1. Solar ABCs

Solar ABCs PV System O&M Fundamentals

This document developed by Solar ABCs in 2013 is 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." This includes many areas focused on safety due to known hazards that O&M technicians may encounter in the field. Sections in this report include 1) Safety requirements, including PPE, lockout/tagout, signage, etc., 2) Routine scheduled preventative maintenance, 3) General isolation procedures, 4) Failure response, 5) Inverter troubleshooting and service, and 4) Diagnosing and testing for low power production, which includes, for example, IR imaging, megohmmeter testing, fuse checks, data acquisition system (DAS) checks, array washing, vegetation management and systems warranties.[3] This effort was used as a starting point for the IEC Maintenance standard that is being considered for a new work item proposal (Section 3.1).

4.2. Interstate Renewable Energy Council

The Interstate Renewable Energy Council (IREC) works to facilitate renewable energy adoption through research and recommendations in interconnection procedures, workforce credentialing and training, and regulatory reform.

Field Inspection Guidelines for PV Systems

This document was prepared by Brooks Engineering for IREC and outlines a procedure to simplify the "Field Inspection Process." According to the author, "The ultimate goal of this guideline is to provide a basic knowledge of how to inspect a PV system, so that a field inspector can take this framework and develop the experience necessary to perform these inspections quickly and thoroughly." This document can be useful for O&M purposes as it provides a high-level overview of issues may arise when PV system components are installed incorrectly.[4]

[3] http://www.solarabcs.org/about/publications/reports/operations-maintenance/index.html
[4] http://www.irecusa.org/wp-content/uploads/2013/09/Model-Inspection-Checklist.pdf

4.3. SunSpec Alliance

SunSpec is an industry trade alliance of over 60 members which creates peer reviewed information standards and data models for the distributed generation industry. SunSpec standards address operational aspects of PV power plants on the smart grid, including residential, commercial, and utility-scale systems with the goal of reducing cost, promoting technology innovation, and accelerating industry growth. SunSpec's primary goal is to deploy their work product to the industry rapidly and then over time feed the SunSpec specifications into long term national and international standards bodies. The O&M process, which is perhaps the longest and most data intensive process in the solar plant life cycle, is ripe for standardization and codification--and thus represents a major need for standards from SunSpec members. Information systems are ideally suited to drive up process quality and drive out transaction costs associated with today's O&M market. These information systems need standards to scale; SunSpec is producing standards for this field of use.[5]

Performance Committee - Guide to Commissioning Measurements

This effort is being led by the SunSpec Performance Committee to develop a "Guide to Performance & Safety Measurements for Commercial PV System Commissioning." Specifically, this document will help in the commissioning and re-commissioning process to ensure the PV system is operating as expected, and help identify any performance issues that should be addressed to ensure the system operates as designed. Some of the methods for testing include a discussion on the business case to be made for what is called "Comprehensive Commissioning" as well as PV System ac Performance, array performance (IV curves), irradiance measurements, module and cell temperature measurements, insulation resistance measurements, thermographic characterization of array and system hardware, as well as example tables for contracts and test procedures. All of the aforementioned commissioning test results contribute to the baseline data and analysis of the plant. This data and analysis is the basis upon which future O&M can be planned and executed.

Securitization, Support, O&M Best Practices and Cost Modelling

This effort is complementary to the O&M Best Practices activity area led by NREL (Walker et al., In Preparation) as SunSpec is under contract to NREL to help complete that task. Collaborating with industry, SunSpec is characterizing and aggregating current industry best practices for (i) system installation and (ii) operation and maintenance (O&M) with a focus on investor and underwriter risk concerns. SunSpec is distilling a set of best practices, minimum maintenance schedules and cost models from industry best practices that represent the elements needed to perform O&M risk analysis.

Active PV Plant Monitoring - Quality Monitoring System

A large part of SunSpec's mission is to define the standards for plant monitoring quality given varied applications. SunSpec delivered the first version of "Best Practices in Solar Performance Monitoring" and are about issue a revision to accommodate changing cybersecurity

[5] http://www.sunspec.org/

requirements. SunSpec believes this work is foundational and will be submitting this revised document to the catalog of best practices for O&M.

oSPARC Plant Extract Document

The SunSpec Plant Extract specification is a comprehensive description of a solar plant and its information attributes. It is one of 10 major specifications in the SunSpec catalog. The SunSpec Plant Extract specification is used to deliver application software such as the Open Solar Performance and Reliability Clearinghouse (oSPARC) (which is a special purpose monitoring system) and more general purpose software like the O&M monitoring systems used by SolarCity, SunEdison, and others. As such, the SunSpec Plant Extract specification is an example of a best practice that states "select products comprising solar plants, in part, on the basis of their support for standard communication and information interfaces" and "when deploying the O&M monitoring system, ensure that all standard measurements required by all stakeholders--O&M providers, investors, warranty agents, etc.--are captured and that the resulting data is encoded in a standard, easy-to-read format."

