Safety Inspection Guidelines for Photovoltaic Residences
A Subcontract Report

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FOREWORD

This report was prepared by the Lincoln Laboratory of the Massachusetts Institute of Technology for the Solar Energy Research Institute (SERI) under Subcontract No. XX-1-1327-1. It is based on their research and development work for the Initial Systems Evaluation Experiments, which involved the installation of photovoltaic systems on unfenced, occupied residences in several locations in the United States.

The purpose of this report is to provide tentative engineering guidelines and instructions for electrical inspectors to use in assessing the safe application and use of photovoltaics in residences. These guidelines are meant to provide a basis for inspection until the National Electrical Code incorporates an article that addresses photovoltaic residential power systems. A proposed article is before the National Electric Code for consideration and inclusion in the 1984 code.

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SUMMARY

Objective

The guidelines presented in this report are for the use of electrical and building inspectors for the examination and code approval of residential photovoltaic (PV) installations.

The intent of the guidelines is to ensure that electrical inspectors, having responsibility in their municipalities for the safe installation of residential electrical equipment, have pertinent and accurate documentation available for them to implement, satisfactorily, inspection techniques and procedures for the safe and effective installation of residential PV systems that might come within their jurisdiction.

Discussion

This document is designed to be analogous to and complementary of the work being undertaken by the ad hoc subcommittee of the National Fire Prevention Association (NFPA), which is proposing a new article on PV systems for the 1984 edition of the National Electric Code (NEC).

The guidelines contained herein are not meant to replace the proposed article to be incorporated in the 1984 National Electrical Code. Close and continuous liaison with the NFPA ad hoc subcommittee was maintained to ensure compatibility with their article.

The guidelines address all relevant engineering and safety considerations for PV residential experiments. These considerations include definitions, source electrical characteristics, grounding, isolation, lightning protection, overcurrent protection, disconnect means, wiring methods, and structural guidelines. Appendices include suggested forms for system component identification and a discussion of equivalent system grounding protection.
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SECTION 1.0
INTRODUCTION

1.1 BACKGROUND

During the next several years, it is expected that a number of private residences will be built and equipped with solar photovoltaic (PV) power generating systems as means to provide electricity. These systems generally will comprise roof-mounted nontracking, flat-plate PV modules, intermodule wiring, power conditioning equipment, and other system components that may introduce several potential safety hazards to the homeowner and the residence. At this time, there are no formal guidelines by which a qualified individual can assess these systems prior to, during, or after installation to ensure that proper precautions have been taken to mitigate any potential safety hazards.

The 1981 National Electrical Code (NEC) has information covering some of the electrical safety aspects of a PV system which are similar to other electrical power generation systems, but there will not be a unified section on PV systems at least until the 1984 National Electrical Code is introduced in September 1983. Local, regional, and national building codes also contain some information regarding safe installation practices for roof-mounted structures, but there is no formal code which deals strictly with solar PV installations. This document will provide a set of interim inspection guidelines which can be used to assess the safety of a PV system until more formal documentation is available from code generating groups. All guidelines introduced here will comply with existing codes and safe practices wherever possible, and exceptions will be noted. Final judgment as to compliance rests with the local inspector, since these guidelines are only recommended practices with no legal bearing.

This document is based on information developed in connection with proposals for the 1984 National Electrical Code on PV systems and other known building code guidelines for roof-mounted solar collectors, as well as MIT Lincoln Laboratory experience in designing, developing, fabricating, and operating PV residences as part of the U.S. Department of Energy's Photovoltaic Program. Whenever possible, standard terminology as developed by the Solar Energy Research Institute (SERI) in its Performance Criteria for Photovoltaic Energy Systems,* and the NEC/PV ad hoc advisory group, in its proposed "Article 690-Solar Photovoltaic Systems,"** will be used.

This document is intended for use by electrical inspectors and other qualified personnel as a source of safety guidelines for use with the PV system prior to, during, and after installation.

Electrical safety guidelines are presented in Sec. 2.0; other safety guidelines which may be of use to a building inspector and which deal with structural and fire hazards are contained in Sec. 3.0. Safety inspection of the residence itself, not including the PV system, its components and attachments, is beyond the scope of these guidelines.

*SERI/TR-214-1567 (August 1982).
1.2 GENERAL

The basic residential PV system utilizes a roof-mounted PV array that generates direct current (dc) electrical power. Normally, all residential wiring and loads are designed for operation with alternating current (ac) and hence a power inverter is utilized to convert the array dc output to ac.

PV array output power varies with the availability of sunlight, so a means is needed to augment the power of the array when sunlight is not available. Presently, and in the near future, most residential systems will draw auxiliary power from the utility when the PV system cannot meet the residential load demand.

