National Electrical Code and Safety Considerations when Grounding Photovoltaic Modules via Rack Mounting Hardware

There are a number of issues which should be considered when evaluating the grounding system for a photovoltaic (PV) installation. Unfortunately, there is often confusion on the part of installers due to the fact that there are sometimes conflicts between the installation instructions, industry practices, and the National Electrical Code®. Compounding this problem is the fact that many PV products are designed to European specifications which do not necessarily equate with their associated standards in the United States and Canada. This manifests itself quite often in the area of photovoltaic equipment grounding where the Europeans seem to see little need and the U.S. photovoltaic establishment has seen little in the way of consistent interpretation and enforcement.

Section 690.43 of the National Electrical Code (NEC®) is clear in its intent in making the statement:

> "Exposed non–current-carrying metal parts of module frames, equipment, and conductor enclosures **shall** be grounded in accordance with 250.134 or 250.136(A) regardless of voltage."

The trail of understanding the NEC grounding requirements continues with applicable portion of Section 250.136(A) which states:

> "Equipment Secured to Grounded Metal Supports - Electrical equipment secured to and in electrical contact with a metal rack or structure provided for its support ***and*** ***grounded by one of the means indicated in 250.134.*** " *(Emphasis added.)*

The applicable portion of the referenced section (250.134) is summarized thusly:

> "Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed) — Grounding
>
> Unless grounded by connection to the grounded circuit conductor as permitted by……, non–current-carrying metal parts of equipment, raceways, and other enclosures, if grounded, shall be grounded by one of the following methods.
>
> (A) Equipment Grounding Conductor Types
>
> By any of the equipment grounding conductors permitted by 250.118."

Section 250.118 lists fourteen different types of recognized equipment grounding conductors, the primary ones being copper, aluminum or copper-clad aluminum conductors. However, it is noteworthy that the section does not recognize grounded metal frames (nor the frames of photovoltaic modules) as being an equipment grounding conductor.

There is a Fine Print Note to Section 250.134 which references Section 250.102 for guidance relating to equipment bonding jumpers. Section 250.102(B) clearly states that these bonding jumpers need to be attached in a manner specified by Section 250.8; and Section 250.8 stipulates that the connect be made by “exothermic welding, listed pressure connectors, listed clamps, or other listed means”.

Basically the grounding guidelines of the Code boil down to this: all electrical equipment is to be grounded by means of direct attachment to an equipment grounding conductor which is recognized by Section 250.118. If a termination involves an intermediary device, the device must be listed and suitable for the purpose. There are few exceptions to this rule, the most notable being that receptacles may be grounded by their mounting screws but only under certain limited guidelines. Yes, it is possible to ground a piece of electrical equipment to a grounded metal rack, but the rack must first be grounded by means of a conductor recognized by Section 250.118 and a suitable bonding jumper.

Even though this method is available, it is rarely used in the field because of the difficulties in establishing and maintaining a solid, low-impedance grounding connection between electrical devices and their associated mounting racks. In fact, general practice in the industry is to require a properly sized copper equipment grounding conductor instead of any other means recognized by the NEC.

Photovoltaic Grounding Clips

There have recently appeared on the PV market at least two different listed “Grounding Clips” designed to create an electrical interface between grounded mounting racks and their associated photovoltaic modules. Another module manufacturer markets a racking assembly which also claims to have obtained a UL 467 listing using a single point on only one mounting rail for grounding. Although these products may have been evaluated to the 467 standard, which apparently involves a bench test for impedance and continuity, there is some question as to the long term efficacy of their grounding connections in an outdoor environment. There is also the issue of whether any of these products meet the requirements of NEC Section 690.43 because of the lack of their connection to a grounding conductor recognized by Section 250.118.

While it could be argued that a stainless steel grounding clip can make an adequate connection to an aluminum rail, and that the aluminum rail is essentially an extruded busbar with a unique shape; there are some other issues that should be considered before judging the adequacy of these products for their respective tasks.

