Solar ABCs Interim Report

Grounding Photovoltaic Modules:

The Lay of the Land

Prepared by:

Greg Ball

BEW Engineering

Solar America Board for Codes and Standards

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EXECUTIVE SUMMARY

This report summarizes the current state of codes and standards that apply to equipment grounding of photovoltaic (PV) modules and systems. The Solar America Board for Codes and Standards (Solar ABCs), with support from the U.S. Department of Energy, commissioned this work with the intent of providing the PV industry with practical guidelines and procedures for module grounding. This initial "lay-of-the-land" report sets the stage for a final report that will draw on feedback from industry experts as well as ongoing research at Underwriters Laboratories, Inc. (UL) to develop guidelines and recommendations for changes to existing standards.

Although there are many PV module and system grounding issues, I will focus on two principal industry concerns. The first is solar professionals' lack of confidence in existing, approved grounding methods, which results from the many grounding failures in fielded systems. Although statistical studies of failure rates are not available, there is enough anecdotal evidence to support recommendations for additional testing and revision of standards.

The second is the limited number of approved grounding methods and devices available for PV modules and systems that are certified or listed by nationally recognized testing laboratories. Industry stakeholders who would prefer to market or use new grounding methods and devices point out that the absence of certification for these products is not necessarily based on issues pertaining to safety or reliability, but rather results from a lack of consensus in the assignment and development of applicable standards.

At present, there are a host of limitations, ambiguities, and conflicts among the standards that apply to PV module and system grounding. UL 1703 (Flat-Plate Photovoltaic Modules and Panels) is the primary governing standard for grounding modules, and it requires module manufacturers to manage all methods of frame grounding. This has hampered the ability of third party grounding components suppliers to certify innovative system-level grounding measures. UL 467 (Grounding and Bonding Equipment) could serve the third party supplier market, but in its current form it is not widely applicable to PV systems. UL 2703 (Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels) is a draft standard that will, in time, address system level mounting and grounding. UL 2703 currently includes the same overall grounding language that is in UL 1703. This standard—together with a UL 467 revised to address PV systems—has the potential to be the long-term solution to today's issues by providing a clear and effective course for manufacturers of modules, structures, and grounding components to have their components tested and listed.

There is much developmental activity within all three of these standards. UL has conducted a set of aggressive environmental tests intended to characterize corrosion related problems and failures, and expects to published the results in the first quarter of 2011. After debate and deliberations, these test results will inform revisions to the standard testing requirements. There is also a comprehensive proposal to update and improve grounding related sections in UL 1703 (and by extension UL 2703), and to provide parallel courses of certification through UL 467 and UL 1703.

The near-term goals between now and the completion of this study are to engage in and monitor the standard development activities and to conduct additional research into outstanding issues (corrosion, current testing, personal safety criteria, etc.). The results will inform the final revisions of all of the appropriate standards.

> "This initial "lay-of-the-land" report sets the stage for a final report that will draw on feedback from industry experts as well as ongoing research . . . to develop guidelines and recommendations for changes to existing standards."

The topic of PV system grounding as a whole covers a wide range of issues outside the scope of this study, including the bonding and grounding of support structures and their multiple internal components, system level equipment ground and electrode ground conductor strategies, lightning protection, grounding of specialized equipment such as AC modules or similar integrated DC/DC converters, and others. Solar ABCs is considering an additional study to address these and other issues.

Author Biography

Greg Ball

Greg Ball is a Principal Engineer at BEW Engineering, and has more than 20 years experience in renewable energy technologies and their integration with the utility grid. Before joining BEW in 2009, he worked for nine years as manager and senior electrical engineer at PowerLight (later SunPower) Corporation, where he was responsible for the electrical design of large-scale photovoltaic system projects in the United States and abroad. He was chief electrical engineer for more than 90 MW of solar power plant installations in Germany, Portugal, and Spain. He has been active in several policy and standards activities, serving as co-convenor on an International Electrotechnical Commission (IEC) PV system working group, a member of California's Rule 21 committee on utility interconnections, a contributor to the National Electrical Code (NEC) photovoltaic code-making panel, and a contributor to various Institute of Electrical and Electronics Engineers (IEEE) activities. Before he joined PowerLight, Mr. Ball held positions at Pacific Gas & Electric and utility consulting companies, where he focused on the distribution system impacts of power conversion based renewable and energy storage technologies. He has co-authored numerous publications on the topic, including an *IEEE Industry Applications Magazine* article that earned that publication's 2006 Prize Paper Award. Mr. Ball earned a bachelor of science in electrical engineering from Tulane University, and a master of science in electrical engineering with a power electronics focus from the University of Tennessee. He is an IEEE member.

Solar America Board for Codes and Standards

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

Solar America Board for Codes and Standards Web site:

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Table of Contents

INTRODUCTION

This is the first of a two-part study of photovoltaic (PV) module equipment grounding issues. The Solar America Board for Codes and Standards (Solar ABCs), with input from a large cross section of U.S. stakeholders, identified the need for this study through a gap analysis process. The objective of this study is to make recommendations for an integrated set of tests and procedures that can be incorporated into the standards governing the grounding of PV components. This report will be followed by a final report that describes practical, publicly available proscriptive procedures that clarify this long-standing and contentious issue. New or expanded test methods will be developed for the purpose of evaluating the long-term reliability of the connections to and between metal parts in a PV array for roof- or ground-mounted systems.

Throughout this document, the terms "ground," "grounding," and "grounded" are used to describe the connections to module frames that are the primary focus of the study. Note that there is a distinction between "grounded" and "bonded." The National Electrical Code (NEC) defines these terms as follows:

- Grounded: Connected to earth or to some conducting body that serves in place of earth.
- Bonded: The permanent joining of metallic parts to form an electrically conductive path that ensures electrical continuity and the capacity to conduct safely any current likely to be imposed.

Much of the scope of this study focuses on the bonding of frames to other parts or conductors that are then grounded. The report uses the more general "grounding" term to describe both bonding and grounding unless bonding is specifically called out.

PV modules are typically installed on aluminum or galvanized, painted, or stainless steel frame structures. These structures and any other electrically conductive components that may become energized by the PV array (or other sources) and that may be accessible during routine servicing, must be bonded to ensure safe touch voltages. Module manufacturers currently provide detailed directions for grounding the modules in their installation manuals. Manufacturers of grounding equipment for PV modules have developed components designed for general use, and have pursued different approaches for certifying or listing these devices. There is little industry consensus on the appropriateness or completeness of the available standards for these general use components.

The result has been a large number of fielded systems that demonstrate:

- unsatisfactory module grounding measures,
- violations of the module's Underwriters Laboratories (UL) 1703 listing because the installation does not comply with the installation manual's prescribed method of module frame grounding,
- incorporation of components listed to more general grounding equipment standards that may or may not be suitable for the application, and/or
- well-engineered grounding means that have, at present, no clear path for demonstrating their adequacy to customers and inspectors.