At times when the array produces more power than needed to meet load demands of the residence, the tie to the utility will offer an opportunity to feed the excess power back into the utility grid. The generic residential system considered in this document will consist, then, of two principal components: a PV array and a dc-to-ac power inverter (power conditioning unit, PCU) that produces utility-compatible ac power.

Intentional means of radiation enhancement, such as reflecting surfaces, should not be installed because the modules may overheat and may increase the output of the array beyond the capability of other system components.

An elementary schematic of the basic system is shown in Fig. 1 and a more detailed schematic of the array to power conditioner circuitry is shown in Fig. 2.

1.3 DEFINITIONS

This section provides a list of definitions relating to the basic components of a PV system.
**Array** - A mechanically integrated assembly of modules or panels with a support structure and foundation and other components, as required, to form a direct-current, power-producing unit.

**Blocking diode** - A diode used to block reverse flow of current into a PV source circuit.

**Interactive system** - A solar PV system that operates in parallel with and may be designed to deliver power to another electric power production/distribution system connected to the same load.

**Module** - The smallest complete, environmentally protected assembly of solar cells, optics, and other components designed to generate dc power under diffuse and direct sunlight.

**Panel** - A collection of modules mechanically fastened together, wired, and designed to provide a field-installable unit.

**PV output circuit** - Circuit conductors between the PV source circuits(s) and the power conditioning unit or dc utilization equipment (see Fig. 2).

**PV power source** - An array or aggregate of arrays which generate dc power at system voltage and current.

**PV source circuit** - Conductors between modules and from modules to the common connection point(s) of the dc system (see Fig. 2).

**Power conditioning unit** - Equipment which is used to make the dc power from the PV array compatible with the intended loads. Commonly, a power conditioning unit is an inverter which changes a dc input to an ac output (see Fig. 2).
Power conditioning unit output circuit - Conductors between the power conditioning unit and the connection to the service equipment or other electrical power production source such as a utility (see Fig. 2).

Solar cell - The basic PV device that generates electricity when exposed to light.

Solar PV system - The total components and subsystems that in combination convert solar energy into electrical energy suitable for connection to a load.

Stand-alone system - A solar PV system that supplies power independently, but which may receive control power from another electric power-production source. (This type of system is not addressed by this document.)

1.4 MANDATORY REQUIREMENTS

In a published code, such as the National Electrical Code, mandatory requirements include verbs such as "shall" and "shall not." The word "should" is generally associated with recommended but not enforceable items.

In the case of this document, in which there are no mandatory requirements but only recommended practices, the words "should" and "should not" are used throughout. Their use is in no way meant to be the same as "shall" and "shall not."

1.5 PHOTOVOLTAIC SOURCE CHARACTERISTICS

The electrical characteristics of a typical photovoltaic source circuit are shown on an I-V curve, Fig. 3. As can be seen on this plot of current versus voltage, there are two major
influences on the characteristic source circuit output: sunlight intensity and the operating temperature of the solar cells. Basically, the greater the sunlight intensity and the lower the cell operating temperature, the higher the electrical power output of a source circuit. For any given set of temperature and sunlight intensity conditions, there exists a unique operating voltage that will maximize the power output of the circuit.

This is called the maximum power point and will change as often as the cell temperature or sunlight intensity on the array changes. Interconnection of modules into a source circuit thus results in a maximum power operating voltage and current which will vary with operating temperatures and sunlight levels.

Diodes may be used in photovoltaic systems in two ways. First, bypass diodes can be placed around each module in a series string to provide a current path in the event of a module open-circuit failure. Second, blocking diodes can be placed at the terminations of a series circuit of modules to prevent solar cell overheating due to the backflow of current from other, slightly higher potential, series circuits of modules. The PV array output is inherently current limited by the intensity of the sunlight available. The nominal peak solar intensity is 1,000 W/m²; however, values as high as 1,470 W/m²* have been measured under conditions of "natural" concentration due to reflections from clouds and snow.

*Reading obtained 6 March 1981 at Natural Bridges National Monument, Utah.
SECTION 2.0

ELECTRICAL INSTALLATION GUIDELINES

2.1 BACKGROUND

When electrical inspectors attempt to determine whether certain aspects of a PV system are in compliance with the present NEC or local codes, they will find either incomplete information or information unrelated to the PV systems. It is the purpose of these guidelines to provide sufficient information on PV systems to enable the inspector to determine whether effective safety, equivalent to the objectives of the NEC, has been established and maintained.

The second paragraph of Section 90-4 of the 1981 NEC states:

The authority having jurisdiction may waive specific requirements in this code or permit alternative methods where it is assured that equivalent objectives can be achieved by establishing and maintaining effective safety.

Section 90-4 also has a provision

to allow the authority having jurisdiction the option of making an individual judgment to permit alternative methods where specific rules are not established in the code.

