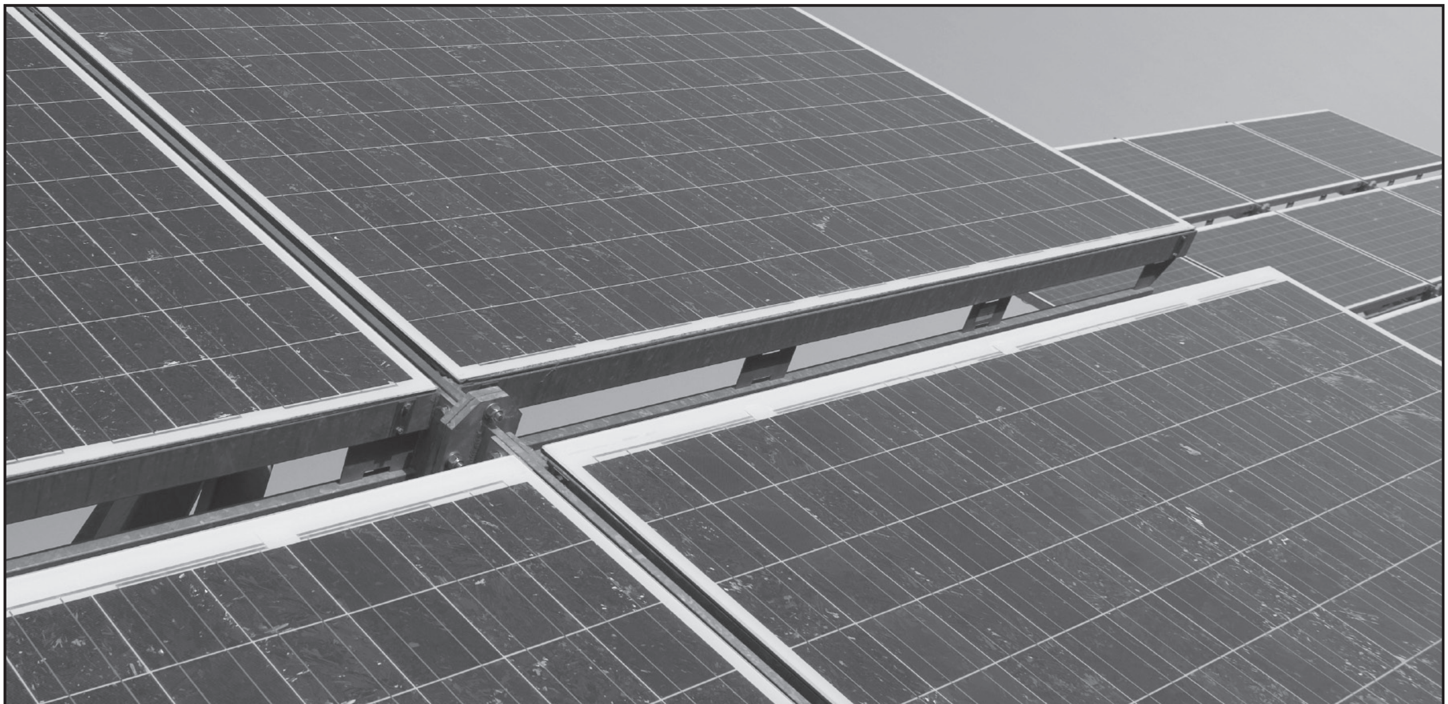

FIELD INSPECTION GUIDELINES FOR PV SYSTEMS

PREPARED FOR:

Interstate Renewable Energy Council

Version 1.1 / June 2010

available at www.irecusa.org

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Acknowledgment: This material is based in part upon work supported by the Department of Energy under Award Number DE-FG36-05NT42401.

Dedication:

This document is dedicated to a person that represents the very best of those who have worked on field inspection processes as they relate to PV systems. Chuck Whitaker, of BEW Engineering, passed away in the months prior to the first release of this field inspection process.

Chuck Whitaker:

Chuck Whitaker passed away in early May of 2009 at the age of 52 in the midst of a distinguished career supporting the development and implementation of most of the codes and standards that govern and support PV systems both nationally and internationally. His passing coincided with the start of this version of the field inspection process. The author had the privilege of knowing Chuck for two decades and working closely with him for over 8 years as his employee and colleague. It is difficult to overstate Chuck's contribution to the PV industry since his influence is found in nearly every code and standard that has been developed for PV equipment and systems over the past 25 years. It is only fitting that this document, which includes his influence, be dedicated to his memory. A huge hole is left in the PV industry with Chuck's passing, and it is the hope of many of us in the codes and standards arena to be able to carry on his tireless work with a semblance of the skill, whit, and humor that was the hallmark of this amazing individual.

INTRODUCTION:

The field inspection process is key to the development of a healthy and safe PV industry. Much focus has been given the permitting process in the past few years for well-deserved reasons. With all the focus that has been placed on the permitting process, the field inspection process deserves even more attention than permitting. A permit package can be assembled that looks quite professional, making the contractor seem knowledgeable and competent. However, the contractor may have little concept of proper installation techniques. The field installation can clearly indicate the competency of the contractor more tangibly than the permit package.

Some jurisdictions around the country are opting for a very simple project review stage to allow contractors to begin construction. These jurisdictions are putting much more emphasis on the field inspection phase. With this increased emphasis on the field inspection part of the approval process, inspectors need to be better informed on what to look for in a system inspection. Contractors also need to be well-versed in proper installation techniques and system design requirements so that costly field mistakes can be avoided.