This overall module grounding study attempts to address these issues via the following steps:

- *Develop this preliminary report, referred to as the "lay-of-the-land report."* This is primarily a BEW Engineering-led survey of the existing situation in which stakeholders (system designers, module and component manufacturers, Nationally Recognized Testing Laboratories [NRTLs], and researchers) share their experiences and recommendations related to the issues listed above.

- *Evaluate existing and new test procedures.* This is primarily a UL-led effort to investigate expanded or enhanced testing methods that can provide greater confidence in the long-term reliability of grounding methods.
- *Develop a final report that incorporates results and feedback from these two efforts.* This report will make recommendations for a set of tests to incorporate into existing or new standards, and document clear guidelines and procedures for public use.

This lay-of-the-land report addresses the following topics:

- General description of the existing state of affairs in PV module equipment grounding.
- Typical bond failure modes.
- Approaches and methods that are working.
- Installation issues.
- Permitting issues.
- Cost issues.
- Applicability and issues with existing standards and tests.
- UL's current activities to address testing deficiencies or needs.
- Industry activity and anticipated changes.

The topic of PV system grounding as a whole covers a wide range of issues outside the scope of this study, including the bonding and grounding of support structures and their multiple internal components, system level equipment ground and electrode ground conductor strategies, lightning protection, grounding of specialized equipment such as AC modules or similar integrated DC/DC converters, and others. Solar ABCs is considering an additional study to address these and other issues.

EXISTING STATE OF AFFAIRS

The sections below cover many issues that can be summarized in two key observations:

- Existing standards do not adequately ensure long-term, reliable, and safe grounding of PV modules.
- Standards lack guidance for evaluating alternative equipment or methods of PV module grounding.

TYPICAL FAILURE MODES

As we begin assessing the current state of PV module and system grounding, it is appropriate to start with the modes under which presently used grounding connections fail. Grounding failure is broadly defined as a connection no longer capable of reliably providing sufficient and appropriate electrical continuity between components. This includes disconnections, loose connections in which continuity is intermittent or weakening at an unacceptable pace, and connections exhibiting corrosion of the material's sacrificial layer and reduced continuity.

A failed connection can take many forms, including but not limited to:

- A loosened nut and/or screw where a ground wire is attached to the module frame with a pre-drilled or field installed hole.
- A loosened nut and/or screw where a ground lug or terminal is attached to the module frame with a pre-drilled or field installed hole.

- A loosened clamp-type bond between the module frame and its clamp device, or between the clamp device and the external bonded equipment.
- A connection in which bonding relies on screw threads and there is insufficient continuity due to insufficient thread contact.
- A connection in which bonding relies on penetration of an anodized frame, or non-conductive frame coating such as paint or vitreous enamel, and where that penetration is insufficient. The bond in this case typically relies on the use of a star washer or serrated screwhead to penetrate the coating.
- A connection using specialized grounding devices in which bonding relies on penetration of the anodized frame or frame coating and where that penetration is insufficient. An example is a clamped device with a sharp point or edge used to penetrate the coating.
- Corroded connections in which the corrosion has either broken down one or both of the bonded conductor materials or has created an insulation barrier between them.

Loose connections can be caused by:

- Over-torquing the bolted or screwed connection, resulting in partial stripping or damage to the frame, which damages the ground component assembly.
- Under-torquing the bolted or screwed connection.
- Stressing the connection during or after installation without re-torquing.
- Drilling into the frame or bolting a connection at an improper angle, thereby failing to achieve the proper tight contact.
- Using incorrect washer/nut or assemblies that do not result in a durably tight connection.
- Using an improperly sized screw/bolt/nut/washer in the assembly.
- Using an improperly selected, sized, or installed clamping device.
- Continually stressing a connection post-installation by applying more tension on the ground wire or force on the assembly than it can reliably endure. An example is a ground cable pulled so tight that it compromises the assembly or the frame itself.
- Improperly selecting the screws, resulting in insufficient thread contact in bonds using screw threads.
- Repeated installing of a self-drilling or thread forming screw.
- Temperature cycling that exceeds the withstand capabilities of the bonding components or their assemblies.
- Non-uniform expansion and contraction from thermal cycling that exceeds the withstand capabilities of the bonding components or their assemblies.

Penetration failures can be caused by:

- Under-torquing the bolt/assembly such that the star washer or serrated bolt surface does not break the frame coating.
- Using improperly sized/selected/installed components in the assembly, including the star washer or serrated component itself. In this case, the washer may be installed backwards, in the wrong position, or—if improperly sized—it may be deformed during tightening so that the sharp edge does not engage with the frame. (UL has observed in environmental testing that results may differ depending on whether the star washer is part of the turning assembly during the installation or part of the fixed assembly.)

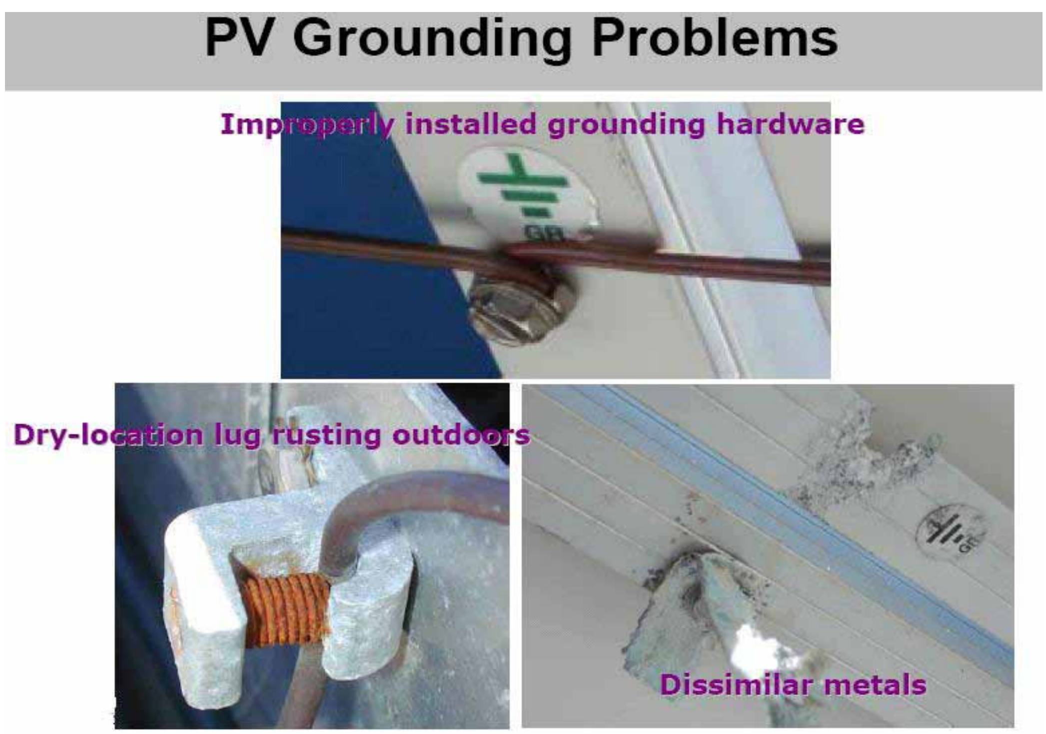
- Using improper or incorrect specialized piercing components designed for other frame or component shapes.
- Inadequate testing, quality control, or improper handling of the specialized components themselves, which can lead to failure.