4.4. TruSolar

The TruSolar working group is led by Distributed Sun with a stated intent of "establishing uniform credit screening standards for commercial and industrial PV projects."[6]

TruSolar Risk Scoring Criteria & Methodology

The Risk Scoring Criteria & Methodology (RSCM) is a way to "Evaluate potential solar project risks across 450 unique risk elements." Specifically, this methodology is a way to improve PV project transparency to those financing these projects, which can ultimately result in higher quality PV systems. For O&M, the RSCM could highlight areas where there is uncertainty in how O&M is planned from a cost perspective and how O&M is performed, in terms of both quantity and quality. Poor O&M could lead to higher risk scores, and ultimately a higher cost of capital. Standardizing that process and adoption by industry could lead to improvements in O&M as companies see there is a clear path to accessing lower cost capital.

4.5. Sandia Technical PV O&M Working Group

The Sandia National Laboratories Technical O&M Working Group started in 2013 during the O&M workshop as part of the larger SNL-led PV Systems Symposium that took place April 30 – May 3, 2013.[7] SNL is working in 4 focus areas that link to actionable processes supporting failure reporting analysis and corrective action systems as a way of improving how O&M is designed into a PV system and implemented throughout its lifetime:

- Failure Reporting
- Preventative and Preemptive Maintenance
- PV System Design
- PV System Installation

[6] http://www.trusolarscore.com/
[7] http://energy.sandia.gov/?page_id=13688

Within these 4 focus areas, the working groups will be addressing Key Performance Indicators (KPIs), fault and failure analysis, data collection and reporting, and proper definitions in these areas, all which can inform cost modeling and tradeoff analysis. SNL is developing a "Precursor Report of Data Needs and Recommended Practices for PV Plant Availability, Operations and Maintenance Reporting," with guidance from the working group. This paper lays out the framework for a reliability-centric approach at asset management, and will be available in 2015.

SNL is facilitating an effort that uses a systems engineering approach to reduce PV System O&M costs while integrating the efforts of SNL's PV Reliability Operations Maintenance (PVROM) process and other existing and previous efforts to improve PV system performance through greater reliability (EPRI, 2014). To reach that goal, SNL is gathering fault and failure data from small and large PV systems for comparative analysis and incorporation into performance models, such as the SNL-developed PV Reliability Performance Model (PV-RPM).[8]

4.6. NREL PV O&M Collaborative Working Group

The National Renewable Energy Laboratory (NREL) has a collaborative working group aimed at "developing well-understood O&M guidelines to inform investor decision-making related to the pooling of PV assets." This working group is a part of NREL's larger Solar Access to Public Capital (SAPC) working group which has a focus on lowering the cost of capital for solar projects through the process of securitizing solar assets. Current activity areas described by Walker et al. (In Preparation) include:

- O&M Best Practices – "Compile best practices with the potential to improve PV performance and reduce O&M costs."

- O&M Cost Model – "Modify existing or new costs models to accurately predict O&M cost, and to quantify associated risk, based on site-specific details.." of the PV system, including environmental factors.

[8] http://energy.sandia.gov/?page_id=6367

5. GAPS ANALYSIS

Even though many of the standards and best practices described above may touch upon some of the aspects of O&M, there are still gaps that exist. For example, it is not clear what percentage of larger PV systems has preventative maintenance schedules. For those that do, what constitutes minimum preventative maintenance, or even quality preventative maintenance?

In addition, many of the standards and best practices that do exist are not being used. Reasons include a lack of rigor in the standard, the cost of implementing the standard, knowledge the standard exists, use of in-house developed best practice, and no requirements by owners or financiers to use a specific standard or best practice (because many do not yet exist).

The process we took was to engage industry at two events in the spring of 2014. The first consisted of a small working group on March 24, 2014 at K&L Gates in San Francisco. The second was as a post conference meeting held March 26, 2014 at the SolarPlaza O&M Workshop in San Francisco, organized by SunSpec. See Appendix B for a list of participants from the two meetings.

In this section, we present information shared by solar industry experts on what constitutes a "gap" in O&M activities, in terms of standards and best practices. Our intent is to highlight areas where additional focused research is needed, and provide discussion around existing efforts to address those gaps and identify industry stakeholders that may have the experience and resources to also address those gaps.

5.1. Framework for Discussion

The process we used consisted of presenting the existing standards and best practices as outlined in Sections 3 and 4. To focus the effort, we moved the existing standards and best practices into high-level categories that we called the "PV System Lifecycle" (Figure 1). Early versions of this were presented in Sandia Technical O&M Working Group meetings on February 11 and March 24, 2014 where the participants helped provide input into the lifecycle categories as well as the standards and best practices identified above.