It is the belief of the authors that this section of the present NEC provides the inspector with sufficient latitude to use the present version of the NEC to judge the safety of residential PV systems before the establishment of formal codes. The guidelines in this document should provide the electrical inspector with sufficient explanatory information as well as recommended practices to facilitate his judgment of compliance with established rules.

In order to perform an assessment of the electrical safety of a residential PV system, it will be necessary to identify the components in the system together with their rated performances. The checklist provided in Appendix 1 will serve as a guide to assist in performing this identification process.

2.2 GENERAL

As shown in Fig. 2, the principal equipment to be installed in a PV-powered residence include a PV array, a power conditioning unit (PCU), interconnecting cabling (within the array, between the array and the PCU, and between the PCU and the utility), overcurrent and overvoltage protection devices, circuit interrupting devices, and grounding connections.

A visual inspection of the array and power conditioning units should be made to determine the kinds of modules and power conditioning units present and whether they are listed by an agency. This listing may apply to the modules, panels, or the entire array and associated conductors or cables, as well as the power conditioning units. Assistance in determining approval for the system may be obtained from the manufacturer or
installer, who may have information on whether the modules have undergone and passed tests to assess their safety in a residential application. Module marking, as well as the rating sheet for the array, should be noted. Appendix 1 provides a convenient checklist to record performance ratings of various components of the array.

Some general guidelines to follow and tasks to perform in inspecting a utility-interactive PV residence follow.

1. A photovoltaic system should be permitted to supply a building or other structure in addition to any service(s) of another electricity supply system(s).

In Section 230-2 of the current National Electric Code, only one service is permitted in a building with the listed exceptions not including PV systems, which were not available at the time the section was written. Section 90-4 should be interpreted to cover installation of another source of supply to a residential building, presently not permitted by Section 230-2 (except for special cases).

2. Photovoltaic source circuits and output circuits should not be contained in the same raceway, cable tray, cable, outlet box, junction box or similar fitting as feeders or branch circuits of other systems, except where the conductors of the different systems are separated by a partition or are connected together.

This statement is based on concern that a fault between the two circuits may impress, for example, direct-current on alternating-current appliances with an associated risk of fire or shock. The alternating-current branch-circuit overcurrent device would not interrupt the direct-current, and the direct-current photovoltaic circuit may not have an overcurrent device. It is recognized that NEC Section 300-3(a) permits conductors in the same raceway without regard to whether the individual circuits are alternating-current or direct-current. In view of the special condition where photovoltaic source circuits are considered protected without an overcurrent device (under certain circumstances), the principle of separation between circuits with and without overcurrent devices (as for example in Section 230-47) is considered valid.

3. Modules should be marked with identification of terminals or leads as to polarity, maximum overcurrent device rating for module protection and with rated (1) open-circuit voltage, (2) operating voltage, (3) maximum permissible system voltage, (4) operating current, (5) short-circuit current, and (6) maximum power.

The marking information is used to judge whether the system components are compatible. Modules which have not been listed may not be marked with complete information, but the manufacturer's specifications may provide it.

4. A marking, specifying the photovoltaic power source rated (1) operating current, (2) operating voltage, (3) open-circuit voltage, and (4) short-circuit current should be provided at an accessible location at the disconnecting means for the photovoltaic power source.
The ratings are calculated by adding the module or panel electrical rating—adding voltage for series connections and adding current for parallel connections.

This information is required to ascertain the suitability of the power conditioning unit and the other system components. This marking should be provided by the system installer.

2.3 SYSTEM CIRCUIT REQUIREMENTS

After completing the identification of the Module, PV Source Circuit, and PV output circuit sections of Appendix I, the inspector now considers the details of the circuitry in order to assess its safety. Maximum voltage criteria are presented below.

1. **Voltage rating** - In a photovoltaic power source and its direct-current circuits, the voltage to be considered should be the rated open-circuit voltage. (This rating is established under standardized conditions of irradiance and temperature.)

2. **Direct-Current Utilization Circuits** - The voltage of direct-current utilization circuits should conform with Section 210-6 of the NEC.

3. **Photovoltaic Source and Output Circuits** - Photovoltaic source circuits and photovoltaic output circuits which do not include lampholders, fixtures, or standard receptacles should be permitted up to 600 volts.

4. **Guarding of Live Parts** - The requirements of the NEC Section 110-17 should be applied in determining adequacy of guarding of live parts.

After determining the maximum voltage requirements, the electrical inspector should assess the circuit sizing requirements by computing the current of the appropriate circuit.

5. **Ampacity and Overcurrent Devices** - The ampacity of the conductors and the rating or setting of the overcurrent devices in a circuit of a photovoltaic system should not be less than 125%* of the current computed as described below (except for circuits containing an assembly together with an overcurrent device(s) that is listed for continuous operation at 100% of its rating). The rating or setting of overcurrent devices should be permitted in accordance with Section 240-3.