This field inspection guideline for PV systems has been developed with many years of field inspection experience working with local jurisdictions and other individuals that routinely perform inspections for jurisdictions, financiers, and manufacturers. The intent of this guideline is to consolidate the most import aspects of a field inspection into a simple process that can be performed in as short as 15 minutes. Explanation and illustrative pictures are provided to instruct the inspector on the specific details of each step.

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. Too many badly designed and installed PV systems have been approved to date. By clarifying the issues of concern, and providing a detailed checklist for the field inspector, fewer poorly designed and installed systems will be approved. As local inspectors become familiar with typical products and sound installation techniques, contractors doing marginal work will be forced to improve or find another line of work.

Field Inspection Guidelines for PV Systems

To perform a field inspection of a PV system properly, it should be done in a consistent and organized fashion. The inspector should start either at the PV array or at the service entrance, and work their way to the other extreme of the system. For the purpose of this document, we will start the inspection at the array and work our way to the service entrance. As we work our way through the inspection, it will be noted which items to pay particular attention to and those items that should be photographed for future reference. If an inspector prefers starting at the service entrance, the reverse order of the inspection can be performed. The key is consistency and thoroughness. After many years of experience inspecting PV systems, it is still easy to miss important points when a methodical checklist is not used. This document will explain, step-by-step, each inspection point with a summarizing checklist to use in the field.

At a minimum, a copy of the one-line diagram and the site diagram should be available at the site for the inspector's use during field inspection. If any variations exist between the reviewed plans and the site installation, those changes should be noted on those drawings along with any necessary explanation as to why adjustments were made to the plans. If substantial changes are found in the field installation, the as-built changes may need to be referred back to plan review to ensure code compliance.

Section 1. <u>Field Inspection Checklist for Array:</u>

a) Number of PV modules and model number matches plans and spec sheets

The very first item to inspect is the PV array. This can be difficult at times, particularly if the array is on multiple roof faces and portions of the building blocks visual access to the roof. Ideally, the inspector will get on the roof, with fall protection supplied by the contractor, so that a detailed inspection of the array can be carried out. At times, the steepness of the roof, or the insurance provisions of the county will not allow inspectors to get on the roof. In the case where the inspector is unable to get on the roof, the array inspection should take place using a secured ladder or personnel lift. The contractor should have one of those options prepared at the time of the inspection.

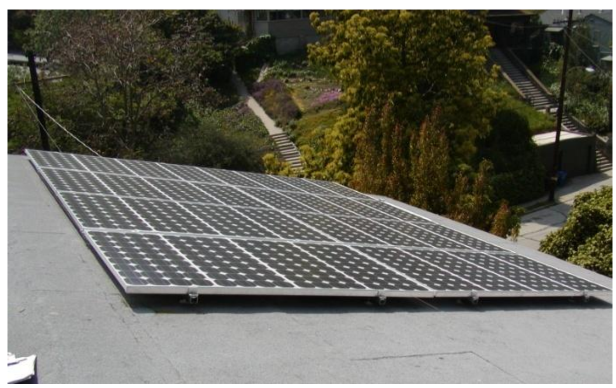

Figure 1 Verify Type and Number of Modules

Once access to the roof has been obtained, or view of the roof is available from a ladder, the first item is simply to count the number of modules in the system. It is critical that number of modules agree with the provided plans since the ratings of equipment, both for voltage and current depend on the proper configuration. It is common for suppliers to substitute different product between when the permit is pulled and the final installation.

Although this is understandable, the new array configuration must be provided in supplied as-built plans, and the alternative calculations made for changes in the photovoltaic power source sign (see section 3).

Once the number of PV modules is confirmed to match the drawing, the PV module model number should be compared with the modules shown in the plans. Occasionally, module model numbers can change between the time that the permit documents are approved and the final inspection. For products that are substantially identical, the different module model number can be substituted without being considered a product difference, provided documentation shows that the products are the same. Confirming the model number of a module can be a challenge. For residential rooftop PV systems, the listing labels supplied by the testing laboratory are on the back side and difficult or impossible to view. One option is for a digital photo to be taken of the PV module label, and a copy of the photo supplied at the time of inspection. An alternative to a printed version would be for the contractor take a picture of the back side of the module and show the picture to the inspector. If neither of these methods can be accomplished, a single representative module should be moved to provide a visual inspection of the label.

Figure 2 PV Module Listing Label

Lastly, with the module model number and quantity of modules confirmed, the physical layout of the array should match the supplied site plan. Small variations may be common to avoid roofing obstacles not noted in the original design which may be acceptable. However, wholesale location changes should be documented in the permit package with an accurate as-built drawing in case the location change has structural implications.