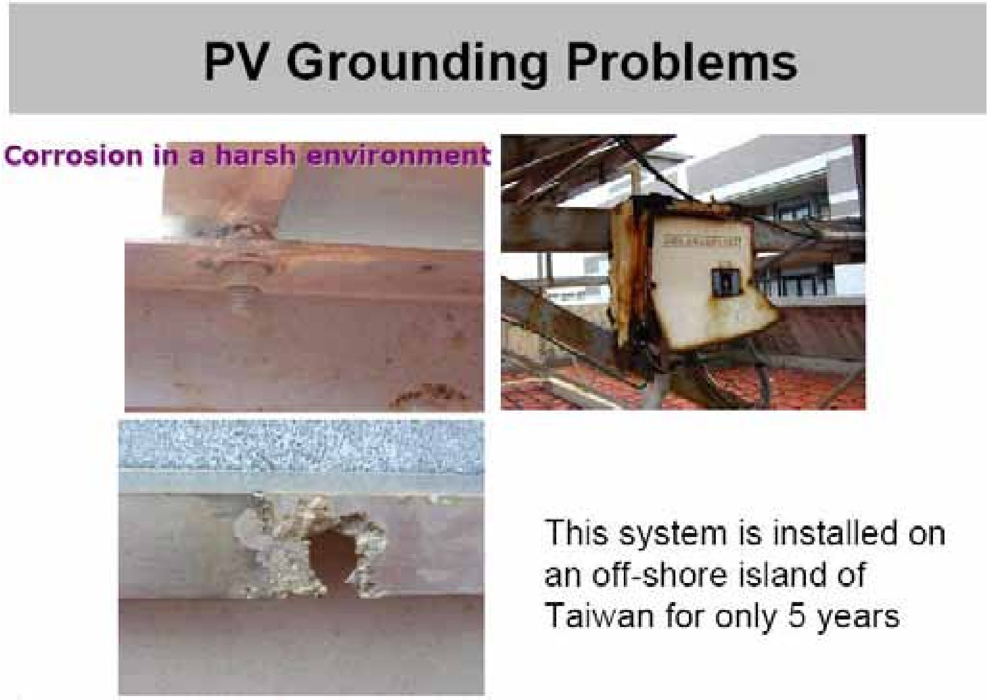
It is important to note that corrosion itself does not imply failure. There is often the expectation of superficial corrosion. Failure occurs only when the bond impedance rises (as a result of excessive corrosion) to a point where an unsafe condition is created or proper operation of protection devices is inhibited (during normal or faulted operation).

Failures from corrosion can have many causes. Galvanic corrosion resulting from the joining of dissimilar metals is probably the most common general cause. However, corrosion can also occur as a result of long-term exposure of components to cycling leakage current, which produces an electrolysis process. Failures due to corrosion can be attributed to the following general causes:

- Improper selection of materials for the bonded connection. Copper and aluminum bonds are the most common and have dramatic results, but other less obvious combinations may break down over time. (See the *Applicability and Issues With Existing Standards and Tests* section for more on this topic.)
- Dissimilar metals in close proximity, which—depending on the electrolyte involved—causes corrosion when exposed to water, soil, or other conductive debris elements.
- Insufficient barriers between dissimilar metals, such as undersized or badly installed stainless steel washers separating copper and aluminum.
- Good but inadequately protected connections after long-term exposure to leakage current, water, salt-humidity, and/or other corrosive agents. An example is a tin-coated assembly joining a copper wire and aluminum frame where the coating is inadequate to serve as a sacrificial barrier over the long term.

The following photos illustrate issues and failures of PV module and system grounds found in the field.





Poor installation connection

Connection of dissimilar (incompatible) materials

Photos caption: *The photos demonstrate a wide variety of issues, some clearly indicating failure of a bond, and some indicating a method issue or apparent problem even if the bond is safely intact. The variety is indicative of the task ahead for improving standards and industry methods. Careful attention needs to be paid to distinguishing real problems from perceived problems, and using the experience of other industries to the extent possible to avoid over-reaching requirements.*

Photo credit: *John Wiles, Southwest Technology Development Institute, New Mexico State University*

APPROACHES AND METHODS THAT ARE WORKING

There are many examples of PV systems with module ground bonds that have performed well for many years, including all of the types of connections described above. The most common are properly installed wired grounds using proper connections and compatible metals. Durable screw/bolt/nut/clamp assemblies of compatible metals that are properly sized, torqued, and checked provide a gas-tight seal and have long proven reliable when located in relatively benign environments. Best practice may also include the use of a protective coating, such as No-Ox, on the connection, which extends the useful life of the bond.

Many in the industry make the case that methods using clips, clamps, or other mechanical bonds between modules, rather than frame-to-frame ground wires, are proving to be equally reliable. Large rooftop systems using multiple grounding clamps or devices that are part of the overall assembly, for example, may be less prone to installation problems (based on anecdotal reports). Device-based methods may be more compatible with repetitive labor processes across large arrays than the labor-intensive steps associated with wiring of washer/screw/nut assemblies from module to module. When clamp devices are part of the overall mechanical assembly, they also provide a level of redundancy that wire-based approaches don't have by providing multiple paths for ground current flow.

At present, it is difficult to report the long-term reliability of these newer, less traditional grounding methods because their field history is short. Another factor that hinders this assessment is that module frames themselves have changed over time with some using thinner gauge metals that may reduce long-term bond reliability. This investigation does not include a statistical assessment of how module frame shapes or gauges may affect bond reliability, but there is anecdotal evidence to indicate that less common shapes or profiles may be more prone to bond installation issues (i.e., user error), particularly when installers use components designed for other, more "standard" frames.

A number of contributors to this discussion on module grounding have concluded that it may be unrealistic to expect a grounding solution to last for the life of a PV system without additional environmental protection or periodic maintenance. This can be particularly true in corrosive environments. There is no consensus on how corrosive the environment must be to warrant such a disclaimer, although locations with routine exposure to chemical or salt spray or humidity are likely candidates. In their proposal to the Standard Technical Panel (STP) for UL 1703, SunPower specifically cited ISO 9224 Category C5.[1]

Nonetheless, for less extreme environments, the goal is grounding methods and practices with design lives equal to or better than the life of the PV system itself. Grounding means in other industries, such as utility, industrial, and petrochemicals have demonstrated this capability.

One recommendation of this preliminary report, therefore, is to seek additional industry expertise (to complement results of ongoing exploratory UL testing) to provide specific guidance for installation and maintenance expectations, as a function of environmental categories and bonding methods.