In other electrical applications aluminum terminations are generally restricted in their use to dry locations only. To deal with the metal’s propensity for corrosion there are prohibitions against running aluminum grounding conductors across concrete or masonry, or within 18 inches of the earth unless other protective means are taken. Aluminum busbars, connectors, lugs, and splicing devices are usually plated with a coating of tin in order to provide a consistently conductive surface and to counteract the fact that aluminum oxidizes rapidly when exposed to air.

In contrast, aluminum mounting racks and photovoltaic module frames are generally covered by a non-conductive anodizing or clear-coating in order to inhibit corrosion in the outdoor environments in which the products will be used. If either the conductive or non-conductive coatings are breached, by whatever means, it is simply a matter of time before oxidation and/or corrosion ensue.

The coating itself presents another Code problem in that Section 250.12 requires that non-conductive coatings be removed from contact surfaces to ensure electrical grounding continuity. The section does stipulate that as an alternative the grounding connection can be made by means of devices which make such removal unnecessary. This methodology is used occasionally on certain electrical equipment used in various applications, but should be thoroughly evaluated before being used in damp or wet locations due to concerns over corrosion and long-term loss of grounding continuity. The use of devices which utilize piercing or puncturing features in order to breach non-conductive coatings in outdoor applications which are subject to prolonged dampness, water, galvanic influences, thermal cycling, and environmental pollution should be carefully considered, especially on aluminum surfaces.

An example of improper component selection and subsequent galvanic corrosion during nine months of outdoor service.

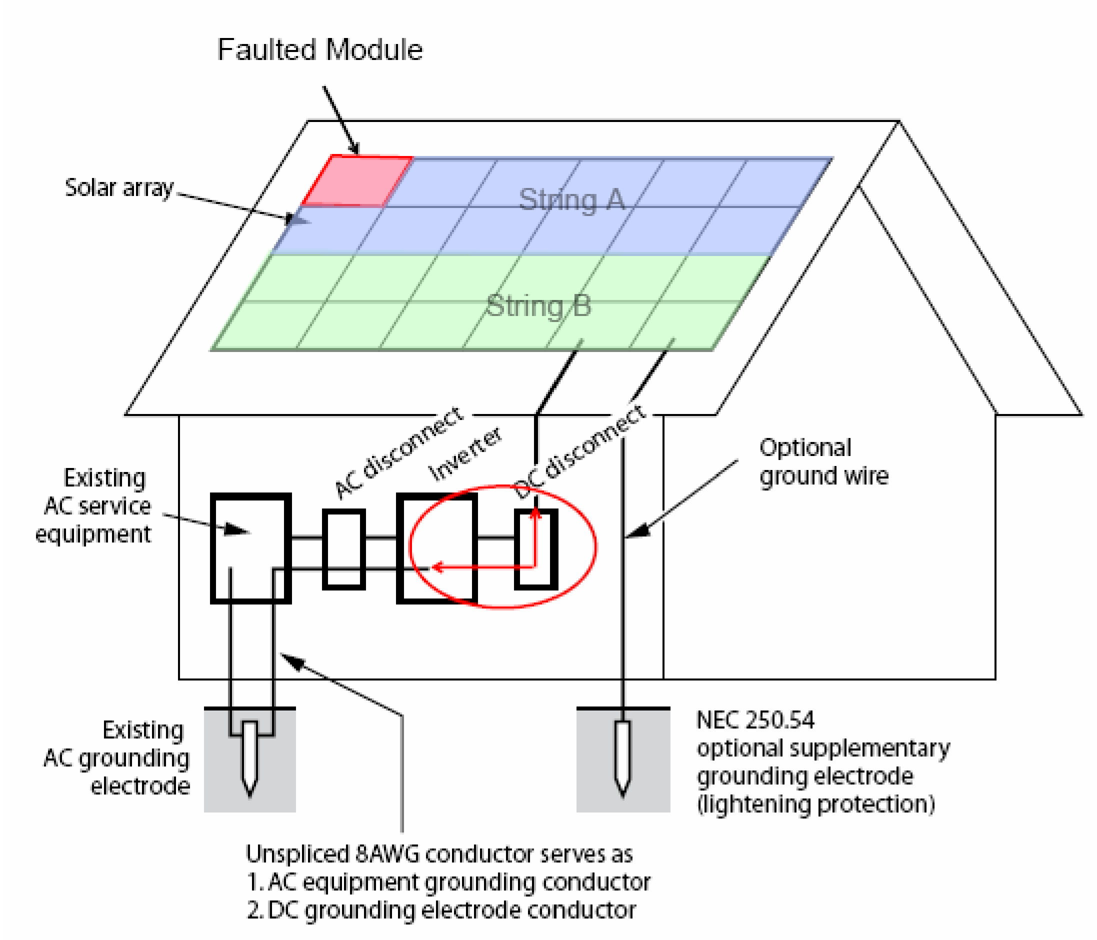
Electricians have been trained for years that the proper preparation of aluminum conductors is pivotal in establishing and maintaining viable electrical connections. Proper lugs rated for use with aluminum conductors and for the installation environment must be used. The surface of the conductors must be abraded in order to break the oxide layer on the aluminum immediately prior to termination. Anti-oxidation compounds must also be applied to exclude air from the connection in order to prevent the re-formation of the oxide layer. Should the insulation on an aluminum cable be breached, allowing moisture to enter and make contact with the aluminum, corrosion ensues and the aluminum is fairly quickly converted to aluminum oxide. This oxide expands, causing the outer jacket of the cable to bulge, and then causing failure of the cable at the point of corrosion.