Common Installation Mistakes with Array Modules and Configurations:

1. Changing the array wiring layout without changing the submitted electrical diagram.
2. Changing the module type or manufacturer as a result of supply issues.
3. Exceeding the inverter or module voltage due to improper array design.
4. Putting too few modules in series for proper operation of the inverter during high summer array temperatures.

b) Wire Management: Array conductors are neatly and professionally held in place

Figure 3 USE-2 conductors touching roof surface

One of the most important safety issues with a PV array is that the conductors are properly supported. It is unacceptable for conductors to lay on roofing materials or come in contact with sharp or abrasive surfaces. The installation methods for the exterior USE-2 conductors, commonly used in PV arrays, is stated in *NEC* 338.10(B)(4). This section refers the installer on to Article 334.30 for support methods. Article 334 is entitled Non-Metallic Sheathed Cable (often referred to by the trade name Romex). The requirements for fastening NM cable are well understood by jurisdictions. The requirements for support in NEC 334 are summarized in the following points:

1. Secured by staples, cable ties, straps, hangers, or similar fittings at intervals that do not exceed 4.5 feet
2. Secured within 12 inches of each box, cabinet, conduit body, or other termination
3. Sections protected from physical damage by raceway shall not be required to be secured within the raceway
4. Cable shall closely follow the surface of the building finish or of running boards ((NEC 334.15)—the analogous installation for USE-2 in PV arrays is for the conductors to follow support rails or module extrusions)
5. Protected from physical damage by raceway when necessary

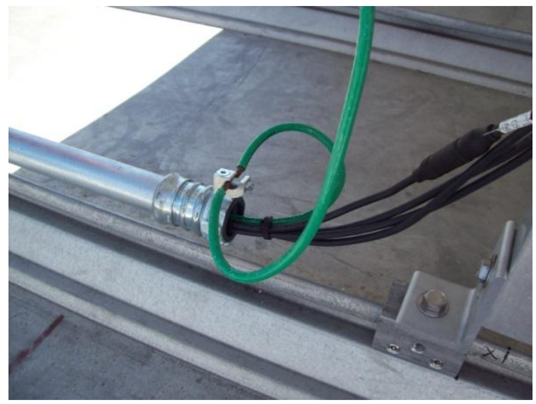

Figure 4 conductors properly protected by raceway with grounding bushing (correct)- should be secured within 12 inches of fitting (not shown)

Wire management is one of the quickest ways to read the competence of a contractor or installation team. Properly installed conductors should be virtually invisible from the ground level with no conductors hanging unsupported. Branches, snow, and ice, have a tendency of pulling loose conductors away from their supports and damaging the conductors or the module. When conductors are run between support rails, or on the upper edge of a PV array, getting visual confirmation of the quality of wire management may require the inspector getting onto the roof or positioning a ladder at the side of the array to view underneath the array. Many wiring sins are covered by PV modules, but these wiring mistakes can eventually turn into system failure or even arcing fires.

Figure 5 (incorrect) FNMC without support

In addition to observing proper support of conductors, the inspector should inspect a sample of plug-and-receptacle connectors to ensure that they are fully engaged. Often installers are not properly trained on how to make these connections and don’t get them fully engaged. Another problem that relates to connectors and conductors is bending the conductor too close to the outlet of a plug or receptacle, potentially damaging the connector. Also the bending radius of USE-2 cable must be observed. As with many cable, the minimum bending radius is 5 times the diameter. If the diameter is 0.2”, the minimum RADIUS is 1” (2” bend).

Figure 6 multiple conductors in single conductor cross-threaded cable gland (incorrect)

Common Installation Mistakes with Wire Management:

1. Not enough supports to properly control cable.
2. Conductors touching roof or other abrasive surfaces exposing them to physical damage.
3. Conductors not supported within 12 inches of boxes or fittings.
4. Not supporting raceways at proper intervals.
5. Multiple cables entering a single conductor cable gland (aka cord grip)
5. Not following support members with conductors.
6. Pulling cable ties too tight or leaving them too loose.
7. Not fully engaging plug connectors.
8. Bending conductors too close to connectors.
9. Bending USE-2 cable tighter than allowable bending radius.
10. Plug connectors on non-locking connectors not fully engaged

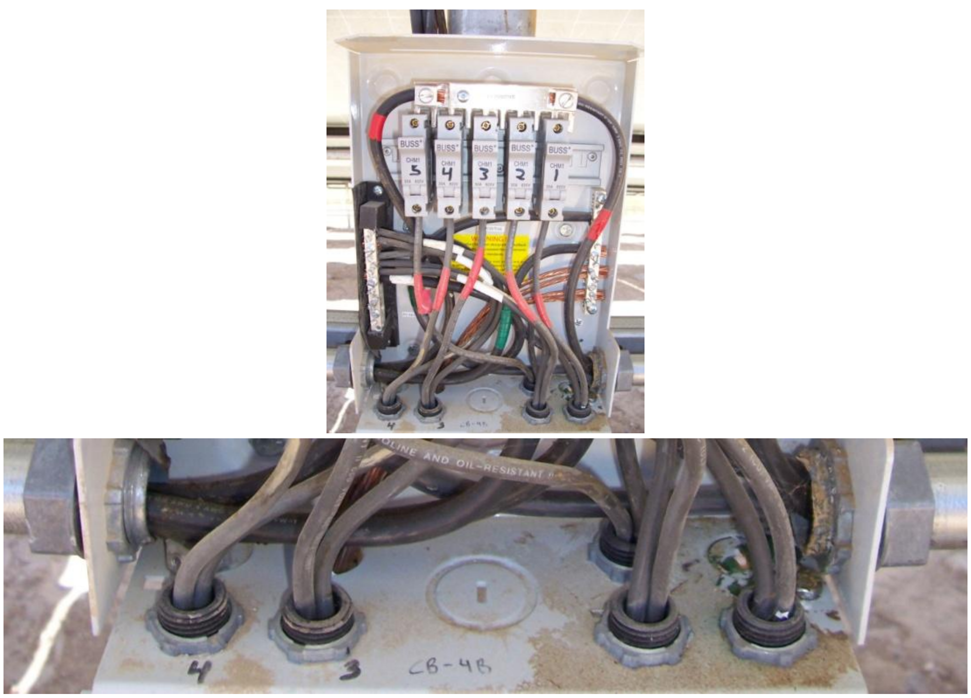

Figure 7 proper cable glands with 2-conductor inserts in combiner box (correct)