[1] ISO 9224 (1992): "Corrosion of metals and alloys -- Corrosivity of atmospheres -- Guiding values for the corrosivity categories." Category C5 indicates "very high" corrosivity, and includes two sub-categories: C5-I (Outdoor air: very humid industrial atmosphere), and C5-M (Outdoor air: saline seaside atmosphere).

COST ISSUES

The cost for compliance is always a concern as existing and new standards evolve. Existing, approved grounding methods have evolved from the industry's early focus on small PV systems. On these small systems, running a ground wire from one module to another does not usually present a cost burden. But as systems have grown to incorporate tens of thousands of modules, a more efficient means of bonding from module to module or module to metallic support structures may yield both material and labor savings. Because present standards limit the application of general use grounding components, integrators and installers of large systems often report that the existing, approved methods are unnecessarily burdensome and costly.

Statistical cost analyses were not conducted for this preliminary study, but anecdotal cost information indicates that ground equipment and labor cost savings associated with the use of device-based methods may range from 20% to 60% compared with conventional wiring-based methods. Labor savings alone can exceed 50% when compared with wiring-based methods.

APPLICABILITY AND ISSUES WITH EXISTING STANDARDS AND TESTS

This section describes the various standards that have bearing on PV module and system grounding. There are a number of unresolved or conflicting issues associated with these standards, and they can conflict with the NEC. In his introduction to proposed language for UL 61730, John Wiles of the Southwest Technology Development Institute at New Mexico State University stated that the instructions required in UL 1703 have been at odds with the requirements in the NEC for at least twelve years and recent changes in the NEC have not been reflected in the module standards.

Standards that currently (or may in the foreseeable future) address module frame grounding include:

UL 1703: *Flat-Plate Photovoltaic Modules and Panels*

UL 467: *Grounding and Bonding Equipment*

UL 1741: *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*

UL 2703: *Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels*

UL 61730-1: *Photovoltaic (PV) Module Safety Qualification - Part 1: Requirements for Construction*

UL 1703 is currently the "primary" standard affecting module grounding and devices. Methods certified to UL 1703 and documented in module manufacturers' listed installation instructions are almost universally accepted by inspectors and authorities having jurisdiction (AHJs). The standard covers a range of safety and construction related requirements for modules, with a few sections dedicated to frame bonding, grounding, and continuity. UL 1703 establishes requirements for the means of grounding as well as continuity requirements subject to applied current and environmental (accelerated life) testing.

As the previous sections stated, the primary issues or concerns associated with UL 1703 as reported by the industry are that:

- it does not provide adequate assurance or guidance for long-term grounding reliability, and

- it is too restrictive in its approach and process to facilitate certification of third party devices.

UL 467 is dedicated to grounding and bonding equipment and is widely perceived in the industry to be a good template, if not the complete answer, to certifying third party, general use ground components. UL 467 currently suffers from a much-contested perception that it is not appropriate for components in a PV system application. Indeed, the authors of the standard have stated that, as written, it does not address some unique aspects of PV system applications. Strictly speaking, it covers only indoor or direct-buried connectors, although that designation is commonly applied to outdoor installations. Others counter that the tests, even though they were written without considering PV systems, lead to adequate qualification of a module-grounding device.

It should be noted that recently UL has initiated a Certification Requirements Decision (CRD) for UL 467 to incorporate PV module grounding device requirements. Historically, UL has not supported the use of UL 467 for this purpose and the controversy was one of the drivers for UL's 2007 CRD. The CRD was issued more or less as an addendum to UL 1703. The CRD adds explicit language tying any grounding means or method to evaluation under UL 1703: "A grounding means shall be provided with each module or specified in detail in the module installation manual that is provided with each module so as to comply with the requirements in 11.1 and Section 48." This requires module manufacturers, if they're not certifying grounding components and means themselves, to specify in detail any acceptable methods or means in their installation manuals.

All of this leads to the primary permitting issues facing the industry. The CRD is not universally applied by NRTLs, who have latitude in determining how standards are implemented. This has led to lack of uniformity in product and installation approval by inspectors and AHJs. Inspectors aware of the discrepancy have, in some cases, begun differentiating approval based on which NRTL is involved (approving components with UL stickers while rejecting others). In addition, module manufacturers have withdrawn product bulletins that had been released to express approval for use of certain third party, general use ground components because they came into conflict with the CRD. The uncertainty around permitting requirements is serious and costs the PV industry significant time and money. However standards evolve to address the issues identified in this report, the industry will be well served to have clear marking and identification of grounding components for AHJ review and approval.

UL 1741 addresses power conversion equipment, but it is included in discussions of module grounding because of the ground circuit fault current tests it incorporates. Also, new technologies are placing the power conversion components at the module and even embedding them in the module. This current test topic will be addressed in more detail in the next section.

> "The uncertainty around permitting requirements is serious and costs the PV industry significant time and money."

UL 2703 is a new standard under development that was created to address PV module mounting systems. Officially, it is an Outline of Investigation for rack mounting systems and clamping devices. In practice, however, it is already available for purchase as a draft standard and UL has begun testing for various equipment suppliers. It covers structural and other general issues for mounting systems, including grounding. The grounding section applies much of the same language used in UL 1703 to the mounting system components. UL is planning to list grounding components independent of the racking certification through this standard. There is also the intent to establish subsystem level testing of bonding—for example, tests using multiple modules and components connected together, rather than single connections—and impedance requirements for metal apparatus containing multiple strings of modules. It is expected that the standard will quantify ampacity and cross sectional area requirements, similar in principle to the approach taken for the cable tray systems used instead of conduit to support electrical and communication cables.

UL 61730-1 is intended to describe the fundamental construction requirements for PV modules in order to provide safe electrical and mechanical operation during their expected lifetime. It is discussed here largely for the proposed language submitted by John Wiles in 2008 on behalf of a small group to address deficiencies in UL 1703.

WHERE TO GO FROM HERE

At present, there is significant momentum behind proposals being drafted by Brooks Engineering and a cross-industry group formed by Wiley Electronics. These were addressed at a UL 1703 Standards Technical Panel (STP) meeting held in December 2010. The new proposals have evolved from past discussions and proposals, most notably by Wiley Electronics, John Wiles, SunPower, Brooks Engineering, and SunLink.

The general intent of these and other proposals, including those by Wiley, SunPower, and others, is to allow grounding equipment manufacturers to list grounding means or products under UL 1703, or, if the product is for general use, under UL 467. SunLink, for example, has listed grounding products under UL 1703 by providing details about the specific module brand and model frames with which its grounding components have been tested. With the general use approach, it should not be necessary to provide a separate listing for each part in combination with each possible module, but should be possible to provide a set of application parameters based on testing that clearly establishes modules and subcomponents for which the devices are compatible. This will include cautions against application parameters that are not appropriate.