In light of these facts it is reasonable to ask the rhetorical question of how likely it is that a grounding connection, which is made by the nibs on a stainless steel plate piercing a non-conductive outer coating on a piece aluminum will be able to maintain the integrity of the electrical connection given the harsh environmental conditions to which it may be subjected. There is also some question as to whether the UL 467 standard adequately addresses these issues in the evaluation of grounding products to be used in the situations in which photovoltaic modules are generally installed. It could be argued that the 467 grounding standard should not be applied to photovoltaic systems components at all, since they are not themselves intended to be grounding components for other electrical equipment.

“Is it really grounded?”

There is a long-standing practice in the electrical trade, reinforced several places in the NEC, which dictates that the equipment grounding conductor be the first conductor to be terminated on or make contact with an electrical device when connecting a circuit. The principal of “first-make, last-break” for the grounding conductor is nearly sacrosanct in the rest of the electrical world, but unfortunately the PV end of the industry hasn’t often seen fit to observe and reinforce this time-honored tradition. As a rule the established connection procedure for conductors is to first connect the grounding conductor, then the grounded circuit conductor, and finally the ungrounded circuit conductors. Through this technique an additional measure of safety is achieved in the event that some sort of electrical fault should occur between the ungrounded conductor and the device enclosure while electrical connections are being made and while the device is in use.

The use of module frame grounding systems which rely on the mounting hardware will undoubtedly alter this age-old practice in a negative way. To nature of this hazard can be seen fairly easily using a modified version of the grounding diagram from an installation manual supplied by a prominent photovoltaic module manufacturer.



In the diagram it can be seen that there are two Photovoltaic Source Circuits feeding the inverter. Note that the depiction of the grounding conductor routing between the grounding electrode and the array has been incorrectly shown by the manufacturer. This is an issue because of the widespread use of non-metallic raceways in the PV industry. Even if it were viable to use a single point ground on a PV array, the conductor needs to run all the way back to the grounding electrode, which in this case is common to both the AC and the DC systems. While the trained professional may pick up on this discrepancy, the history of the PV industry suggests that many “Unqualified Persons” (an NEC term) are performing these installations, thus reinforcing the need for accurate documentation.

In the installation manual for the mounting system the manufacturer claims that all of the modules can be grounded via the mounting rails and the associated hold-down hardware. There are a couple of problems with this approach. First of all, the mounting hardware relies upon galvanized metal components which will probably react with the aluminum frames of the modules and thus begin to corrode due to galvanic action. (The mounting system carries a ten-year warranty, much shorter than the warranty on the PV modules themselves.)