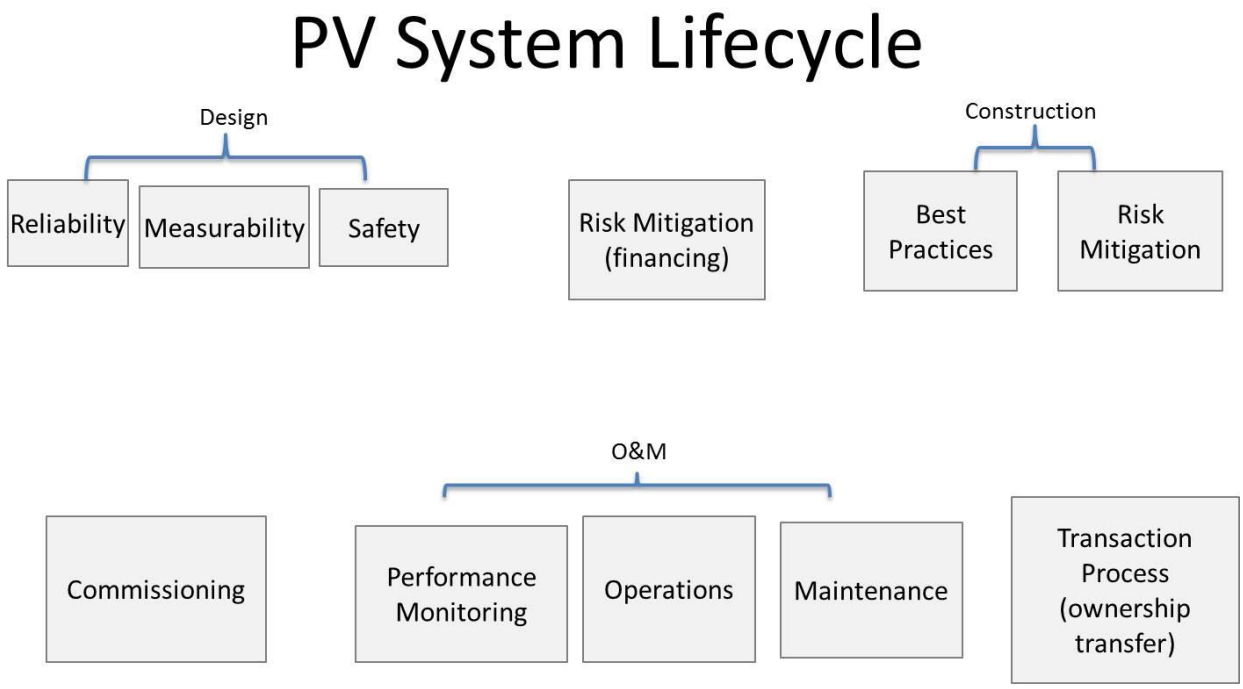

Figure 1. Categories used for organizing standards and best practices

At the March 24th meeting, participants took the opportunity to review the existing standards and best practices printed on large posters, add known efforts that are currently on-going to improve O&M practices (Appendix C), and finally identify gaps that are currently not being addressed. A few photographs of this process are shown in Figure 2.

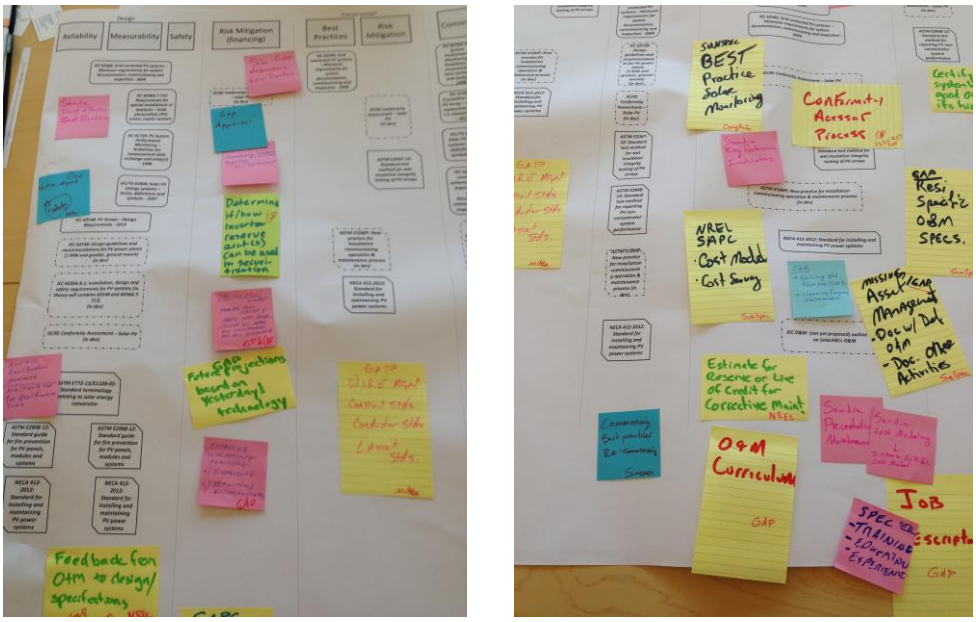

Figure 2. Workshop participant notes for O&M gaps and best practices

5.2. Gaps Identified by Participants

Presented below are the initial gaps organized by category (Figure 1) as recorded from participants during the two events (Appendix B). Efforts were made to accurately capture the essence of what was suggested with few edits. Gaps that are being addressed as identified and discussed in Sections 3 and 4, including other efforts not described in those sections, are mapped to the categories below. The degree to which an effort will help reduce the gap or remove it completely is not discussed here. The purpose of this paper is to help connect those in the PV industry with both the gaps and solutions that have been gathered in a collaborative environment. This is not an exhaustive search as there may be other efforts that are not identified below, or are used internally by an O&M service provider or EPC that if shared, may improve PV system O&M activities. A discussion of areas that will require additional effort is presented in Section 5.3.