As an example of this, Wiley Electronics created a draft testing proposal for its Washer, Electrical Equipment Bond (WEEB) products that provides descriptions and diagrams detailing the minimum thickness, rigidity, profile, and cross section requirements for module frames. It provides additional guiding parameters for the interconnecting components (i.e., components to which the modules are bonding), the mounting hardware, and the required contact area to ensure proper application. This process may be improved further with the establishment of standardized frame categories that address thickness, coating type and thickness, rigidity, and shape.

To cover the issues, discussion, and opinions regarding these standards, we will list the relevant requirements of UL 1703 Section 11, Bonding and Grounding, along with accompanying discussion points and proposed changes. Sections 11.9 through 11.12 covering marking and identification requirements are excluded. Following this is a separate discussion of two major testing issues—current tests and accelerated life/corrosion tests.

Many of these issues were also addressed in proposed language for UL 61730-1, created by a group of STP and other participants, and submitted by John Wiles in 2008. Sections of this proposal are included in Appendix A. Especially noteworthy is the full description of requirements for external field connections, specific tests cited for continuity, and specific tests cited for torque.

UL 1703 Section 11

11. Bonding and Grounding

11.1 A module or panel shall have a means for grounding all accessible conductive parts. The grounding means shall comply with the applicable requirements in Connection Means, Section 10. The grounding means shall be bonded to each conductive part of the module or panel that is accessible during

> normal use. The grounding means shall be described in detail in the installation manual. See Installation and Assembly Instructions, Section 48.
>
> *Exception: When the grounding means is a module or panel mounting member intended to contact an array structural member, the module or panel grounding means are not required to comply with the requirements for Connection Means, Section 10.*

Wiles, Wiley Electronics, and others have proposed making a greater distinction between requirements for bonding frame components within the module, and those for bonding to components exterior to the module. Some of the existing language, clearly written for internal bonding, can be confusing if read to apply to external bonding. The proposals clearly separate the sections and there seems to be consensus on the change.

> 11.2 Routine maintenance of a module or panel shall not involve breaking or disturbing the bonding path. A bolt, screw, or other part used for bonding purposes within a module or panel shall not be intended for securing the complete device to the supporting surface or frame.
>
> 11.3 Bonding shall be by a positive means, such as clamping, riveting, bolted or screwed connections, or welding, soldering (see 11.5), or brazing. The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel.

Proposals from Wiles and Wiley Electronics have expanded on the examples of non-conductive coatings to include oxidized metal, anodizing, and clear coatings. SunPower's proposal for external grounding emphasizes expanding this and similar sections to require installation manual descriptions by either the device manufacturer (e.g. minimum thickness and appropriate profile) or the module manufacturer (minimum requirement for the means of attachment). It also calls for minimum and maximum installation torque or force requirements to be specified.

> 11.4 A bolted or screwed connection that incorporates a star washer under the screwhead or a serrated screwhead may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon screw threads, two or more screws or two full threads of a single screw shall engage the metal.

SunPower's proposal adds language requirements in the installation manual (again for external bonding) that specifies thread pitch for means that depend on screw threads. For methods using self-tapping or thread-forming screws, it also includes a requirement that module installation manuals must state specific requirements and limitations with respect to how many times self-tapping or thread forming screws can be inserted in the same location. This addresses concerns shared by many that, in practice, self-tapping screws are sometimes re-installed and should either be moved or tested to demonstrate a certain number of insertions in the same location.

The STP proposal calls out a specific set of external grounding means to be added:

- A terminal for connecting an external grounding conductor.
- A lead that is electrically bonded to the frame.
- A device that effectively and durably bonds the module frame to a mounting rack.
- A device that effectively and durably bonds the module frame to an adjacent module frame when used in conjunction with listed grounding means for the system of bonded module frames.

The terminal or lead option should be compatible with both copper and aluminum conductors and should prevent copper conductors from contacting an aluminum module frame at the connection point.

11.5 All joints in the bonding path shall be mechanically secure independent of any soldering.

11.6 A separate bonding conductor or strap shall:

a) Be of copper, copper alloy, or other material acceptable for use as an electrical conductor;
b) Be protected from mechanical damage; and
c) Not be secured by a removable fastener used for any purpose other than bonding, unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

11.7 A ferrous metal part in the grounding path shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing, or plating. Stainless steel is acceptable without additional coating.

11.8 A metal-to-metal multiple-bearing pin-type hinge is considered to be an acceptable means for bonding.

There is a range of proposals for clarifying and/or expanding on the use of appropriate metals, and avoiding inappropriate dissimilar metals to meet the objective of paragraph 6.8 from 1703:

6.8 Metals used in locations that may be wet or moist shall not be employed in combinations that could result in deterioration of either metal such that the product would not comply with the requirements in this standard.

UL's 2007 CRD introduced a matrix of acceptable and unacceptable metal combinations that can be used in the grounding means, shown in the figure below. Acceptable combinations are those resulting in combined electrochemical potentials of less than 0.6V, which are those shown below the stepped cutoff line.

534260

	Magnesium, magnesium alloys	Zinc, zinc alloys	80 tin/20 Zn on steel, Zn on iron or steel	Aluminium	Cd on steel	Al/Mg alloy	Mild steel	Duralumin	Lead	Cr on steel, soft solder	Cr on Ni on steel, tin on steel, 12 % Cr stainless steel	High Cr stainless steel	Copper, copper alloys	Silver solder, Austenitic stainless steel	Ni on steel	Silver	Rh on Ag on Cu, silver/gold alloy	Carbon	Gold, platinum
Magnesium, magnesium alloys	0	0.05	0.55	0.7	0.8	0.85	0.9	1.0	1.05	1.1	1.15	1.25	1.35	1.4	1.45	1.6	1.65	1.7	1.75
Zinc, zinc alloys		0	0.05	0.2	0.3	0.35	0.4	0.5	0.55	0.6	0.65	0.75	0.85	0.9	0.95	1.1	1.15	1.2	1.25
80 tin/20 Zn on steel, Zn on iron or steel			0	0.15	0.25	0.3	0.35	0.45	0.5	0.55	0.6	0.7	0.8	0.85	0.9	1.05	1.1	1.15	1.2
Aluminium				0	0.1	0.15	0.2	0.3	0.35	0.4	0.45	0.55	0.65	0.7	0.75	0.9	0.95	1.0	1.05
Cd on steel					0	0.05	0.1	0.2	0.25	0.3	0.35	0.45	0.55	0.6	0.65	0.8	0.85	0.9	0.95
Al/Mg alloy						0	0.05	0.15	0.2	0.25	0.3	0.4	0.5	0.55	0.6	0.75	0.8	0.85	0.9
Mild steel							0	0.1	0.15	0.2	0.25	0.35	0.45	0.5	0.55	0.7	0.75	0.8	0.85
Duralumin								0	0.05	0.1	0.15	0.25	0.35	0.4	0.45	0.6	0.65	0.7	0.75
Lead									0	0.05	0.1	0.2	0.3	0.35	0.4	0.55	0.6	0.66	0.7
Cr on steel, soft solder										0	0.05	0.15	0.25	0.3	0.35	0.5	0.55	0.6	0.65
Cr on Ni on steel, tin on steel, 12 % Cr stainless steel											0	0.1	0.2	0.25	0.3	0.45	0.5	0.55	0.6
High Cr stainless steel												0	0.1	0.15	0.2	0.35	0.4	0.45	0.5
Copper, copper alloys													0	0.05	0.1	0.25	0.3	0.35	0.4
Silver solder, Austenitic stainless steel														0	0.05	0.2	0.25	0.3	0.35
Ni on steel															0	0.15	0.2	0.25	0.3
Silver																0	0.05	0.1	0.15