The second hardware issue is that the hold-down clips are secured with stainless steel 8mm bolts which are prone to galling, stripping, and cross-threading even when installed with nothing more aggressive than a nut driver. Because the pre-packaged system does not provide extra hardware there is virtually no possibility that damaged hardware will be replaced as the installation is made.

Let's imagine a scenario where the module at the upper left of the diagram has developed an intermittent wiring fault between the ungrounded string conductor and the module frame. Given the open circuit voltage of the 187 watt modules at 32.7 volts, the string voltage may very well be at 400 volts or more at the point where the ungrounded conductor is faulted. Wiring for photovoltaic modules is quite often concealed beneath the modules making it necessary to loosen the mounting hardware and lift the modules in order to investigate what is going on beneath them, and this is where the fun begins.

The NEC states in Section 690.18 that open circuiting, short circuiting, or opaque coverings can be used to disable an array. The reality is that opaque coverings are almost never used (for various reasons), which means that the person servicing the array must either open and/or short the array circuit in order to perform maintenance and repairs on the modules. However, to do that they must lift the module, and in this case to lift the module is to break the grounding circuit!

Even if the worker were to wear voltage rated gloves in order to do the investigation the fact is that at some point other portions of their body would probably come in contact with the now-energized module and the still-grounded mounting frame. At 400 volts and 8 (or more) amps of available current we can leave it to speculation as to whether some homeowner would now be hosting an impromptu barbeque in their backyard! This is a serious problem as many (if not most) photovoltaic arrays are capable of delivering several times the amount of current needed to cause a fatality.

Had the module been grounded (bonded) by means of an appropriate bonding jumper and a low impedance grounding connection, the worker would be able to lift the module and safely disconnect the wiring with a significantly reduced likelihood of receiving a fatal shock.

The Role of the Listing Agency

What is the role of those who list the products that will be used in photovoltaic installations? There seems to be some issues with inadequate evaluations of the installation instructions which are to accompany many listed products, photovoltaic and otherwise. While it appears that it has not been a standard practice to evaluate the installation manual, it makes sense for the listing agency to thoroughly scrutinize the recommended installation procedures in order to determine if the product at least has a chance of being installed in an electrically and mechanically safe manner. This is especially true with products that are unfamiliar to a majority of electrical installation professionals. This importance is echoed by the NEC in Section 110.3(B):

> "Installation and Use - Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling."

How is it then that so many products are put onto the market as being listed when their installation instructions contain blatant errors, omissions, or misinformation, and make recommendations which are contrary to the guidelines of the NEC? Do the listing agencies perform a re-evaluation of the installation instructions as manuals are changed and updated? The evidence would seem to suggest that there are some inadequacies in the process of evaluating the written material that is associated with certain listed products. This is unfortunate given the expectation in the electrical industry that an agency listing is as good as gold. Alas, it appears that the emperor has no clothes, or has at least taken up streaking in his spare time.

There also seems to be some problems with evaluating certain products to standards that do not appear to be applicable to the way in which the device will actually be used. While it may be viable to use a grounding clip to ground a piece of utilization equipment which can be readily de-energized by means of a switch or overcurrent protective device, photovoltaic arrays present a unique set of circumstances in that they cannot be easily de-energized. These products and their associated hardware should therefore be reviewed with more stringent safety goals in mind. It is one thing to do a bench evaluation of a product under ideal conditions in a controlled environment, but something quite different to consider the field application of the product and try to examine it in light of how it will actually be used.

The allowance of the installation of circuits of up to 600 volts in residential installations is unprecedented in the history of the NEC, and thus presents new challenges to establish and maintain safety for both the homeowner and the electricians who will be servicing these systems for many years to come. The listing, electrical, and photovoltaic entities would do well to err on the side caution in the interest of keeping these installations safe for the foreseeable future.

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