Figure 8 Connectors loose and not supported within 12 inches of connector (incorrect)

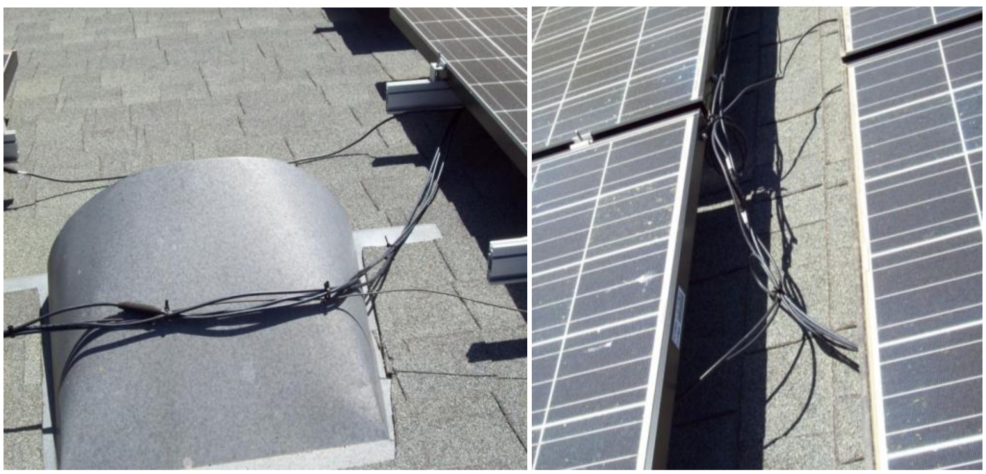

Figure 9 improper cable support with exposure to physical damage (incorrect)

Figure 10 poor conductor handling and bending radius too tight (incorrect)

Figure 11 improper use of chase nipple and exceeding conduit fill with no end fitting (incorrect)

c) Module and Array Grounding

An area of intense concern to the inspector is PV module and array grounding. Much confusion and controversy has surrounded this issue, but it is one of the most important safety issues in a PV installation. Many inspector focus the majority of their time and effort on this one item. This focus is justifiable since an improperly grounded PV array can be hazardous. This section will focus on module and array grounding and leave PV system grounding to the section that covers the inverter inspections. The key to module grounding is creating an electrical connection between the module frame, most often an aluminum extrusion, with the equipment grounding conductor (EGC). Creating this connection can be handled in a few specific ways.

1. Some modules are designed to be grounded using a stainless-steel thread-forming screw threaded into the module frame holding the EGC at a grounding symbol. An isolating washer, such as a stainless cup washer is often used to isolate the copper conductor from the aluminum frame to prevent galvanic corrosion.
2. Some modules can be grounded to their mounting structures with stainless steel star washers placed between the module and the support structure. This creates an electrical bond while isolating the aluminum frame from dissimilar materials such as galvanized steel. The EGC is attached to an electrically continuous support member with a properly installed grounding lug.
3. Some modules can be grounded by properly installing a properly rated lay-in lug to the either the grounding point on the module, or any unused mounting hole. The EGC is run through this lay-in lug to bond the modules together.
4. For specific module mounting products (e.g. UniRac, ProSolar, DPW, etc…), there exists listed grounding clips to bond typical aluminum framed modules to the mounting structure. Only the proper clip can be used with each mounting structure as there are differences in how each mounting structure attaches PV modules. These grounding clips offer a solid electrical

connection allowing the electrically continuous rail to be grounded with the EGC. This method is consistent the *NEC* 690.43 and *NEC* 250.136.

5. Lastly, some modules can be grounded using serrated clips that hold the module to the support structure and electrically bond with the module. In this case, the EGC is connected to the last module in a row of modules that each have this specially-rated clip.

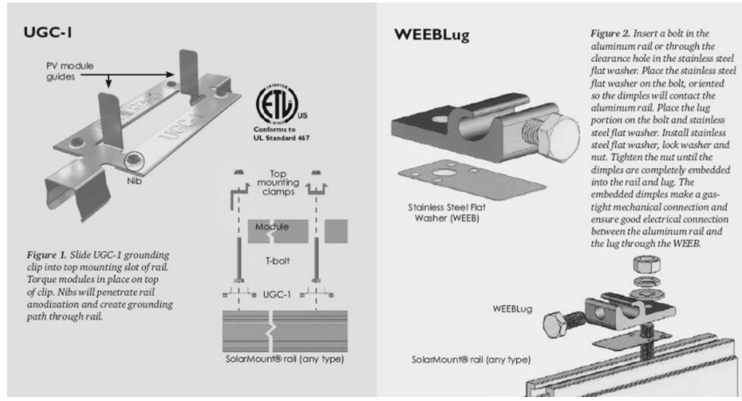

Figure 12 grounding clip and lug designed for UniRac rail

Once it is confirmed that the modules are properly bonded and grounded to the EGC for the dc portion of the system, the 2008 NEC in 690.47(D) requires all arrays to have additional array grounding. This additional grounding is primarily for lightning and surge grounding. For ground-mounted systems, this is typically a driven ground rod with a Grounding Electrode Conductor (GEC) sized according to 250.166 (minimum 8 AWG). The support structure may comply as an electrode, provided the steel is buried at least 8 feet in the earth just like a ground rod. Rooftop systems are not exempt from this requirement. If a building has building steel available that is properly grounded, that building steel can be used as the grounding electrode. A properly sized GEC is connected from at least one common point on the array and the building steel. If no building steel is available, as with most residential installations, then a separate GEC must be run from a common point on the array directly to a ground rod at the closest practical point to the array. If that closest point is within 6 feet of the main service grounding electrode, then the main building ground can be used rather than driving a new ground rod.