5.2.1. Design: Reliability, Maintainability, Safety

Gap Identified by Industry	Known Effort to Address Gap
Wire Management.	Best practices in wire management discussed in a February/March issue of SolarPro.[9]
Supplement the requirements of IE 62446 commissioning standard; for example string-level I-V curve tracing.	The SunSpec Alliance Guide to Commissioning Measurements is being drafted at the time of this publication. See Section 4.3 above.
Clear need for safety standards.	- The Occupational Safety and Health Administration (OSHA) has a page dedicated to workplace hazards for PV systems[10] - An older example of "Solar Construction Safety" was published in 2006 by Oregon SEIA[11] - Solar Pro has an article on how to implement a successful safety program.[12]
O&M standards are needed to eventually improve the reliability of components and systems. Information provided back to manufacturers required by O&M standards. This would improve manufacturing quality.	This may be partially addressed by the Qualification Plus initiative led by TUV. See Section 3.4.
Look at Reliability standards of other more mature industries such as fossil-fueled generators. This approach would be useful to emulate rather than re-invent the wheel. Look to wind industry as well.	SNL is addressing this with Availability and Key Performance Indicator research and definitions, provided by PV industry experts. See discussion in Section 4.5.
Need for bar-code scanning of every piece of equipment on a job site so placement of inventory is known and trends in failure can be spotted.	SNL has a white paper on this subject from a PVROM partner that discusses the time it takes to implement barcode scanning for use in inventory tracking and reliability analysis.

[9] http://solarprofessional.com/articles/products-equipment/racking/pv-array-wire-management?v=disable_pagination
[10] https://www.osha.gov/dep/greenjobs/solar.html
[11] http://www.coshnetwork.org/sites/default/files/OSEIA_Solar_Safety_12-06.pdf
[12] http://solarprofessional.com/articles/operations-maintenance/implementing-a-successful-safety-program?v=disable_pagination

Other gaps identified by participants for O&M include the following:

- Feedback from O&M to design specifications / design for lifecycle management best practice.
- Consider measurability in the specification of equipment during design. For example, combiner boxes with current transducers built in or other measures to facilitate performance measurements and diagnostics.
- Standards regarding simple things, like fasteners and materials could be taken directly from other industries.
- Involve developers in a consensus standard. They will argue against measures that incur cost and will have to be convinced that it results in lower financing cost or other benefits to them.

5.2.2. Risk Mitigation: Financing

Gap Identified by Industry	Known Effort to Address Gap
There is a clear need for definitions of "operation," "maintenance" and "asset management" for risk mitigation in financing.	Some of these definitions may be addressed by NREL/SunSpec SAPC O&M Best Practices (Section 4.3/4.6), the IEC NWIP Maintenance of PV Systems effort (Section 3), the ASTM WK43549 ICOMP effort, and potentially in the TruSolar CSM (Section 4.4).
Need for standard listing of what O&M data is needed for an appraisal. Thought is O&M data would increase the value of an appraisal.	SNL has been working in the market valuation area for the past 3 years, developing tools and training for real property appraisers. Additional efforts like a standard O&M contract or proof that consensus standards are being used may assist in the appraisal process.
There is a need to define and recommend what the KPIs are or combine KPIs.	SNL is addressing this with Availability and Key Performance Indicator research and definitions, provided by PV industry experts. See discussion in Section 4.5.

Other gaps identified by participants for O&M include the following:

- Site assessment/environmental Factors.
- Determine if/how inverter reserve accounts can be used for securitization.
- Specification Standard: feeds into design, provide all details for all environments.
- Future predictions based on yesterday's technology.
- Effective education & training, experience, definitions and communications.
- Need for real data to argue with penny pinchers. Guidelines that show value.
- Need consistency for the insurance industry. Unknowns = risk = cost.

- Complexity is a challenge. Cost for accountants, lawyers, engineers, etc. mount as O&M program becomes more complex.

5.2.3. Construction

Gap Identified by Industry	Known Effort to Address Gap
Clear need for safety standards	See safety standard comments in Section 5.2.1.

Other gaps identified by participants for O&M include the following:

- Wire Management, conduit standards, conductor standards, layout standards.
- Need for protocol to test and certify incoming equipment to a site. Not the same as "Quality Plus" standard because this refers to each piece of equipment (module, inverter, etc.) coming onto job site and not just the make and model. Need to manage delivery through the supply chain.

5.2.4. O&M Performance Monitoring, Operations, Maintenance

Gap Identified by Industry	Known Effort to Address Gap
O&M Curriculum, training, education, experience, and job description.	NABCEP has a few items that speak to O&M practices, such as Section 7 in their PV Installation Professional Resource Guide, which includes "Conducting Maintenance and Troubleshooting Activities" that outline best practices for 1) performing a visual inspection, 2) verifying system operation, and 3) performing maintenance activities. The Appendix has a break-down of specific activities and level of knowledge required by the installer for O&M activities, including references. Most references point to NFPA NEC codes, OSHA regulations, textbooks and articles, though there are no specific standards (IEC, ASTM, NECA) called out in these references. It should be noted that this is not an O&M specific certification as it calls out O&M activities that a NABCEP certified installer could perform.
● Residential specific O&M specifications ● Don't recycle old O&M schedule that has been circulating around. Need modern O&M guideline. ● Asset Management: document with defined O&M. Document other activities.	For fleet-wide O&M aimed towards third-party owned PV systems, the Institute for Building Technology and Safety is developing a quality protocol for third-party owned PV systems. NREL, through their Solar Access to Public Capital (SAPC) effort has developed a paper on: PV O&M Best Practices: Considerations for

