PV Array Grounding

John Wiles

Sponsored by the Photovoltaic Systems Assistance Center, Sandia National Laboratories

Nearly all electrical systems in the United States are solidly grounded to limit and stabilize the voltage to ground during normal operation, and to prevent excessive voltages due to lightning, line surges, or unintentional contact with higher voltage lines. The grounding requirements in the *NEC* have been developed through the school of hard knocks. For a detailed history on the arguments for and against grounding, see the International Association of Electrical Inspectors (IAEI) *Soares Book on Grounding*.

PV systems need to be grounded just like other electrical systems. PV arrays are usually mounted away from tall objects that could shade the array. In these exposed locations, PV arrays with metal module frames, metal mounting racks, and conductors connected to grounded electrical systems (for utility-interactive systems) are subject not only to induced electrical surges, but to possible direct lightning strikes.

With the increasing numbers of utility-interactive PV installations in urban environments, PV systems are being located in close proximity to high voltage transmission lines. In the event of high winds, earthquakes, or accidents, there is a remote possibility that high voltage lines may come into contact with PV arrays. In dry climates, high winds can build up high static electric voltages on large PV arrays. Utility-interactive PV systems are subject to the same line surges that affect other line-connected devices.

Necessary But Difficult

Grounding PV modules to reduce or eliminate shock and fire hazards is necessary, but can be difficult. Systems typically use copper conductors for electrical connections, and the module frames are generally aluminum. Copper and aluminum don't mix, as was discovered in numerous fires in houses wired with aluminum wiring in the 1970s.

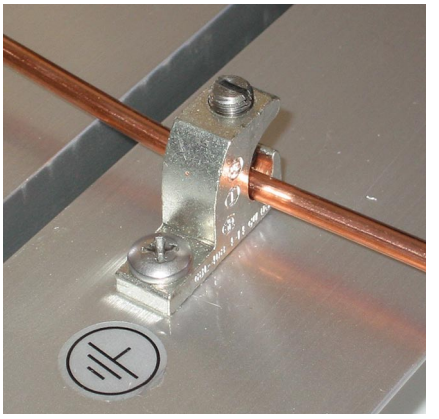
Most PV modules have a mill finish, some are clear coated, and some are anodized for color. Mill finish aluminum and any aluminum surface that is scratched oxidize quickly. This oxidation and any clear coat or anodizing form an insulating surface that makes it difficult to achieve long lasting, low-resistance electrical connections (such as frame grounding). The oxidation/anodizing is not enough of an insulator to prevent electrical shocks, but it is enough to make good electrical connections difficult.

Underwriters Laboratories (UL), which tests and lists all PV modules sold in the U.S., requires very strong mechanical connections between the various pieces of the module frame to ensure that these frame pieces remain mechanically and electrically connected over the life of the module. These low-resistance connections are required because a failure of the insulating materials in the module could allow the frame to become energized at up to 600 volts (depending on the system design). The *National Electrical Code (NEC)* requires that any exposed metal surface be grounded if it could be energized.

Code Requirement

The installer of a PV system is required to ground each module frame. The *NEC* and UL Standard 1703 require that the module frame be grounded at the point where a designated grounding provision has been made. The connection must be made with the hardware provided and using the instructions supplied by the module manufacturer.

The designated point marked on the module must be used, since this is the only point tested and evaluated by UL for use as a long-term grounding point. UL has established that using other points, such as the module structural mounting holes, coupled with typical field installation techniques do not result in low-resistance, durable connections to aluminum module frames for the long term. If each and every possible combination of nut, bolt, lock washer, and star washer could be evaluated for electrical properties and installation torque requirements *and* the installers would all use these components and install them according to the torque requirements, it might be possible to use the structural mounting holes for grounding.



An Ilsco GBL-4DBT lug is attached to the module frame with a 10-32, thread-forming, stainless steel screw.

Most U.S. PV module manufacturers are providing acceptable grounding hardware and instructions. Japanese module manufactures are frequently providing less-than-adequate hardware and unclear instructions. Future revisions of UL 1703 should address these issues. BP Solar is to be congratulated for getting their module listing to include making new grounding points at other locations than the marked points.