Common Installation Mistakes with Module and Array Grounding:

1. Not installing a grounding conductor on the array at all.
2. Using cad-plated Tek screws to fasten ground wires or lugs to modules.
3. Using indoor-rated grounding lugs on PV modules and support structures.
4. Not protecting EGCs smaller than 6 AWG from physical damage.
5. Allowing copper EGC to come in contact with the aluminum rails and module frames.
6. Assuming that simply bolting aluminum frames to support structures provides effective grounding.

d) Electrical Boxes and Conduit Bodies on Roof Reasonably Accessible and Electrical Connections Suitable for the Environment

It is understandable for contractors to preserve aesthetics by placing electrical junction boxes and combiner boxes under PV modules so that they cannot be seen from the ground. This is acceptable only if the panel covering the box can be easily removed and held in place on the roof while working on the box or conduit body. Generally speaking, it is always best to have boxes or conduit bodies that need access to be adjacent to, rather than under the PV array. Mounting these devices at or near the top of the array may provide the best access and hide them most effectively for aesthetics purposes.

If a disconnecting means is located on the roof of a building, proper installation and clearances are required for access to the disconnect. Most disconnects commonly on the market are rated to be mounted only in the upright position. Mounting disconnects on their backs on sloped or flat roofs should be avoided unless the disconnecting means specifically allows mounting in that way in the installation manual. If the disconnecting means includes fuses, inspect the fuses for proper ratings as with source combiners. Be aware that common class R fuses will say 600 Volts in large letters, but the small print often shows the dc rating at 300 Volts if the fuse has any dc rating at all. Also, be aware that most disconnecting means operating at 600 Vdc require passing through the disconnect blades twice in series. A few import exceptions exist including the Square D H361, H362, and H363 disconnects in their fused and unfused versions. These special Square D disconnects have been tested by the manufacturer to handle 600 Vdc per pole for PV arrays. The Square D H361 disconnect is also listed for two conductors per terminal. Most other disconnects have been evaluated to 600 Vdc by passing the conductor through two of the poles in series. Regardless of the manufacturer, any application of a disconnecting means for a dc application must be documented by the manufacturer.

While on the roof, any junction box with terminations and/or fuses should be inspected for proper connectors and fuses. A variety of rooftop junction boxes are used including waterproof NEMA 4 boxes and rainproof NEMA 3R boxes. In either case, penetrations into the box must be with proper fittings suitable for wet locations and NEMA 3R boxes may restrict the angle at which the box is to be mounted. Unless specifically allowed in the installation manual, most NEMA 3R rainproof boxes must be mounted vertically. Any exceptions must be documented in the installation manual or other official documentation. Outdoor boxes, mounted at roof angles, notoriously fill with water over time. It is advisable that all connectors be waterproof in such boxes. Options include waterproof twist-on wire splices, heat shrink butt splices, and various direct burial options. Twist-on wire splices for indoor boxes should always be avoided in outdoor applications as they corrode quickly. Terminal strips in junction boxes should be installed above standard knockout locations and any water outlets in NEMA 3R boxes.

Figure 13 incorrect NEMA 3R disconnect on sloped roof designed for vertical mounting only

Any source combiners with fuse holders should be mounted in such a way that the fuses can be accessed without having to remove modules or disable the PV system. Fused combiners are intended to be accessed and tested on an ongoing basis while the system is operating. During the field inspection, any roof-mounted combiner boxes should be opened and the fuses examined to be certain that properly rated fuses are used in the source combiner. Some source combiners may specify a specific fuse model and size to be used, while others many simply state the fuse voltage rating and maximum fuse size. The fuse should be identified on the barrel with the ac/dc voltage ratings and fuse current setting. If this information is not found on the barrel of the fuse, then proper documentation must accompany the fuse if the specific fuse is not listed on the source combiner cover or documentation. A common way to make a well-engineered, well-installed PV system dangerous is to install improper fuses.

Figure 14 properly flashed roof penetration (correct)

Common Installation Mistakes with Electrical Boxes, Conduit Bodies, and Disconnecting Means:

1. Installing disconnects rated for vertical installation in a non-vertical application.
2. Installing improperly rated fuses in source combiners and fused disconnects.
3. Covering boxes or conduit bodies making them nearly inaccessible for service.
4. Not following manufacturer's directions for wiring disconnect for 600 Vdc ratings.
5. Installing dry wire nuts in wet locations and inside boxes that get wet routinely.
6. Using improper fittings to bring conductors into exterior boxes.

e) Array Fastened and Sealed According To Attachment Detail

The attachment detail should be supplied with the mounting system manufacturer's information. The contractor should supply this detail with an explanation of the sealing process used to preclude roof leakage, should the array be mounted on a roof surface. Typical sealing of roof penetrations are done with flashing at round pipe penetrations, special lag screw flashings (see QuickMount.com and ttisolar.com), and various caulking materials to seal lag screw holes using caulk that is compatible with the roofing material. Leaking roofs are of primary concern to homeowners and can cause significant property damage. Sloppy or improper installation of penetrations should not be tolerated.

