Photovoltaic System Grounding

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INTRODUCTION

Proper grounding of a photovoltaic (PV) power system is critical to ensuring the safety of the public during the installation's decades-long life. Although all components of a PV system may not be fully functional for this period of time, the basic PV module can produce potentially dangerous currents and voltages for the life of the system. Effective, code-compliant, properly maintained grounding helps ensure the overall safety of the system, even if it is no longer producing usable power.

More than a century ago, the United States and most of the Americas elected to use grounded electrical systems, in which one of the circuit conductors is connected to the earth. The rest of the world (ROW) for the most part chose to employ ungrounded electrical systems, in which none of the circuit conductors are connected to earth. The normally non-energized metal surfaces of electrical equipment are, however, required to be connected to earth in the ROW.

This course addresses the requirements for PV system grounding contained in the U.S. *National Electrical Code*® (*NEC*®) published by the National Fire Protection Association (NFPA). The *NEC* and the *NEC Handbook* are copyrighted by NFPA and the term NFPA-70 is a trademark owned by the NFPA (NFPA, 2011). It does not address in any detail the various American or European standards that are used to design and produce electrical equipment, nor does it cover the many electrical codes used in other countries.

The *NEC* requires that the authority having jurisdiction (AHJ or electrical inspector) examine all electrical equipment for safety. Electrical equipment has generally been standardized from an input/output interconnectivity perspective through the Nationally Recognized Testing Laboratory (NRTL) evaluation, certification, and listing process. The NRTL certification ensures the equipment meets all applicable safety standards. Underwriters Laboratories (UL) coordinates the development of many of the safety standards that apply to PV systems (e.g., UL 1703; UL 1741). The U.S. Occupational Safety and Health Administration (OSHA) authorizes NRTLs to test and certify/list electrical equipment to various standards. The American National Standards Institute (ANSI) authorizes the development of standards by UL and others. Although the *NEC* does not specifically require all equipment to be certified/listed, many local jurisdictions and many AHJs establish requirements that all equipment be certified/listed because they feel unqualified to examine uncertified/unlisted equipment for safety as the *NEC* requires.

DEFINITIONS

Before discussing the subject of grounding, the term "grounding" requires definition. There are two types of grounding in electrical and PV systems—equipment grounding and system grounding.

Equipment Grounding

Equipment grounding is known in the ROW as safety grounding or protective earthing. The equipment grounding system in the United States effectively bonds (electrically connects) all exposed non-current carrying metal parts of the electrical system together and eventually connects these metal parts to the earth (ground).

Metal enclosures containing electrical conductors or other electrical components may become energized as a result of insulation or mechanical failures. Energized metal surfaces, including the metal frames of PV modules, can present electrical shock and fire hazards.

By properly bonding exposed metal surfaces together and to the earth, the potential difference between earth and the conductive surface during a fault condition is reduced to near zero, reducing electric shock potential. The proper bonding to earth by the equipment grounding system is essential, because most of the environment (including most conductive surfaces and the earth itself) is at earth potential. The conductors used to bond the various exposed metal surfaces together are known as equipment grounding conductors (EGCs).

In a conventional electrical power system (utility, generator, or battery sourced), the equipment grounding system provides a path for ground-fault currents to return to the energy source. By allowing these currents to return to the source in an expeditious manner, properly positioned overcurrent protective devices (OCPDs, typically fuses or circuit breakers) are allowed to function, removing the source of the fault currents. The National Electrical Code Requirements part of this course describes equipment grounding procedures used in the United States.

System Grounding

In system grounding, one of the circuits (current-carrying) conductors is bonded (connected) to the equipment grounding system and also to earth. This is known as *functional grounding* in the ROW. The circuit conductor that has been connected to the equipment grounding system and to earth is known as the *grounded conductor*. The connection between the grounded conductor and the equipment grounding system is known as the system bonding jumper in the *NEC*. Only one system bonding jumper is allowed in each separate electrical system in which the system grounded conductor is isolated from the grounded conductors of the source or other systems. See *NEC* Article 100 for definitions of bonding, bonding jumpers, and system bonding jumpers. Section 250.28 expands on the proper installation of system and main bonding jumpers.
The system ground connection, made by a system bonding jumper, is the path that allows fault currents to return to the source. If the equipment grounding system and the system bonding jumper have sufficiently low impedance (i.e., proper conductor size and good connections), currents that originate from an ungrounded conductor faulting to a grounded surface or the equipment grounding system will be sufficient to trip the OCPD supplying that circuit. PV systems, as noted below, may not perform the same under fault conditions as other types of electrical systems.