6. **Computation of Circuit Current** - The current for the PV output circuits is the sum of parallel module operating current ratings; the current for the PV output circuits is the PV power source operating current rating. An exception is for the current rating of a circuit without an overcurrent device (which is permitted in certain cases); the current rating in this case is the short-circuit current, and it shall not exceed the ampacity of the circuit conductors.

*As presently written the proposed NEC PV article contains this constraint. As indicated in the last sentence on Page 7, values as high as 147% have been achieved. It is felt that a design value of 150% would probably be the safest one to use.
7. Circuits and Equipment - Photovoltaic source circuit, photovoltaic output circuit and power conditioning unit output circuit, conductors and equipment should be protected in accordance with the requirements of Article 240. Circuits connected to more than one electrical source should have overcurrent devices located to provide overcurrent protection from all sources.

Two exceptions to this guideline are as follows:

A conductor in a photovoltaic source circuit, photovoltaic output circuit, or power conditioning unit output circuit having an ampacity not less than the maximum available current under short-circuit or ground-fault conditions with the condition of a shorted blocking diode should be permitted without an overcurrent device.

Furthermore, possible backfeed of current from any source of supply, including a supply through a power conditioning unit into the photovoltaic output circuit and photovoltaic source circuits, must be considered to determine whether adequate overcurrent protection from all sources is provided for conductors and modules. The overcurrent devices for these circuits can be omitted in some cases because overloading may not be possible due to the current limitation of a PV source.

A power transformer with a current rating on the side connected toward the photovoltaic power source not less than the short circuit output current rating of the power conditioning unit should be permitted without overcurrent protection from that source.

8. Photovoltaic Source Circuits - Branch-circuit or supplementary-type overcurrent devices should be permitted to provide overcurrent protection in photovoltaic source circuits. The overcurrent devices should be accessible, but they need not be readily accessible.

2.4 DISCONNECTING MEANS

The use and location of disconnecting means in a photovoltaic system play an extremely important role in judging the safety of the system because the system may contain more than one source. Some rules and guidelines are as follows:

1. All Conductors - Means should be provided to disconnect all current-carrying conductors of a photovoltaic power source from all other conductors in a building or other structure.

2. Additional Provisions - The provisions of Article 230, Part H of the 1981 NEC should apply to the photovoltaic power source disconnecting means. Two exceptions are: (1) Due to the limited nature of the PV power source and special grounding considerations, a minimum rating and certain equipment features for disconnecting means are not needed; the disconnecting means should not be required to be suitable as service equipment (device rated disconnect equipment is not needed in PV circuits because there are no high fault currents). Further the disconnecting means should be rated in accordance with the load to be carried. (2) Equipment such as photovoltaic source circuit isolating switches, overcurrent devices and blocking diodes should be permitted on the source side of the PV power source disconnecting means.
3. Disconnection of Photovoltaic Equipment - Means should be provided to disconnect equipment, such as a power conditioning unit, filter assembly and the like, from all ungrounded conductors of all sources. If the equipment is energized (live) from more than one source, the disconnecting means for all sources should be physically located together and identified.

4. Fuses - Disconnecting means should be provided to disconnect a fuse from all sources of supply if the fuse is energized from both directions and is accessible to other than qualified persons. Such a fuse in a photovoltaic source circuit should be capable of being disconnected independently of fuses in other photovoltaic source circuits. (Note: It would be useful if fuse holders were marked with fuse ratings.)

5. Switch or Circuit Breaker(s) - A disconnecting means located on the direct-current side shall be permitted to have an interrupting rating less than the current-carrying rating when the system is designed so that the direct-current switch cannot be opened under load.

The disconnecting means for ungrounded conductors should consist of a manually operable switch(es) or circuit breaker (1) located where readily accessible, (2) externally operable without exposing the operator to contact with live parts, (3) plainly indicating whether in the open or closed position, and (4) having ratings not less than the load to be carried. Where disconnect equipment may be energized from both sides, the disconnect equipment should be provided with a marking to indicate that all contacts of the disconnect equipment may be live.

6. Disablement of an Array - Means should be provided to disable an array or portions of an array.

The method of disablement should be one or more of the following:

a. The safest way to deenergize a PV module or source circuit is to cover it with an opaque material which acts as a shield against sunlight.

b. Most maintenance activities involve working with live, uncovered, circuits in the array field. These activities should be performed with the array circuitry shorted and electrically floating from ground.

c. Most array diagnostic measurements should be performed with the array or array portion in an open-circuit mode, either tied to ground or floating from ground.

2.5 WIRING METHODS

The permissible wiring methods used in a PV residence are described below. The checklist provided in Appendix 1 is a useful source to determine which wiring materials and methods have been used. Suitable guidelines to follow are presented below.