	Financial Managers and Industry Practitioners. The primary purpose of this paper is to help reduce risks for securitizing PV assets and uses example documentation from third-party owned providers. It could however be used outside of the third-party context by other O&M service providers. A companion O&M cost model was built to predict O&M costs considering PV system performance, preventative and corrective maintenance schedules, scope of work, salary, and qualifications (Section 4.3/4.6).
There is a need for better documentation of O&M activities to record trends: identify sources of failure.	SNL is developing a best practice for PV system owners and operators to improve PV system reliability. The PVROM project has data on PV system faults and failures that can be shared, with additional data and systems being added through fiscal year 2015. A 2013 progress report published by EPRI and SNL outlines this process and what has been learned working with PV system partners and their fault/failure data (EPRI, 2014). SunSpec has partnered with Greentech Media on the (oSPARC) project, with an enhanced oSPARC Plus product that will provide data partners with "regular customized reports on their fleet performance and tailored benchmarks." It appears that customizable reports (such fault or failure information) can be made available to data partners beyond what is available in the standard oSPARC data dictionary.
Clear need for safety standards.	See safety standard comments in Section 5.2.1.
Need to define standard "tags" to be used in performance monitoring and reporting (XML, etc.).	The oSPARC project by SunSpec (Section 4.3 and above) uses XML to store data based on their Plant Extract Document. There are multiple devices, such as sensors and telemetry equipment that can use the SunSpec standard, which also use Modbus and SEP 2.0 for transferring data. More detail is available in the oSPARC Implementer's Guide.
O&M standards are needed to eventually improve the reliability of components and systems. Information provided back to manufacturers required by O&M standards would improve manufacturing quality.	This concern may be addressed by the IEC NWIP Maintenance of PV Systems effort as well as the ASTIM ICOMP standard (both in development) (Section 3).
Look at Reliability standards of other more mature industries such as fossil-fueled generators. This approach would be useful to emulate rather than re-invent the wheel. Look to	SNL is addressing this with a best practice "Precursor Report of Data Needs and Recommended Practices for PV Plant Availability, Operations and Maintenance

wind industry as well.	Reporting." Some of the structure is based on published IEC wind standards and IEEE power plant reporting standards that are compliant with NERC-GADS. See discussion in Section 4.5.
Need for bar-code scanning of every piece of equipment on a job site so placement of inventory is known and trends in failure can be spotted.	See bar-code scanning comments in Section 5.2.1 described above.
There is a need to define and recommend what the KPIs are or combine KPIs.	SNL is addressing this with Availability and Key Performance Indicator research and definitions, provided by PV industry experts. See discussion in Section 4.5.

- Define maintenance in a systems process format.
- Certification of O&M providers.
- Need to specify duration over which data is archived. One year is not sufficiently to spot trends and investigate sources of failure.
- Disclosure requirements – or "client's bill of rights" that would require those responsible (EPC's, O&M service providers, manufacturers) to disclose common failures and to disclose the cause and consequences of events.
- Need a list of services and what is included and excluded from scope of O&M contract. Detail will help estimate costs.
- Need calculated baseline that accounts for weather and other variables.

5.2.5. Transaction Process

Gap Identified by Industry	Known Effort to Address Gap
Need for standard listing of what O&M data is needed for an appraisal. Thought is O&M data would increase the value of an appraisal.	See comment on PV system appraisals in Section 5.2.2.
There is a need to define and recommend what the KPIs are or combine KPIs.	SNL is addressing this with Availability and Key Performance Indicator research and definitions, provided by PV industry experts. See discussion in Section 4.5.

- Certify that the PV system has had effective O&M over its history.
- End of life analysis.
- Standard contracts for O&M service providers and EPCs.
- Disclosure requirements – or "client's bill of rights" that would require those responsible (EPC's, O&M service providers, manufacturers) to disclose common failures and to disclose the cause and consequences of events.
- Need a list of services and what is included and excluded from scope of O&M contract. Detail will help estimate costs.

5.3. Conclusions

This paper presents efforts made over the past year to 1) identify what standards and best practices already exist to aid in PV O&M activities, 2) convene industry experts to then consider what gaps exist, 3) catalog current efforts that are already addressing some of the gaps both known and unknown to industry, and 4) emphasize some of the gaps that should be addressed immediately to help improve the long-term bankability of solar PV systems by mitigating O&M risks with adherence to industry driven standards and best practices.

Homologized Standards

Many of the international standards that have been developed for the PV industry are not widely used in the U.S. due to different codes such as NEC, electrical systems and operating voltages. One way to get these international standards "homologized" for use the U.S. is to have them either developed in parallel in accordance with a U.S. based Standards Developing Organization (SDO) such as ANSI, NEC, UL and TUV Rheinland PTL, or have one of these organizations adopt an international standard and localize it to local codes and standards. Not all international standards have an electrical component that may conflict with U.S. electrical systems or voltages, however when new standards such as those for O&M are being developed, those in charge of that committee, especially if it may have a large impact when adopted in the U.S. market, should consider working with SDOs that are accredited for developing standards in the U.S.