Ag Silver
Al Aluminium
Cr Chromium
Cd Cadmium
Cu Copper
Mg Magnesium
Ni Nickel
Rh Rhodium
Zn Zinc

NOTE – Corrosion due to electrochemical action between dissimilar metals which are in contact is minimized if the

Figure: Electro-chemical matrix of common metal combinations

SunPower's proposals disputed some findings in the table, and—partly to prevent misapplication—proposed a minimalist set of acceptable combinations that covers the vast majority of currently acceptable approaches. Other combinations would not be prohibited, but the onus would be on the manufacturer to investigate and demonstrate their acceptability.

SunPower's specific suggestions included:

- A requirement (with exception described above) that grounding devices and mounting means shall be constructed of:
    - copper or a copper alloy containing not less than 80 percent copper, which may be coated or plated to avoid galvanic corrosion;
    - stainless steel containing a minimum of 16% chromium (Cr) or 5000 or 6000 series aluminum alloys; and
    - carbon steel, which may be coated or plated to avoid corrosion.
- An explicit requirement that there be *"no direct contact between different metals that may exhibit galvanic corrosion in atmospheric environments either between parts within the grounding device, or when the device is attached as specified to the accessible conductive part."*

The acceptable combinations include any combination of:

- 5000 or 6000 series aluminum alloys and commercially pure aluminum,
- stainless steel containing a minimum of 16% Cr,
- nickel,
- tin,
- zinc, and
- zinc-aluminum alloys.

These material combinations are galvanically compatible in almost all service environments. However, plating or coatings must be of sufficient thickness and quality to withstand the service environment for the service life in order to provide an effective buffer layer. The basis of the minimum Cr composition is that stainless steels that contain less than 17% Cr, while providing effective continuity, may exhibit rapid surface staining, which is likely to be construed as corrosion by inspectors and customers. Type 316 stainless, which contains 16% to 18% Cr, is the most commonly selected highly corrosion resistant alloy.

- An installation requirement that *bare copper conductors be located at least one-quarter inch from the aluminum frame of the module to prevent moisture accumulation and effective contact between the two metals.* Wiles notes that bare copper conductors are typically used for equipment-grounding conductors for modules and that inadvertent (not for grounding) contact between the copper conductor and aluminum module frame is not detrimental. Some aluminum may be corroded away, but because the connection is not intended and the copper conductor is not compromised, there is no harm in this common contact. However, even if this doesn't directly impact the quality of the grounding connection, corrosion damage to the aluminum module frame may also be a concern for the general installation.

SunPower also suggested that if the table is to be used, or a blanket requirement that acceptable materials should have electrochemical potentials less than 0.6V, then the specific conditions under which the electrochemical potential measurements were taken should be clarified or cited. For additional guidance, they pointed to the use of ASTM G82 Standard Guide for Development and Use of a Galvanic Series for Predicting Galvanic Corrosion Performance.

John Wiles has identified another tangential issue. He noted that in most applications, mechanical threaded fasteners are primarily used to force electrical conductors or materials together to create an electrical bond, although the fasteners themselves are not intended to be the primary current carrier. He proposes that grounding instructions prohibit or discourage using stainless-steel washers or other dissimilar-metal isolation devices between a copper conductor and aluminum module frame unless the hardware has been specifically tested under the new grounding device requirements. Not testing the isolation devices as electrical conductors could cause the steel screw to carry most of any fault current through the connection. Others have commented that this issue could be addressed more generically, rather than requiring prescriptive certification of specific modules, screws, washers, etc.

Current Tests

Somewhat separate from the requirements for grounding means and methods is their electrical performance. The table below summarizes tests now applied under 1703 for module certification, tests for (AC) general use components under 467, and tests derived from UL 1741.

	UL 1703	UL 467	UL 1741 (short-term)
Test Current	2 x module series fuse rating (e.g. 30A)	Current requirement dependent on ground conductor size, e.g. 750A for #10 AWG	1.000A, e.g.
Test Duration	Sufficient to measure impedance	4 seconds	TBD – until string sized fuse, e.g. 15A operates.
Result Requirement	Resistance between ground connection and accessible conductive part should be < 0.1 Ohm, repeated after temperature, humidity, and corrosive atmosphere tests.	"The fitting shall not crack, break, or melt" Repeated after environmental tests.	Resistance between ground connection and accessible conductive part should be < 0.1 Ohm, tested with 25A @ 60 Hz.

There has been much commentary on appropriate current tests in previous STP discussions and more recently at the STP meeting in December 2010. The points are summarized below:

- UL 1703 uses a relatively low current test based on the maximum series fuse rating to address the potential current flowing through the bonding path for some period of time before the string fuse would be expected to blow. Low current is also representative of anticipated leakage currents that will naturally flow and increase with age (much less than 30A, typically). Some believe, therefore, that this is more representative of the actual conditions and parameters the module is likely to experience in its lifetime.
- UL 1703 could be simplified to allow more generic component testing at 30A, rather than as a function of each and every module's series fuse rating. Many also expect that this test should be performed for longer periods while the modules are undergoing environmental exposure tests rather than performed separately.
- John Wiles is among those who prefer UL 1703 to high current tests. He argues that the low current test could reveal issues not observed in proposed high current tests because of the potential for high currents to bridge, weld, or break down gaps that would otherwise result in lowered continuity.

- Others believe the higher current tests used in UL 467 or UL 1741 are more appropriate for the application. It is a fact that the grounded equipment (i.e. frame) in a faulted string of modules can experience the full array short-circuit current (limited by ground circuit impedance) briefly before the string fuse blows. Systems using AC modules also create potential for short-term AC fault current subject to the time-current curves of the over-current protection device (OCPD). Non-isolated inverters can also cause the utility voltage to appear on the module frame under some single fault conditions. Ultimately the system (inverter) ground fault detection devices should interrupt this current, but the equipment will experience a transient current spike prior to OCPD clearing. So a fast test at 1,000A, for example, is not unrealistic. Several, including Wiley Electronics, SunPower, and SunLink have endorsed the use of such a test to demonstrate the integrity of specific and general use grounding components. Wiley Electronics specifically endorses using UL 467 with a table tying current levels to the size of the ground wire.
- Discussions at the STP meeting related to the revision of UL 467 and whether low or high current tests should be used led to a general consensus that both should be required for certification of module and general use components. Additional proposal language was developed addressing proper sequences of current tests performed before and after environmental conditioning tests.
- The current testing criteria generally addresses impacts of bond failure and impedance degradation on maintaining an effective equipment ground connection—that is, ensuring OCPD device operation will not be compromised. These directly impact personal safety issues as well, but additional considerations of safety will also need to be addressed. The subsequent work in this study will include a review of safety related fault scenarios that will identify conditions under which touch-safe voltages or currents may be exceeded. This work will draw on established safety related criteria, such as International Electrotechnical Commission (IEC) Technical Specification 60479.2, which describes current threshold levels and their effect on the human body. It will also rely on guidelines used in the NEC to designate circuit safety categories (Class 1, 2, and 3 circuits). Results of this analysis will provide guidance in answering basic questions related to the total acceptable resistances in the ground connections in a given area to maintain safety at the module frame.