1. Wiring System - All raceway and cable wiring methods included in this Code and other wiring systems and fittings specifically intended and identified for use on photovoltaic arrays should be permitted. Where wiring devices with integral enclosures are used, sufficient length of cable should be provided to facilitate replacement.
2. **Routing of Conductors** - In PV source circuits, all conductors of a circuit do not necessarily have to be routed together because the effect of increased impedance of the dc circuit due to separate routing is negligible because of the low fault current capability.

3. **Component Interconnections** - Wiring fittings and connectors, which are intended to be concealed at the time of assembly into PV roof-mounted wiring harnesses, should permit the easy replacement of modules and other components. Such fittings and connectors should be equal to the wiring method employed in insulation, temperature rise and fault-current withstand, and should be capable of resisting the effects of the environment in which they are used.

   Note: Should any electrical components be oversized for whatever the reason, it should not be required that other components be oversized.

4. **Connectors** - The connectors permitted above should comply with (a) through (e) below:
   
   (a) The connector should be polarized and should have a configuration that is non-interchangeable with receptacles in other electrical systems on the premises.
   
   (b) The connectors should be constructed and installed to guard against inadvertent contact with live parts by persons.
   
   (c) The connectors should be latched or locked with nonexposed live parts.
   
   (d) The grounding member should be the first to make and the last to break contact with the mating connectors.
   
   (e) The connectors should be capable of interrupting the circuit current without hazard to the operator.

5. **Access to Boxes** - Wiring contained in junction, pull and outlet boxes located behind modules or panels could be considered to be accessible if access can be gained by displacement of one or more modules or panels secured by removable fasteners and connected by a flexible wiring system.

2.6 **GROUNDING**

The issue of grounding of a PV source circuit or the PV output circuit is related to the type of inverter chosen. There are, however, noncircuit related parts of the system which should be grounded. System grounding guidelines will be provided in the PCU section, and frame and equipment grounding rules are presented here.

1. **Common Grounding Electrodes** - Exposed noncurrent-carrying metal parts of equipment and conductor enclosures of a photovoltaic system should be grounded to a common grounding electrode. It may be that this grounding electrode is also used to ground the direct-current system. Two or more electrodes that are effectively bonded together should be considered as a single electrode in this sense.
The following rule should be adhered to for all systems:

2. The connections to a module or panel should be arranged so that removal of a module or panel from a photovoltaic source circuit does not interrupt a grounded conductor to another photovoltaic source circuit or does not disrupt the grounding connections to noncurrent-carrying metal parts of components in other PV source circuits.

2.7 POWER CONDITIONING UNIT INSTALLATION

Guidelines III A-F deal with the electrical safety of the photovoltaic source and output circuits for the most part. In this section, the joining of these circuits to the PCU, the PCU itself, and the delivery of power to the utility are addressed.

Power conditioning may be either wall mounted or floor standing depending on type and size. The section of Appendix 1 dealing with the PCU may be used as an aid to the following guidelines and rules to be listed in this section. The comments on the listing of modules in Section II-B apply here for the PCU.

Each PCU is designed to operate according to certain circuit and grounding interconnections. It should be determined whether the PCU rating is compatible with the expected currents from the PV output circuit. This can be accomplished using the information in Appendix 1.

1. The maximum voltage, the circuit size, and current ratings of a PCU are to be suitable for the photovoltaic source circuits and PV output circuits.

For current flow from the array to the PCU, the overcurrent protection requirements for the power conditioning unit and the PCU output circuits are the same as for the photovoltaic source circuits and photovoltaic output circuits. To protect against backfeed of current, additional fusing is required at the PV system interconnection with the ac supply. In addition, some power conditioning units incorporate a transformer for which overcurrent protection should be provided in accordance with the marking on the PCU. If a separate power transformer is used in the system, the following should be considered.

2. Overcurrent protection for a transformer with a source(s) on each side should be provided in accordance with Section 450-3 by considering first one side of the transformer, then the other side of the transformer as the primary. Exception: A power transformer with a current rating (on the side connected toward the photovoltaic power source) not less than the short-circuit output current rating of the power conditioning unit may be permitted without overcurrent protection from that source.

Grounding requirements for certain power conditioning units are critical. For that reason the following rules should be observed:

3. **System Grounding** - A method must be provided for grounding the photovoltaic array and the power conditioning unit. One of the following methods should be used:
a. Grounding achieved by connection to one conductor of a 2-wire system or the neutral conductor of a 3-wire system.
b. Grounding achieved at a point other than any of the photovoltaic source output conductors, such as the center tap or neutral wire of the utility distribution transformer.
c. Grounding achieved by means of an appropriate bleeder resistor(s) and/or over-voltage protector(s) connected to one or more of the photovoltaic source conductors.

Refer to Appendix 2 for a discussion of equivalent system grounding protection.