To remediate this issue going forward, a guide should be developed to help those preparing new work items that originate in the U.S. to ensure a proper set of steps is taken so that it is adopted in the U.S. concurrently along with adoption by other countries.

O&M Practitioner

One area that stands out is who will be performing the O&M work? There are many trained PV system installers and electricians becoming O&M practitioners, mostly out of necessity to troubleshoot systems they've installed, or someone has installed. Fleet-wide O&M is now an area of interest as third-party PV providers have systems that are at most 7-8 years old with some requiring corrective maintenance. The O&M skills for performing preventative and corrective maintenance for all sizes of PV systems will require specific training.

Based on the information presented in Section 5.2.4, there are no currently funded efforts to develop an O&M Practitioner certification program. The leading organization dedicated to certifying solar professionals, the North American Board of Certified Energy Practitioners (NABCEP), includes "conducting maintenance and troubleshooting activities" as a major content domain in the *PV Installation Professional Job Task Analysis*. Their *PV Installation Professional Resource Guide* discusses maintenance and troubleshooting, and provides information on required knowledge for specific O&M related activities. NABCEP has recently started a new program to accredit PV Installation Companies, recognizing quality best practices in how the company is managed, works with customers and their own employees.

These efforts by NABCEP help to ensure high quality PV installations, though the needs of an O&M practitioner will be much different depending on the type, size, complexity, and

contractual terms associated with that PV system. The job tasks are much different when troubleshooting or repairs are needed. It is probably the case that many NABCEP certified installers and licensed electricians are currently performing O&M related tasks. According to Richard Lawrence, Executive Director of NABCEP, certification of O&M staff and accreditation of O&M companies, including detail on the types of services necessary for different types of PV systems, would help fill this gap.

IREC has a workforce training program accreditation and instructor certification that could be applied to O&M activities. However, to make this happen they need a specific job task analysis, which has not been formally developed for O&M service providers. This information is likely available in different forms from many of the existing O&M service providers, though it would take a concerted effort to pull this information together for developing the necessary job task analysis.

PV System Specification

To really emphasize the role of O&M through a PV system's lifetime is to make O&M activities a cornerstone of the specification process. When recognized and addressed early on, adherence to quality and rigorous O&M activities can survive through multiple ownership changes.

The way the process works is typically, a general specification is prepared for bidding that provides basic details on system size, location, general requirements for bidding and in some cases specifics on technology type along with other open considerations. In these types of arrangements, systems specification is left to the developer and their design team. The specification that takes place by the design team then gets into the details of components, subsystems and overall system design.

Best practices in all areas of design, construction, safety and O&M need to be recognized and available when specified for that PV system. The balance between lowering costs and having a highly reliable system has impacted many decisions made. Due to the lack of available standards and best practices for O&M in the past, those developing specifications did not have much to rely on. However, as shown above with the many activities underway to improve an understanding of O&M activities and costs, there will be more opportunities to make O&M a large part of the specification process. What is needed is a guidance document that lays out each area with a specification document and the existing standard and best practices that can be used to help develop the language for including O&M. In this way, O&M will be considered at every stage in the PV system's lifecycle.

Consistency for the Insurance Industry

For the insurance and re-insurance industry to develop insurance products to support PV transactions, long-term actuary and cost data is required. At this point O&M data and system performance data from fleet operations are not complete enough to allocate and underwrite risk. Projects like oSPARC Plus and PVROM are starting to collect industry data, and it will be critical for these projects, and others in the future, to recruit industry participation to support the development of insurance products.

6. REFERENCES

Bolinger, M., and S. Weaver, 2013, An Empirical Analysis of Project Cost, Performance, and Pricing Trends in the United States, Lawrence Berkeley National Laboratory, Berkeley, CA.

Electric Power Research Institute (EPRI), 2010, Addressing Solar Photovoltaic Operations and Maintenance Challenges – A Survey of Current Knowledge and Practices, 1021496.

International Energy Agency (IEA), 2014, Technology Roadmap – Solar Photovoltaic Energy

Kurtz, S., E. Riley, J. Newmiller, T. Dierauf, A. Kimber, J. McKee, R. Flottemesch, and P. Krishnani, 2013, Analysis of Photovoltaic System Energy Performance Evaluation Method, NREL/TP-5200-60628, National Renewable Energy Laboratory, Golden, CO.

Tidball, R., J. Bluestein, N. Rodriguez, and S. Knoke, 2010, Cost and Performance Assumptions for Modeling Electricity Generation Technologies, NREL/SR-6A20-48595, National Renewable Energy Laboratory, Golden, CO.

Walker, A., K. Ardani, and T.J. Keating, In Preparation, SAPC PV Operations and Maintenance (PV O&M) Best Practices: Considerations for Financial Managers and Industry Practitioners, National Renewable Energy Laboratory, Golden, CO.