Environmental and Corrosion Resistance Testing

UL 1703 specifies the following tests on ground connection samples, after which the continuity tests must be repeated:

Section 35—Temperature Cycling Test, 200 cycles of various temperature changes from as low as minus 40 to plus 90 Celsius.

Section 36—Humidity Test, 10 cycles of humidity-freezing.

Section 37—Corrosive Atmosphere testing, including saltspray test and moist carbon dioxide/sulphur dioxide test.

Many in the industry believe these tests do not adequately subject components to the rigors experienced in actual installations, so UL has embarked on exploratory tests to inform future revisions. Recently, Liang Ji at UL has conducted enhanced testing which exceeds the requirements of present UL 1703 environmental tests. These tests have been developed to better reveal connection degradation. A preliminary report is due to be released soon. We include a summary of the testing and preliminary results here.

Test procedures included:

- numerous types of ground connectors,
- continuous damp heat and salt mist environmental exposure,
- periodic electrical current cycling,
- measured change in resistance in connections, and
- tests of roof-mounted modules with and without anti-oxidation compound.

Preliminary results included:

- In the salt mist condition, most samples corroded severely and failed in weeks.
- Identical samples in the damp heat chamber were still in good condition.
- Assembly force and anti-oxidant coating affect integrity.
- Failure mechanisms caused by galvanic, pitting, and crevice corrosion were observed.
- Insulating metal oxide formed by corrosion broke the electrical connections and the grounding system failed.
- Some tests show improved performance when current was flowing through the ground connection.
- Results indicate differences in performance are affected by the details of installation, such as the manner in which a star washer is installed.

Industry review of this report will be critical for the development of tests that will ultimately be incorporated into new or revised standards. While it is widely acknowledged that corrosion tests need to be more rigorous, some in the industry have expressed concern about using some of these testing methods, in particular those that are derived from ASTM B117, which involve continuous exposure to salt mist.

SunPower in particular provided comments to the STP pointing out that the corrosion mechanisms induced by the B117 tests often differ from those observed in the field. Their conclusion is that results do not accurately provide a correlation between the accelerated tests and long-term performance in fielded conditions. The B117 practice itself cautions against the use of the method to predict corrosion performance in the field. SunPower cites corrosion experts from the auto and electronics industry who have expressed concerns about the use and interpretation of such tests.

In general, the use of accelerated corrosion test procedures that have not demonstrated correlation with performance in natural environments is of limited value and must be interpreted with caution. Attempting to accelerate galvanic corrosion is particularly problematic. For example, the ASTM reference on corrosion tests and standards states "Accelerated testing to get a result in a shorter time period than would be possible naturally should be avoided whenever possible, because the mechanism of galvanic corrosion can change if the rate is altered significantly" (*Corrosion tests and standards: application and interpretation 2nd Edition*, R. Baboian, 2005, p. 239). Relevant excerpts of ASTM B117 are included in Appendix B for additional reference.

CONCLUSIONS AND RECOMMENDATIONS

This preliminary report documents many of the challenges facing the PV industry today with respect to module grounding standards and reliability. The timing of this report coincides with a significant level of activity at all levels, particularly at UL. There, STP activity has increased again, exploratory tests are being performed, and at least three STPs are taking a fresh look at PV system grounding. Given the fluid nature of PV module and system grounding requirements, here are a few near-term recommendations to consider for the interim:

- Perform research testing to qualify the impact of different current levels in the continuity and component performance tests.
- Monitor and review developments during the revision of UL 467 to incorporate PV system-specific applications.
- Monitor and review results and developments from UL's enhanced environmental and corrosion resistance testing.
- Engage additional corrosion experts outside of the PV industry to help interpret the new test results and provide guidance on how they can be applied effectively in new or revised standards.
- Explore the possibility of developing special tests for coastal environments, again using guidance from other industries (such as the maritime industry) with relevant experience.
- Seek additional expertise on whether and how strain relief and force tests may be incorporated to evaluate grounding means based on the forces experienced during installation.
- Conduct additional research to identify and classify installation environments and to determine how they might impact grounding design, installation, and maintenance decisions.

APPENDIX A: Excerpts from grounding requirement proposal for UL61730-1, submitted by John Wiles with support of others, 2008.

Section 8 Bonding and Grounding

8.1 Bonding within the module frame—factory connections

8.1.1 Bonding shall be by a positive means, such as clamping, riveting, bolted or screwed connections, or welding, soldering (see 8.1.3), or brazing. The bonding connection shall penetrate nonconductive coatings, such as oxidized metal, clear coatings, paint, or vitreous enamel.

8.1.2 A bolted or screwed connection that incorporates a star washer under the screwhead or a serrated screwhead may be acceptable for penetrating nonconductive coatings. If the bonding means depends upon screw threads, two or more screws or two or more full threads of a single screw shall engage the metal.

8.1.3 All joints in the bonding path shall be mechanically secure independent of any soldering.

8.1.4 A separate bonding conductor or strap shall: a) be of a material electrically and chemically compatible with the module or panel frame material in accordance with 8.4.1 and acceptable for use as an electrical conductor; b) be protected from mechanical damage; and c) not be secured by a removable fastener used for any purpose other than bonding, unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

8.1.5 A ferrous metal part in the grounding path shall be protected against corrosion by metallic or nonmetallic coatings, such as painting, galvanizing, or plating. Stainless steel meeting the requirements of 8.4.1 is acceptable without additional coating.

8.1.6 A metal-to-metal multiple-bearing pin-type hinge is considered to be an acceptable means for bonding.

8.2 Grounding the module frame—field connections

A module or panel shall have a means for connecting all accessible conductive parts to an external grounding (earthing) system. The grounding means shall consist of one or more of the following methods listed in 8.2.1, 8.2.2, or 8.2.3. These grounding means shall be tested following the Ground Continuity Tests MST 13 of ANSI/UL 16730-2.

8.2.1 A Terminal. A terminal shall be used for connecting an external equipment-grounding conductor. The terminal shall be compatible with a copper conductor and shall prevent the copper conductor from contacting the aluminum module frame at the connection point.