Figure 15 properly installed flashed roof penetration (correct)

While examining the roof attachments, a simple test can be done if the inspector is on the roof. With protective gloves to prevent cuts on sharp edges, pull up on a PV module near one of the supports. If the support moves a significant amount, it is likely not attached properly. Several years ago in Southern California, a PV system blew off a roof during high winds since it was attached to the roof tile with plastic anchors rather than being properly attached to the roof rafters or trusses. A simple pull test would have quickly identified that the array was not properly attached to the roof.

Figure 16 uninstalled flashing (incorrect)

Even if the proper lag screws are used for the mounting system, installers can poorly install the lag screws. Proper lag screw mounting requires a pilot hole in the center of the roofing member at approximately 75% of the diameter of the lag. Any unthreaded shank must be piloted at the full diameter of the lag to the full depth of the unthreaded shank. It is difficult to inspect for lag screw mounting with other than the simple pull test mentioned earlier. Another option to inspect lag screws is to enter the attic under the PV array and see if any lag screws are showing or there is any evidence of improper pilot holes such as split rafters or trusses.

Common Installation Mistakes with Mounting Systems:

1. Not using supplied or specified hardware with the mounting systems.
2. Substituting Unistrut for special manufactured aluminum extrusions.
3. Not installing flashings properly.
4. Not using the correct roof adhesives for the specific type of roof.
5. Not attaching proper lag screws to roofing members.
6. Not drilling proper pilot holes for lag screws and missing or splitting roofing members.

f) Conductor Ratings and Sizes

<u>Exposed array conductors</u>

One of the most common errors in PV system design and installation is the specification and installation of the conductors based on the conductor ratings and sizes. The correct choice of conductor must be based on the environmental conditions it is exposed to. The PV array conductors at the modules to the first junction box must be outdoor-rated cables since

Figure 17 incorrect conductors exposed and touching roof and no strain relief (incorrect)

few, if any PV modules sold allow for raceways to be installed on them. The 2008 NEC allows specifically two types of cables for exterior use: (1) USE-2, underground service entrance conductors with a 90°C rating; and, (2) PV Wire, also labeled PV Cable, that is an identified cable specifically for exterior use and double-insulated to comply with the requirements for NEC 690.35 (D)(3) for ungrounded PV power systems.

Conductors in raceways on rooftops

Once the exterior cables are brought to the first junction box, it is typical for the conductor type to be transitioned from exterior rated cable to conduit-rated conductors due to the ease of installation and lower cost of conduit-rated conductors. The most commonly available conductors are dual rated THHN/THWN conductors. However, due to the fact that the NEC treats conductors in exposed conduit as a wet location (NEC 300.9), the wet rating of the conductor prevails. This often causes issues of insufficient conductor ampacity due to the 75°C rating of THWN. It is therefore strongly recommended that contractor specify and install higher rated THWN-2, XHHW-2, or RHW-2 conductors instead of THWN.

The use of 90°C rated conductors is particularly important in light of updates in the 2005 and 2008 versions of the NEC. In the 2005 NEC 310.10 FPN No.2, a note was added addressing the concern of high operating temperatures in raceways in direct sunlight in close proximity to rooftops. The 2008 NEC codified these concerns by establishing Table 310.15(B)(2)(c) that provides required temperature adders for sunlit raceways on rooftops at differing distances from the roof surface. Even more moderate temperature climates throughout the U.S. can have rooftop raceway temperatures that severely impact the ampacity of 75°C conductors. If more than three current carrying conductors are enclosed in the raceway, an additional ampacity adjustment must be made for four or more conductors according to Table 310.15(B)(2)(a).

Terminal temperature ratings are of concern to many jurisdictions, because this is the most common type of ampacity limitation for standard electrical wiring in buildings. The reason terminal temperature rating limitations are common is that most wiring systems are installed indoors in a temperature controlled environment. Field experience with PV system design for rooftop PV system shows that the terminal temperature restrictions, covered in NEC 110.14(C), rarely constrain the ampacity of the conductors. Due to the high temperatures of rooftops, the temperature and conduit adjustments routinely supersede the terminal ampacity concerns. Ground mounted PV systems are more likely to use the terminal temperature limitations since the underground conduit does not require temperature corrections.

Common Installation Mistakes with Conductors:

1. Not accounting for high operating temperatures in rooftop conduit.
2. Specifying THHN conductors rather than wet rated conductors in drawings where raceways are clearly located outdoors.
3. Specifying or installing THWN conductors in raceways that may exceed 60°C without properly correcting the THWN conductors for this temperature.

Section 2. Specifics For Ground-Mounted Arrays

Inspecting ground-mounted PV systems is similar to inspecting roof-mounted systems with several important differences. As with roof-mounted systems, the mounting structure being installed according to plans is key.

a) Foundation and mounting structure review

Ground-mounted systems have foundations that must be reviewed. These foundations are common structural elements that are familiar to most jurisdictions. A common ground-mounted PV foundation is galvanized steel poles set in concrete. With these simple foundations, the depth of the concrete and cover diameter of the concrete around the pole are the important elements to inspect. The plans should clearly indicate the method of foundation installation and have details for assembling the structure in the mounting system. The field inspector should familiarize themselves with the structural mounting system being employed so that field modifications or departures from manufacturer's instructions can be identified. It is common for installations to have field modifications that are not allowed by the structure manufacturer.

b) Electrical bonding of structural elements

Next, the grounding of the structure and the structural elements should be inspected. It is common for the steel elements in a structure to be bonded with bolted or welded connections. Structural elements used for thermal expansion may be purposefully left loose and may not be effectively grounded. Bonding jumper should be installed around expansion joints to ensure adjacent members are bonded to one another. This bonding jumper may be as simple as a lug installed on both members with a 6 AWG bare copper wire run between the two lugs.