Earth Connection

The metallic device used to make contact with the earth is the *grounding electrode*. The conductor that connects the central grounding point (where the equipment grounding system is connected to the grounded circuit conductor on grounded systems) and a grounding electrode that is in contact with the earth is known as the *grounding electrode conductor* (GEC).

Solidly Grounded

The *NEC*, in Article 100, defines *solidly grounded* as being connected to ground without inserting any resistor or impedance device in the circuit. This definition does allow for the use of fuses, circuit breakers, and mechanical relay contacts in certain grounding circuits, but typically precludes the use of solid-state devices such as transistors, silicon-controlled rectifiers, and bi-junction field effect transistors. This is because these devices would likely be considered impedance devices. Although language in *NEC* 690.41 allows equivalent grounding methods in listed equipment, no listing agencies certify products in a configuration other than solidly grounded.

NATIONAL ELECTRICAL CODE REQUIREMENTS

Article 250 in the *NEC* covers most of the grounding requirements for any electrical system. This article is more than 30 pages long, and it is not possible to elaborate on or restate all of these requirements here. Article 690 has other requirements for grounding PV systems, and many parts of the *NEC* are revised every three years, including Articles 250 and 690. To further complicate matters, different editions of the *NEC* are in use in different jurisdictions, from the most recent edition (2011) back to the 2002 *NEC* and earlier versions.

For the entire text of the *NEC* and additional explanatory material provided by NFPA, go to the *NEC* Handbook (NFPA, 2011). The Soares book on grounding published by the International Association of Electrical Inspectors (IAEI, 2011) is also an excellent resource on *NEC* requirements for grounding. For an individual installation, refer to the *NEC* edition in use in that jurisdiction to establish specific project requirements. This course will highlight a few of the *NEC* requirements for both equipment and system grounding that apply to PV systems and that are sometimes overlooked in PV installations. Unless specifically mentioned, all references to the *NEC* in this course will be to the 2011 edition.

Good Workmanship Is an *NEC* Requirement

In Section 110.12, the *NEC* states that good workmanship is required on all electrical installations. The phrase "in a neat and workmanlike manner" is not defined in the *NEC*, but has been addressed in other material such as the National Electrical Contractors Association Standard 1. The electrical trades teach good workmanship through on-the-job-training and in more formal courses taught in International Brotherhood of Electrical Workers schools. The workmanship associated with the installation of PV systems is coming under increased scrutiny by inspectors throughout the country.

Unfortunately, this scrutiny has found some less than quality PV installations. Fires have originated because metal conduits have not been installed properly and conductors have not been installed properly in the conduits. Conductors have had insulation damaged during installation, and in instances when proper grounding methods or hardware was not used, ground faults have occurred that led to fires. When the electrical system is not installed properly and is not in compliance with *NEC* requirements, the safety of the system becomes questionable, either at the time of the installation or at some future date as the system ages and deteriorates.

Equipment Grounding

Section 690.43 of the *NEC* requires that PV systems have equipment grounding systems when there are any exposed metal or conductive surfaces that may become energized. This requirement applies to PV systems operating at any voltage, including small standalone 12-volt PV systems and even a 6-volt, PV-powered water pump on a solar hot water system. The exposed metal surfaces include PV module frames, metal mounting racks, metal conduits, and enclosures for combiners, disconnects, inverters, and charge controllers as well as other electrically conductive parts. Exposed conductors with failing insulation as a result of a 40- or 50-year-old less-than-optimal installation could even energize a metal roof under a PV array.

The emergence of PV modules with nonmetallic frames may simplify the grounding of PV modules. The 690.43 requirement is a reiteration of the basic requirement for equipment grounding found in Article 250, Part VI. For a complete assessment of the state of module grounding according to the *NEC* and various UL Standards requirements, see the Solar ABCs report *Photovoltaic Module Grounding* (Ball, Zgonena, & Flueckiger, 2012).

Purchase this course to see the remainder of the technical materials.