4. **Point of System Grounding Connection** - If the array output circuit is to be grounded, then the direct-current circuit grounding connection should be made at any single point on the photovoltaic output circuit. However, locating the grounding connection point as close as possible to the photovoltaic source will better protect the system from voltage surges caused by lightning.

5. **Size of Equipment Grounding Conductor** - The equipment grounding conductor should be no smaller than the required size of the circuit conductors in systems (1) where the available photovoltaic power source short-circuit current is less than twice the current rating of the overcurrent device, or (2) where overcurrent devices are not employed as permitted above. In other systems, the equipment grounding conductor should be sized in accordance with Section 250-95 of the 1981 NEC.

The power conditioning unit output circuits connect to their intended loads and to the utility in a utility-interactive system. In an interactive system, it should be ensured that:

6. The power output from a utility-interactive power conditioning unit is automatically disconnected from all ungrounded conductors of the utility system upon loss of voltage in the utility system, and should not reconnect until the utility voltage is restored to protect utility company personnel from risk of shock due to energization of otherwise de-energized lines. This should include self-excited operation of the PCU.

The ampacity of a neutral conductor is covered by the following rules.

7. If a single-phase (2-wire) power conditioning unit output is connected to the neutral and one ungrounded conductor of a 3-wire system or of a 3-phase, 4-wire wye-connected system, the maximum load connected between the neutral and any one ungrounded conductor plus the power conditioning unit output rating should not exceed the ampacity of the neutral conductor.

8. To prevent unbalanced interconnections, the output of a single phase power conditioning unit should be connected to a 3-phase, 3- or 4-wire electrical service derived directly from a delta-connected transformer.

9. To prevent a 3-phase unbalanced condition, a 3-phase power conditioning unit should be automatically disconnected from all ungrounded conductors of the interconnected system when one of the phases opens in either source.
10. An exception for both unbalanced interconnections is where the interconnected system is designed so that significant unbalanced voltages will not result.

11. The output of the power conditioning unit should be connected to the supply side of the service disconnect.

2.8 LIGHTNING PROTECTION

When lightning protection is provided, it should be installed in accordance with the Lightning Protection Code, NFPA No. 78.
SECTION 3.0
STRUCTURAL INSTALLATION GUIDELINES

3.1 BACKGROUND

This section is intended to list inspection guidelines to ensure that safe structural practices, including guarding against fire hazards, have been utilized during installation. At present, there are four commonly used mounting methods for roof-mounted PV arrays. These are direct mount, integral mount, standoff mount, and rack mount. The local building code and inspection authority having jurisdiction should be consulted before installation.

An illustration of the direct mount concept is shown in Fig. 4 where the PV modules are mounted directly on the roof sheathing and shingles or replacing standard asphalt shingles.

Figure 5 illustrates the integral-mount concept, where the PV modules replace the roofing material including the sheathing and are mounted directly on the rafters.

Figure 6 illustrates the standoff mounting technique where the modules are mounted several inches above and parallel to the roof surface.

The fourth mounting concept is the rack-mounted array which is shown in Fig. 7. Here a frame or rack is mounted on the roof to support the PV modules at some appropriate angle to the sun.

Figure 4. Direct Mount
Figure 5. Integral Mount
3.2 GENERAL STRUCTURAL HAZARDS

For all the mounting methods illustrated in Figs. 4 through 7, the addition or inclusion of modules on a roof will add extra loads above and beyond those normally expected. For rack- and standoff-mounted modules, wind uplift loads will be increased and the application of snow loads will be altered. All the mounting techniques can introduce roof leakage problems.

The structural loading guidelines indicated below are recommended during the design, installation, and inspection of a roof-mounted system. The local building code should be consulted for the wind and snow load requirements.

1. Dead Loads

a. In the case of new construction, the structure should be designed so that it can support the added loads of PV modules, wiring, and supporting structure.

b. For retrofit construction, the existing structure should be evaluated for its capability to support the additional loads and it should be strengthened as necessary before any solar PV equipment is installed.

2. Wind Loads for Roof-Mounted Flat-Plate Modules

a. Modules (including all mounting hardware) which are direct or integral mounted should be designed to resist the wind loads normally imposed on the areas of the roof where the modules are mounted. These wind loads include both direct (positive) and uplift (negative) loading conditions.
b. Modules (including all mounting hardware) which are standoff or rack mounted should be designed to resist wind loads (both direct and uplift).

c. Wind loads on modules mounted at an angle to a vertical wall should be the same as those for equivalent roof eave area as described in the local building code.

3. Snow Loads

a. Modules, including all mounting hardware, which are direct or integral mounted should be designed to support the snow loads normally imposed on the areas of the roof where modules are mounted.

b. Flat-plate modules (including all mounting hardware) that are mounted parallel or at any angle to the roof on open or closed racks should support the snow loads that would be imposed on roofs of similar shape.

c. For rack and standoff mounted modules, roof areas near the modules should be designed for twice the ground snow load for a distance \( h \) (in front and behind) equal to the height of the PV modules as shown in Fig. 8 (where \( g \) is the ground snow load).