8.2.1.1 A terminal of a module or panel (for example, a wire-binding screw, a pressure wire connector, or a nut-on-stud) intended to accommodate an equipment grounding conductor shall be identified by being marked with a grounding symbol, or by “G,” “GR,” “GROUND,” “GROUNDING,” or the like, or shall have a green-colored part. No other terminal shall be so identified.

8.2.1.2 If a marking is used to identify an equipment grounding terminal, it shall be located on or adjacent to the terminal, or on a wiring diagram affixed to the module or panel near the terminal.

8.2.1.3 If a green-colored part is used to identify the equipment-grounding terminal, it shall be readily visible during and after installation of the equipment-grounding conductor and the portion of the terminal that is green shall not be readily removable from the remainder of the terminal.

8.2.1.4 The terminal shall be subject to the Terminal Torque Tests of ANSI/UL 61730-2. Where the terminal used cannot pass this test and can be used only once, the instructions provided with the module shall show alternate positions for installing the terminals and provide specific instructions for using those alternate positions.

8.2.2 A Lead. A lead that is electrically bonded to the module frame shall be used for grounding the module or panel. The lead shall be compatible with a copper conductor.

8.2.2.1 The surface of a lead of a module or panel intended for the connection as an equipment-grounding conductor shall be identified by insulation or color coding colored green, or green with yellow stripe(s), or be bare, or bare tinned, without insulation. No other lead shall be so identified. Where an insulated conductor is used, the insulation shall meet the requirements of the insulation used on USE-2 or PV Wire.

8.2.2.2 The lead shall comply with the Strain Relief Tests of 10.6.

8.2.3 A Device. A grounding device that effectively and durably bonds the module frame to a mounting structure or other adjacent modules or panels may be used. This device shall comply with 8.2.3.1 or 8.2.3.2.

8.2.3.1 A grounding device that effectively and durably bonds the module frame to a mounting structure where the mounting structure used is grounded with a means compliant with the requirements of ANSI/NFPA 70, The National Electrical Code.

8.2.3.2 A device that effectively and durably bonds the module frame to an adjacent module frame where the system of bonded modules is grounded with a means compliant with the requirements of ANSI/NFPA 70, The National Electrical Code.

8.2.3.2.1 Devices that penetrate a module coating to establish electrical contact shall specify the maximum coating thickness with which they are compatible in the installation instructions.

8.2.3.3 Devices that attach to a module frame shall specify the minimum area that must be available and the minimum and maximum thickness of the module frame over that area. Clearance depth behind the frame for nut or other attachment device will also be specified.

8.2.4 Grounding means having threaded connections. Any grounding means having threaded connections shall comply with the applicable requirements in Connections 7 and the Terminal Torque Tests of ANSI/UL 61730-2.

8.4 Material Requirements

8.4.1 The module grounding means shall not result in the combination of dissimilar metals shown above the cutoff line in Table DVC-1 of Annex DVC. The following combinations are considered to be acceptable: a) stainless steel (min 17% Cr content) with Aluminum alloys, tin, zinc, or copper; b) aluminum alloys with stainless steel (17% Cr min), tin, or zinc; and c) other combinations that can be demonstrated to not be susceptible to galvanic corrosion.

The following items will be listed in the instruction manual for each specific module covered by the instructions:

- The thickness of any and all insulating coatings on the frames of the module for areas identified for the connection of field-installed grounding means, including paint, powder coatings, clear coatings, and anodizing.
- The temperature coefficient of open-circuit voltage (Voc) expressed as a percentage change in the Voc standard test conditions (STC) per change in temperature from the STC temperature expressed in degrees Celsius.
- All grounding methods, devices, and materials.
- The OEM part number(s) or the appropriate national or international standard(s) for the hardware if common hardware items such as nuts, bolts, and lock washers are specified rather than provided.

These instructions are part of the listing/certification of the product and shall not be changed without the review and approval of the listing/certification agency. The instructions may specify that an independent grounding means tested and listed to this standard be used. The grounding means shall comply with 8.2 through 8.4. The instructions shall state that any mounting methods not complying with the mounting methods described in these instructions may result in a mechanical attachment that may damage the module or fail to restrain it under high wind loading conditions. Such mounting methods will violate the listing/certification of the module and must be evaluated by the listing/certification agency prior to use. The series overcurrent device required to be marked on back of the PV module shall be identified as “Maximum series overcurrent device, where required.” The words “fuse” or “circuit breaker” shall not be used.

Appendix B: Excerpts from ASTM B117, Standard Practice for Operating Salt Spray (Fog) Apparatus

3. Significance and Use

3.1 This practice provides a controlled corrosive environment, which produces relative corrosion resistance information for specimens of metals and coated metals exposed in a given test chamber.

3.2 Prediction of performance in natural environments has seldom been correlated with salt spray results when used as standalone data.

3.2.1 Correlation and extrapolation of corrosion performance based on exposure to the test environment provided by this practice are not always predictable.

3.2.2 Correlation and extrapolation should be considered only in cases where appropriate corroborating long-term atmospheric exposures have been conducted.

3.3 The reproducibility of results in the salt spray exposure is highly dependent on the type of specimens tested and the evaluation criteria selected, as well as the control of the operating variables. In any testing program, sufficient replicates should be included to establish the variability of the results. Variability has been observed when similar specimens are tested in different fog chambers, even though the testing conditions are nominally similar and within the ranges specified in this practice.

X2. Use of the salt spray (fog) test in research

X2.1 This practice is primarily used for process qualification and quality acceptance. Regarding any new applications it is essential to correlate the results of this practice with actual field exposure results.

X2.2 The salt spray has been used to a considerable extent for the purpose of comparing different materials or finishes. It should be noted there is usually not a direct relation between salt spray (fog) resistance and resistance to corrosion in other media, because the chemistry of the reactions, including the formation of films and their protective value, frequently varies greatly with the precise conditions encountered. Informed personnel are aware of the erratic composition of basic alloys, the possibility of wide variations in the quality and thickness of plated items produced on the same racks at the same time, and the consequent need for a mathematical determination of the number of specimens required to constitute an adequate sample for test purposes. In this connection it is well to point out that Practice B 117 is not applicable to the study or testing of decorative chromium plate (nickel-chromium) on steel or on zinc-base die castings or of cadmium plate on steel. For this purpose Method B 368 and Practice G 85 are available, which are also considered by some to be superior for comparison of chemically treated aluminum (chromated, phosphated, or anodized), although final conclusions regarding the validity of test results related to service experience have not been reached. Practice B 117 and Practice G 85 are considered to be most useful in estimating the relative behavior of closely related materials in marine atmospheres, because they simulate the basic conditions with some acceleration due to either wetness or temperature or both.

ACRONYMS

AHJ	authorities having jurisdiction
ASTM	ASTM International (formerly the American Society for Testing and Materials)
Cr	chromium
CRD	Certification Requirements Decision
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
NEC	National Electrical Code
NRTL	Nationally Recognized Testing Laboratory
OCPD	over-current protection device
PV	photovoltaic
STC	standard test conditions
STP	Standards Technical Panel
UL	Underwriters Laboratories

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