Grounding Hardware Option

In the meantime, installers have to struggle with the existing hardware and instructions, even when they are poor. The Southwest Technology Development Institute has identified suitable grounding hardware, and provides that information when installers ask about grounding—a frequent topic. For modules that have been supplied with inadequate or unusable hardware or no hardware at all, here is a way to meet the intent of the *NEC* and UL Standard 1703.

When mechanical protection is necessary or the magnitude of the short-circuit current requires it, conductors larger than #10 (5 mm^2) may be required. A 10-32, thread-forming, stainless steel screw can be used to attach an Ilsco GBL-4DBT lug to the module frame at or adjacent to the point marked for grounding. A #19 drill bit is required to make the proper size hole for the 10-32 screw. The 10-32 screw is required so that at least two threads are cut into the aluminum (a general UL requirement for connections of this kind). The thread-forming screw is required so that an airtight, oxygen-free mating is assured between the screw and the frame to prevent the aluminum from reoxidizing.

It is not acceptable to use the hex-head green grounding screws (even when they have 10-32 threads) because they are not listed for outdoor exposure and will corrode eventually. The same can be said for other screws, lugs, and terminals that have not been listed for outdoor applications. Hex-head stainless steel "tech" screws and sheet metal screws do not have sufficiently fine threads to make the necessary low-resistance, mechanically durable connection. The only thread-forming, 10-32 stainless steel screws that have been identified so far have Phillips heads.

The Ilsco GBL-4DBT is a lay-in lug (see photo at left) made of solid copper, which is then tin-plated. It has a stainless steel screw to hold the wire. The lug accepts a #14 (2 mm^2) to #4 (21 mm^2) copper conductor. It is listed for direct burial (DB) and outdoor use and can be attached to aluminum structures (the tin plate). The much cheaper Ilsco GBL-4 lug looks identical, but is tin-plated aluminum, has a plated screw, and is not listed for outdoor use. I have not been able to identify an alternative to the GBL-4DBT, but continue to search.

If the module grounding is to be done with a #14 through #10 conductor, the Ilsco lug is not needed. In that case, two, number 10, stainless steel, flat washers can be used on the 10-32 screw, and the copper wire can be wrapped around the screw between the two flat washers that isolate the copper conductor from the aluminum module frame.

Yes, we would all like to use the module mounting structure for grounding. The *NEC* allows metal structures to be used for grounding and even allows the paint or other covering to be scraped away to ensure a good electrical contact. We see numerous types of electrical equipment grounded with sheet metal screws and star washers. This works on common metals like steel, but not on aluminum, due to the oxidation.

The right parts used improperly—copper wire in contact with an aluminum module frame is a recipe for corrosion.

Unfortunately, many PV systems are being grounded improperly, even when the proper hardware has been supplied. The photo above shows that even the proper hardware can be misused. Here, the stainless steel isolation washer has been installed in the wrong sequence, and the copper grounding wire is being pushed against the aluminum frame, a condition sure to cause corrosion and loss of electrical contact in the future.

Access

John C. Wiles, Southwest Technology Development Institute (SWTDI), New Mexico State University, Box 30,001/MSC 3 SOLAR, Las Cruces, NM 88003 • 505-646-6105 • Fax: 505-646-3841 • jwiles@nmsu.edu • www.nmsu.edu/~tdi

Sponsor: Sandia National Laboratories, Ward Bower, Department 6218, MS 0753, Albuquerque, NM 87185 • 505-844-5206 • Fax: 505-844-6541 • wibower@sandia.gov • www.sandia.gov/pv

IAEI *Soares Book on Grounding*, 8th Edition, paper, 384 pages, 1-890659-27-4, US$44.25 from International Association of Electrical Inspectors, 901 Waterfall Way Suite 602, Richardson, TX 75080 • 972-235-1455 • Fax: 972-235-6858 •customerservice@iaei.org • www.iaei.org

Ilsco Corporation, 4730 Madison Rd., Cincinnati, OH 45227 • 800-776-9775 or 513-533-6200 • Fax: 513-533-6274 • sales@ilsco.com • www.ilsco.com • Grounding lugs

The 2002 *NEC* and the *NEC Handbook* are available from the National Fire Protection Association (NFPA), 11 Tracy Dr., Avon, MA 02322 • 800-344-3555 or 508-895-8300 • Fax: 800-593-6372 or 508-895-8301 • custserv@nfpa.org • www.nfpa.org