Bonding requirements for aluminum is different from steel in that firmly bolted connections may not provide effective bonding. Bonding aluminum elements requires more care and attention then required for the steel elements since aluminum is prone to quick oxidation, or has a relatively thick anodized coating. Regardless of whether the aluminum is anodized or not, the bond between aluminum parts must be intentional with stainless star washers, pointed grounding clips, or lugs and grounding jumpers or conductors to keep these aluminum pieces at the same electrical potential.

The NEC requires that all metal "likely to become energized" be grounded. At some point on the structure, the equipment grounding conductor must be established and run in close proximity to the supply conductors. This is normally done at or near the module framework. Some installations may run a grounding conductor to each module frame. This method, although it can be effective, places the copper conductor in close proximity to many aluminum members that could eventually corrode and damage the grounding conductor. The copper conductor method is slowly being replaced with improved methods that do away with the copper conductor and bond modules to their support structures (NEC 250.136, NEC 690.43). This allows a single grounding lug to be placed on each mounting rail with the grounding conductor run to the combiner box, establishing an effective grounding path for proper ground-fault and overcurrent device operation.

At some point in the structure, it is common for a transition to be made between the steel substructure and the aluminum of the module frames. Wherever that transition occurs, proper techniques must be employed to prevent galvanic corrosion. This transition can occur either at the module frame, or at aluminum rails that fasten to the module frames. To make this transition properly, this connection is typically made with stainless steel fasteners and stainless washers to isolate the steel from the aluminum. Historically, in the California market due to the low corrosion rates, dissimilar metals are commonly seen in contact with one another. The fact that installations often have this error should not be seen as license to continue a practice that can have severe consequences in high corrosion environments. Since this connection point is often a high-resistance electrical connection, a bonding jumper or a stainless star washer should be used to bond the aluminum mounting system to the steel mounting system.

c) Additional array electrode

Lastly, the structure must be connected to a grounding electrode in the proximity of the ground-mounted array. This additional array grounding electrode (NEC 690.47(D)) is primarily for lightning protection and is required in the 2008 NEC. This may be as simple as a driven ground rod at some point in the array with a grounding electrode conductor attached from the mounting structure to the electrode. The electrode may be any method allowed in NEC 250.52 and would include steel mounting structures that have at least 8 feet of ground cover, which is common with large pole mount structures.

d) Attachment method according to plans

As with any PV mounting system, the employed mounting system should be specifically allowed in the installation manual for the modules. Some modules have specific restrictions on how they are to be mounted. Sometimes these restrictions are due to limitations of the frame extrusions to withstand extreme wind or snow loading. Mounting details should be supplied with the structural documentation so that it is clear what method is to be used and so the field inspector can evaluate whether or not the proper method was followed.

e) Wiring not readily accessible

Figure 18 typical ground mount system with readily accessible wiring (incorrect)

A common misunderstanding in the field relates to wiring within a ground-mounted array. The 2008 NEC specifically requires that array conductors be in a raceway or otherwise not readily accessible. Since module wiring cannot be placed in raceways due to the plug connectors used universally in the PV industry, the wiring must be rendered "not readily accessible." Making wiring not readily accessible is easier than some may initially think. Ready access implies that anyone can walk up to the array and touch the wires. Wiring is not readily accessible in the following example situations:

1. Where conductors are protected by a fence only allowing authorized personnel.
2. Where conductors are above 8 feet from the ground.
3. Where conductors are protected by guards that require tools to remove the guards.

Figure 19 Wiring above 8 feet (correct)

The safety hazard of allowing children to touch wiring in a 600 Volt PV system is extreme. If an array is mounted close to the ground with readily accessible wiring, the easiest and generally most cost effective method to render the wiring not readily accessible is to place non-metallic lattice work around the back, sides, and under the front of the PV array. By enclosing the array with non-metallic guards, the guards require no grounding but allow air to flow to the backside of the array for cooling.

Common Installation Mistakes with Ground Mounting Systems:

1. Not using supplied or specified hardware with the mounting systems.
2. Substituting Unistrut for special manufactured aluminum extrusions.
3. No bonding of support structure or discontinuous grounding of support structure.
4. Dissimilar metals in contact with one another (e.g. aluminum and galvanized steel).
5. No bonding of aluminum structural elements to steel structural elements.
6. Array wiring readily accessible to other than authorized personnel.

Section 3. Appropriate Signs Installed

a) Check proper sign construction

The signs should be of sufficient durability to withstand the environment involved. For outdoor signs, the sign should be either metal or plastic with engraved or machine printed letters, or electro-photo plating, in a contrasting color to the sign background. Plexiglas-covered paper or laminated paper directories may also be acceptable provided that the signs are sufficiently protected from the environment involved. The signs or directories should be attached to the electrical equipment or located adjacent to the identified equipment.

b) Check for sign identifying PV power source system attributes at dc disconnect [690.53. Photovoltaic Power Source]. This sign must include:

i. Operating current (provided in initial plan review--sum of parallel source circuit operating currents)
ii. Operating voltage (provided in initial plan review--sum of series modules operating voltage in source circuit)
iii. Maximum system voltage [690.7]
iv. Short-circuit current [690.8(A)] (maximum circuit current)

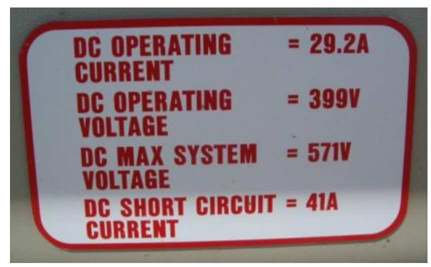

Figure 20 PV Power Source sign (correct)

c) Check for sign identifying ac point of connection [690.54].