APPENDIX A: MATRIX OF STANDARDS AND BEST PRACTICES WITH PV O&M ELEMENTS

Standard or Best Practice	Target Market	Field of Use	Focus	Effort Status
Consensus Standards				
IEC 60364-7-712	R,C,U	specification, design, installation	Technical	Completed
IEC 61215/61646	R,C,U	specification, testing, design, monitoring		Completed
IEC 61724	R,C,U	specification, testing, design, installation, commissioning, monitoring, finance and insurance	Technical	Revision in progress
IEC 61730-1,-2	R,C,U	specification, testing, design, finance and insurance		
IEC 61829	R,C,U	specification, testing, commissioning, monitoring	Technical	Completed
IEC/TS 61836	R,C,U	specification, testing, design, installation, commissioning, monitoring, finance and insurance	Technical	Completed
IEC 62446	R,C,U	specification, testing, design, installation, commissioning, monitoring	Technical	Revision in progress
IEC 62548	R,C,U	specification, design, installation	Technical	Completed
IEC/TS 62738	C,U	specification, design, installation, commissioning, monitoring	Technical	In development
IECRE Solar PV Rules of Procedure	R,C,U	specification, testing, design, installation, commissioning, monitoring, finance and insurance	Technical	In development
IEC Maintenance of PV Systems - WG 3 NWIP (to be submitted)	R,C,U	specification, design, installation, commissioning, monitoring	Technical	In development
ASTM E772-13/E1328-05	R,C,U	specification, testing, design, installation, commissioning, monitoring, finance and insurance	Technical	Completed
ASTM E2047-10	R,C,U	specification, testing, commissioning, monitoring	Technical	Completed
ASTM E2848-13	R,C,U	specification, testing, commissioning, monitoring, finance and insurance	Technical	Completed
ASTM E2908-12	R,C,U	specification, testing, design, commissioning, monitoring	Technical	Completed
ASTM E2939-13	R,C,U	specification, design, commissioning, monitoring,	Technical	Completed

		finance and insurance		
ASTM WK43549 ICOMP	R,C,U	specification, design, installation, commissioning, monitoring, finance and insurance	Technical	In development
TUV-R 71732-01:201X: Qualification PLUS (Q+)	R,C,U	specification, testing, design,	Technical	In development
NECA 412-2012	R,C,U	specification, design, installation, commissioning, monitoring	Technical	Completed
Best Practices				
SolarABCs PV System O&M Fundamentals	R,C,U	specification, design, installation, commissioning, monitoring	Technical	Completed
IREC – Field Inspection Guidelines for PV Systems	R,C,U	commissioning, installation, monitoring	Technical	Completed
Sandia Technical PV O&M Working Group	C,U	specification, design, installation, commissioning, monitoring, finance and insurance	Technical /Finance	In development
NREL PV O&M Collaborative Working Group	R,C,U	specification, design, monitoring, finance and insurance	Finance /Technical	In development
SunSpec Commissioning	R,C,U	specification, design, installation, commissioning, monitoring	Technical	In development
SunSpec Investment Risk Assessment	R,C,U	specification, design, monitoring, finance and insurance	Finance /Technical	In development
SunSpec Active PV Plant Monitoring - QMS	R,C,U	specification, design, monitoring	Technical	In development
oSPARC Plant Extract Document	R,C,U	specification, design, monitoring, finance and insurance	Technical /Finance	Completed
TruSolar Risk Scoring Criteria & Methodology	R,C,U	Specification, design, monitoring, finance and insurance	Finance /Technical	In development

R – Residential, C – Commercial, U – Utility

APPENDIX B: PV O&M GAPS ANALYSIS PARTICIPANTS – MARCH 24 & 26, 2014

March 24, 2014 - K&L Gates – San Francisco, CA

Mike Whitson	PCG Solar
Rob Andrews	Calama Consulting
Andy Walker	National Renewable Energy laboratory
Geoff Klise	Sandia National Laboratories
Sarah Disch	Wells Fargo
Richard Pizzella	Hartford Steam Boiler (MunichRe)
Jaya Krishna Mallineni	Arizona State University
Govindasamy Tamizhmani	TUV Rheinland (U.S.)
Tim Keating	SunSpec Alliance
Christine DeJong	ASTM International
George Kelly	IEC Secretariat
John R. Balfour	High Performance PV & TRIP
Tom Tansy	SunSpec Alliance

March 26 - Solar Plaza Conference – San Francisco, CA

Adolf Stoegbauer	Amatec GmbH
Andy Walker	National Renewable Energy Laboratory
Ben Compton	SolPatrol
William Stueve	Atonometrics
Craig Hamilton	Celestica
Charles Mazzacato	CPE Inc.
C. Smith	Psomas FMG
Fred Chen	Tokyo Electron Taiwan TEL
Gary Buchanan	Borrego Solar systems
Geoff Klise	Sandia National Laboratories
Greg Sellers	Clean Power Finance
Govindasamy Tamizhmani	TUV Rheinland (U.S.)
J. Halsey Kendrick	Ecoplexus
James Kieley	First Solar
J. Caling	GCL Solar Energy, Inc.
J. Jackson	CPE Inc.
Jason Kechijian	SolBright Renewable Energy
Joe Cunningham	Centrosolar
John R. Balfour	High Performance PV & TRIP
Kevin Christy	SunEdison
Laks Sampath	NRG Energy, Inc.
Mike Whitson	PCGSoIar Inc.
Mark Liffmann	Clean Power Research
Nadav Enbar	Electric Power Research Institute
Prasanna Krishnan	SunEdison
Peter Novotny	OMIFIN solutions Inc.
Richard Pizzella	Hartford Steam Boiler (MunichRe)
Richard Lawrence	NABCEP
Rob Andrews	Calama Consulting
Ross Biesemeyer	First Solar
Rue Phillips	True South Renewables, Inc.
Samuel Van Dam	DNV GL
Skip Dise	Clean Power Research
Tim Keating	SunSpec Alliance
Tom Tansy	Sunspec Alliance
Andrew Truitt	Acuity Power Group, Inc.