4. Roof Leakage

a. PV array installations should be designed to allow normal water drainage from the roof.

b. Flashing or equivalent protection should be provided at all penetrations of the roof membrane.

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**Figure 8. Snow Load Calculations**
3.3 FIRE HAZARDS

Fire hazards include the combustibility of the material used in the construction of the solar PV modules and the power conditioning unit and the effects that the presence of these materials have on the overall fire resistance of residential building assemblies. Some PV modules have incurred elevated temperatures* (over 100°C) in the past. It is conceivable that these temperatures might have caused roofing material ignition in a residential application. The following recommendations pertain to roof-installed PV systems.

a. The roofing material under an array should at least be a Class C roof, but Class B is preferable as defined in UL Standard 970.

b. Combustibles, including roofing materials, adjacent to solar equipment or an integral part of a solar component should not be exposed to temperatures that may cause ignition; or protection should be provided against such exposure.

c. Standoff-mount modules which are mounted parallel to the roofing material may adversely affect the fire-retardant performance of rated roofing materials. (The inspector should rely on the installation instructions provided by the manufacturer.)

d. Direct and integral mount modules should provide the same degree of fire resistance as the roofing materials that they replace.

*These elevated temperatures have been incurred in modules prone to "hot spot heating" and in certain failures where in-circuit arcs and arcs between circuits and ground have occurred.
APPENDIX I

IDENTIFICATION OF SYSTEM COMPONENTS
The following checklist will serve as a guide to assist in identifying the system components and their rated performance and will provide a convenient record of the data on the system.

| Modules |
|------------------|------------------|
| Manufacturer     | Rated Output*    |
|                  | Open-circuit voltage in volts (Voc) |
|                  | Short-circuit current in amperes (Isc) |
|                  | Maximum power in watts (Pmax) |
|                  | Voltage at maximum power in volts (Vmp) |
|                  | Current at maximum power in amperes (Imp) |

<table>
<thead>
<tr>
<th>Module Output Terminations:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposed terminal screws or standoffs (Yes or No)</td>
</tr>
<tr>
<td>Enclosed terminal screws or standoffs (Yes or No)</td>
</tr>
<tr>
<td>Connectors used at output terminations (Yes or No)</td>
</tr>
<tr>
<td>Other means of output terminations (Yes or No)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bypass diodes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diodes built into module circuitry (Yes or No)</td>
</tr>
<tr>
<td>Diodes external to module circuitry (Yes or No)</td>
</tr>
<tr>
<td>Contained in a junction box (Yes or No)</td>
</tr>
<tr>
<td>External to junction box (Yes or No)</td>
</tr>
<tr>
<td>Diode ratings (external diodes only) (Yes or No)</td>
</tr>
</tbody>
</table>

*Note: The rated outputs are determined at an air mass of 1.5, an irradiance of 100 MW/cm² and a cell temperature of 20°C. The only exception is for Voc which is rated at either 0°C or -20°C.*
IntermoduleWirings:

<table>
<thead>
<tr>
<th>Wire size</th>
<th>Wire ampacity</th>
<th>Type of cable</th>
<th>Type of connectors used (if any)</th>
<th>Means of wire routing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Module Mounting Technique:

- Direct ______  Integral ______  Standoff ______  Rack ______

Module Grounding Technique (where applicable)

Module Support Grounding Technique (where applicable)

Module Listing Agency (where applicable)

PV Source Circuits (where applicable)

Rated Output:

- Open-circuit voltage in volts (Voc)
- Short-circuit current in amperes (Isc)
- Maximum power in watts (Pmax)
- Voltage at maximum power in volts (Vmp)
- Current at maximum power in amperes (Imp)

Source Circuit Blocking Diode (Yes or No)

Physical location of diodes

__________________________________________
### Diode Ratings

<table>
<thead>
<tr>
<th>Source Circuit</th>
<th>Electrical Features</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fuses (or other overcurrent devices) (Yes or No)</td>
</tr>
<tr>
<td></td>
<td>Location</td>
</tr>
<tr>
<td></td>
<td>Disconnects (Yes or No)</td>
</tr>
<tr>
<td></td>
<td>Ratings</td>
</tr>
<tr>
<td></td>
<td>Location</td>
</tr>
<tr>
<td></td>
<td>Ground (Yes or No)</td>
</tr>
<tr>
<td></td>
<td>Location</td>
</tr>
</tbody>
</table>

### Source Circuit Listing Agency (where applicable)

### PV Output Circuit (PCU input circuit)

**Rated Output:**

- Open-circuit voltage in volts (Voc)
- Short-circuit current in amperes (Isc)
- Maximum power in watts (Pmax)
- Voltage at maximum power in volts (Vmp)
- Current at maximum power in amperes (Imp)

---

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PV Output Circuit Electrical Features

Blocking diodes (Yes or No) Ratings Location

Fuses (Or other overcurrent devices) (Yes or No) Ratings Location

Disconnects (Yes or No) Ratings Location

Ground (Yes or No) Location

Alternative grounding method used

Wiring size Ampacity Routing method

Output Circuit Listing Agency (where applicable)

Power Conditioning Unit(s)

Manufacturer

Model No.