This sign must include:

i. Maximum ac operating current
ii. Operating voltage (e.g. 240 Volts)

d) Check for sign identifying switch for alternative power system.

Figure 21 sign in PV ac disconnect (correct)

A sign should be mounted on or next to the PV system disconnecting means with the words to the effect of "PV System Disconnect" in a minimum of 3/8" high letters. If this disconnect is not located at the service disconnect, follow the requirement in NEC 690.56 (B):

NEC 690.56 (B) Facilities with Utility Services and PV Systems. Buildings or structures with both utility service and a photovoltaic system shall have a permanent plaque or directory providing the location of the service disconnecting means and the photovoltaic system disconnecting means, if not located at the same location.

Section 4. <u>Check that equipment ratings are consistent with application and signs</u>

Figure 22 properly rated midget fuse (correct)

a) Check that inverter has a rating as high as max voltage on PV Power Source sign.
b) Check that circuit breakers or fuses in combiner or fused disconnect are dc rated at least as high as max voltage on sign.
c) Check that switches and OCPDs are installed according to manufacturers specifications (i.e. many 600Vdc switches require passing through the switch poles twice in a specific way).

    Example: If the PV Power Source sign has a maximum system voltage of 553V, then the inverter, dc disconnect, and any OCPD on the dc side of the inverter must be rated for 600Vdc.

d) Check that inverter is rated for the site ac voltage supplied and shown on the ac point of connection sign.
e) Check that OCPD connected to the ac output of the inverter is rated at least 125% of maximum current on sign, and is no larger than the maximum OCPD on the inverter listing label.

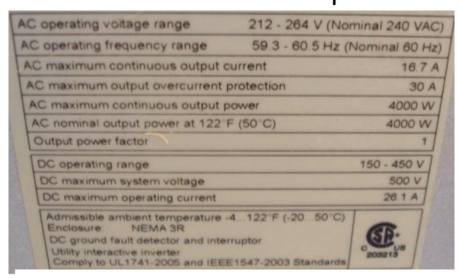

Figure 23 inverter listing label

    Example: If the ac point of connection sign has a rated ac output current of 21 amps, then the inverter OCPD on the ac side of the inverter must be at least 30 amps (1.25 x 21 amps = 26.25 amps—round up to next larger standard OCPD). If the inverter shows a maximum OCPD of 50 amps, then a 30-, 35-, 40-, 45-, or 50-amp OCPD would be acceptable for the listing of the inverter.

f) Check that the sum of the main OCPD and the inverter OCPD is rated for not more than 120% of the busbar rating.

    The 2008 NEC also requires that the inverter OCPD be located at the opposite end from the input feeder location and that a sign be applied to the panelboard stating, "Warning, Inverter Output Connection, Do Not Relocate This Overcurrent Device."
    The inverter OCPD is often a circuit breaker installed in a distribution panelboard. In this case the final limitation on OCPD size is the ratings of the panelboard that the inverter OCPD is installed in. For instance, if the panelboard has a 200-amp bus rating and a 200-amp main breaker rating, the breaker size is limited by the 120% rule in NEC 690.64(B)(2). The NEC allows for the sum of the OCPDs to not exceed 120% of the 200-amp bus is 240-amps. Subtracting the 200-amp main breaker size from the 240-amp value yields 40-amps—the largest size PV breaker allowed for this panelboard. With this panelboard, the allowable OCPDs in our example would be 30-, 35-, 40-amps. The 45- and 50-amp breakers would exceed the 120% rule.

Section 5. Worksheet for PV System Field Inspection

Field Inspection Checklist for Array:

________ # of PV modules and model # matches plans and spec sheets number matches plans and spec sheets

________ Wire Management: Array conductors are neatly and professionally held in place

________ PV array is properly grounded

________ Check that electrical boxes are accessible and connections suitable for environment

________ Array Fastened and Sealed According To Attachment Detail

________ Check conductors ratings and sizes

Specifics For Ground-Mounted Arrays

________ Foundation review

________ Mounting structure review

________ Electrical bonding of structural elements

________ Additional array electrode

________ Attachment method according to plans

________ Wiring not readily accessible

Appropriate Signs Installed

________ Check proper sign construction:

________ Check for sign identifying PV power source system attributes at dc disconnect

________ Check for sign identifying ac point of connection [690.54].

________ Check for sign identifying switch for alternative power system.

Check that equipment ratings are consistent with application and signs

________ Check that inverter has a rating as high as max voltage on PV Power Source sign.

________ Check that dc-side OCPDs are dc rated at least as high as max voltage on sign.

________ Check that switches and OCPDs are installed according to manufacturers specifications
(i.e. many 600Vdc switches require passing through the switch poles twice in a specific way).

________ Check that inverter is rated for the site ac voltage supplied and shown on the ac point of connection sign.

________ Check that OCPD connected to the ac output of the inverter is rated at least 125% of maximum current on sign,
and is no larger than the maximum OCPD on the inverter listing label.

________ Check that the sum of the main OCPD and the inverter OCPD is rated for not more than 120% of the busbar rating.