APPENDIX C: REIVEW OF EXISTING EFFORTS BY PARTICIPANTS IN MARCH 24, 2014 MEETING

ORG	NREL	SANDIA	SUNSPEC	ASTM	High Performance PV	TUV Rheinland	IEC
No. 1 Goal	Recruit solid working group to deliver SOW, coordinate , research and gain consensus	Determine who is working in what standards/best practices areas. Clearly delineate what effort is going to fill a 'need' and hopefully identify gaps.	Achieve agreement that a common set of terms is required in order to properly scope the O&M problem/opportunity in the rooftop space.	A prioritization of key items that need standardization to fit into the timeline phases outlined and concurrence of devoting efforts to carry out the roadmap.	An agreement between the participants that although this initial O&M team members have different foci and scopes, that we will leave with a clear foundation for the comprehensive development of PV standards that covers the full range from PV System delivery from concept development through site restoration	To use the field and accelerated testing data obtained at ASU-PRL and TUV-PTL for financial calculations	Agreement on priorities for new standard development
SCOPE	The working group will deliver products related to PV system O&M that address the needs of securitization by the private financial market. These include OM Best Practice and market driven cost model	Improve PV system design, installation O&M Develop benchmark report on PVROM from active participants. fault and failure analysis, and preventative maintenance.	Survey of best industry practices framework, investor care abouts, sample O&M contract terms, definition of key O&M terms, O&M cost survey and description of O&M cost elements in working model.	To work with others around the world to guide the Installation, Commissioning, Operation and Maintenance of Photovoltaic Systems (ICOMP) by providing standards for foundational metrics and processes that enable consistent delivery and operation of quality photovoltaic systems over their useful life. This foundational effort will define the integrated process for consistent system delivery throughout the lifecycle of reliable and effective PV systems.	The highest level of PV system "systems process" and O&M training and experience, the development of a local technology incubator focused on Large Commercial, Industrial and Utility scale systems.	Detailed non-intrusive and intrusive evaluations of fielded PV systems for reliability, safety and durability; Identification of field failure modes and mechanisms; Accelerated testing for quality evaluations of fresh PV modules and materials	Formation and operation of a new conformity assessment system under the management of the IEC Conformity Assessment Board (CAB).
TIMELINE	It is expected to take the working group two years to complete. The result of the first year will be an interim version of the above products, with the second year to refine them.	Collect fault and failure data and lead working group efforts through FY 15.	All work will be completed FY 2014	Phase 1 - April 30th – Framework Document Phase 2 May / June– Identify & Work on Priority item 1 (8th EPRI) Phase 2 July / August part 2 Phase 3 September / October part 3 Phase 4 November - February part 4 (factoring in holidays) Phase 5 March 2015 – draft to subcommittee ballot	A substantive, extreme and effective environment for the development of advanced highly innovative and disruptive energy and environmental sciences technologies, systems, process and approaches applied to PV system delivery	Ongoing; Intermediate goals: failure modes and degradation rates both in field and accelerated testing	Approval of basic rules by CAB – June 2014; Approval of PV rules of procedure – September 2014; Begin operation of system – January 2015
Resource	NREL	SANDI workgroup	SunSpec Workgroup	ASTM	2 People	Various	20% George Kelly
Market Segme	RESI/C&I/Utility	C&I/Utility	RESI/C&I	RESI/C&I/Utility	C&I/Utility	RESI/C&I/Utility	C&I/Utility
Other							

DISTRIBUTION

1 High Performance PV
Attn: John R. Balfour
9436 N. Arroya Vista Dr. E
Phoenix, AZ 85028
John@HighPerformancePV.com

1 SunSpec Alliance
Attn: Tim Keating
4030 Moorpark Ave
Suite 109
San Jose, CA 95117
tjkeating@sunspec.org

1 US DOE Elaine Ulrich EE-2A (electronic copy)
Building LENF950
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC, 20585
elaine.ulrich@ee.doe.gov

1 US DOE Christina Nichols EE-3D (electronic copy)
Building LENF950
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC, 20585
christina.nichols@ee.doe.gov

1 US DOE Guohui Yuan EE-4S (electronic copy)
Building LENF950
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC, 20585
guohui.yuan@ee.doe.gov

1	MS1137	Geoffrey T. Klise	6926 (electronic copy)
1	MS0899	Technical Library	9536 (electronic copy)

Sandia National Laboratories