Number of units

Location(s)

Interactive or Stand-alone

Temperature range:
    Operating
    Nonoperating

Mounting requirements:
    Dry conditions
    Wet conditions

Test point common at ground (Yes or No)

Power conditioning unit case grounded (Yes or No)

Input voltage

Input current

Input ground (Yes or No)

Output voltage

Output current, rated

Output current maximum available, any condition of load

Output frequency
A.2.1 TECHNICAL DISCUSSION

For the most part, there are two requirements for grounding: (1) equipment grounding and (2) system grounding. Equipment grounding should be accomplished with a solid ground. The solid grounding of all the equipment cabinets, and all the exposed metal parts of the array and its supporting structure is presently covered by NEC documentation in Article 250.

The question now arises as to whether the dc electrical circuitry of the systems needs to have a solid ground. Established codes for dc circuits are not valid for PV systems.

A PV power source has two unique characteristics which make it different from a conventional dc circuit: (1) a limited fault current, and (2) an uninterruptible power supply. A rationale for grounding a PV system based on these two characteristics is presented in the following section.

A.2.2 SYSTEM GROUND RATIONALE

Because the PV power source is inherently current limiting (the maximum current occurs when the array operates into a short circuit) and the PV source cannot be turned off unless the sunlight is blocked, it can be shown that it is not necessary to employ a solid system ground in all cases. Refer to NEC Section 250-1 (fine print note).

Most other electrical power supplying sources, such as a utility system, may be described as ideal voltage sources. They tend to maintain a fixed voltage with any load applied to the circuit; if the load impedance is zero, the ideal voltage source will try to produce an infinite current so as to maintain the intended voltage. Normally, when an overcurrent device is protecting a circuit, the event of a fault to ground causes a large current to flow through the circuit, opening a fuse or circuit breaker. At the other extreme, with an open circuit no current will flow.

A photovoltaic source, in contrast, is best described as an ideal current source. An ideal current source will try to maintain a fixed current independent of the load. Therefore, the fault and safe conditions for an ideal current source are opposite to those for an ideal voltage source. For example, for an ideal current source a short circuit is a safe condition and an open circuit is an unsafe condition. The reasoning behind this is that when a current source is operated into an open circuit (infinite impedance), it will try to form an infinite voltage to maintain the current flow. The recommended method to protect an ideal current source is not a fuse or circuit breaker. It is the employment of a device capable of detecting an unsafe voltage level and then short-circuiting the current source.
In the event of a ground fault in a PV circuit, fuses and circuit breakers cannot be used for protection since the limited value of the short-circuit current would not open the fuse or trip the circuit breaker.

The only definite way to mitigate a ground fault in a photovoltaic circuit is to stop the current flow to it (see Fig. A-2). If the array conductors are opened, hence stopping the current flow, there is no path for the ground fault current. However, opening the circuit to mitigate ground faults leaves all or part of the array ungrounded, which may lead to the buildup of excessive static charges.

From this discussion, it may be concluded that protection of a photovoltaic array falls in either of two categories:

a. If a solid ground is used it must be interrupted to mitigate a fault.
   
   Note: When a fault occurs, its immediate location is usually unknown. When the location of the fault is identified, it is only necessary to remove the ground for that portion of the array. Generally, since the entire array is usually grounded together and the location of the fault is unknown, it is most expedient to remove the entire array ground. Field experience has not revealed any detrimental effects of leaving the dc side ungrounded for up to several hours at a time.

b. If an alternative approach is used, it must provide the photovoltaic array with protection against ground faults.

A2.3 ALTERNATIVE PROTECTION METHOD

An alternative protection system to solid ground is the use of a system with ground effected through a resistor. The resistor is placed in parallel with a surge protector to limit the system voltage rise below the insulation rating required for all possible fault conditions.

The resistor must be large enough to limit fault current below a level that could sustain a fault, yet small enough to drain off system static charges. This method is an example only; other methods may become available.

Relays are provided to disconnect the ac side of the inverter from the utility service in the event of a fault current in the ground resistor or surge protector.
Figure A-1. Current and Voltage Sources

Figure A-2. PV Ground Fault Current
This report provides a set of interim inspection guidelines to assess the safety of a residential PV system until more formal documentation is available from code-generating groups.