Code Corner

Ground Fault Protection and PV Checklists

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Sponsored by the Photovoltaic Systems Assistance Center, Sandia National Laboratories

This month's Code Corner will deal with two subjects. The first is a discussion of Section 690-5 of the National Electrical Code (NEC) that requires ground-fault protection equipment for PV arrays mounted on the roofs of dwellings. The second subject presents a check-list that can be used to ensure NEC compliance in a PV installation.

Ground Fault Protection

NEC Section 690-5 requires that a ground-fault protection device (GFP) be used on PV arrays that are installed on the roofs of dwellings. Inspectors in Oregon, Colorado, New Mexico, and elsewhere are requiring this device which has been an NEC requirement since 1984. The electrical engineers at the National Fire Protection Association (NFPA) who officially interpret the NEC are telling inspectors that this is a valid requirement and that the PV industry is behind in making the device available.

As spelled out in the NEC, this GFP is intended as a fire protection device and not a shock protection device (GFCI). In the 1996 NEC, the GFP must detect fault currents, interrupt these fault currents, and then disable the array. The only effective method of automatically interrupting the fault currents is to unground the PV array. Disabling the array is controversial with the NEC Handbook suggesting that both conductors to the array be disconnected from the load and then shorted together. Some PV manufacturers maintain that this shorting action may damage modules in high-voltage PV arrays.

There are several devices on the market that meet the NEC requirements. They are manufactured by Alternative Power Technologies-previously Ananda Power Technologies (916-478-6645), and Trace Engineering (360-435-8826).

If the price is too high and the inspector still requires such a device, consideration should be given to moving the array off of the roof of the dwelling.

Solar Photovoltaic Systems Checklist

The checklist presented below can be used in the initial planning stages of a PV system. It is designed for use by an electrician or electrical contractor to ensure that the PV-specific requirements of the NEC are met. It is not meant to be an all-inclusive design or installation guide. Specific details have been covered in past issues of Code Corner in *Home Power Magazine* and will be covered again in future issues.

The following checklist is an outline of the general requirements found in the 1996 National Electrical Code (NEC) - Article 690 for Photovoltaic (PV) Power Systems installations.

This list should be used in conjunction with Article 690 and other applicable articles of the NEC and includes requirements for both stand-alone PV systems (with and without batteries) and utility-interactive PV systems. Where Article 690 differs from other articles of the NEC, Article 690 takes precedence [690-3].

References in brackets [ ] are to the 1996 NEC and other relevant documents.

PV Arrays

- Listed PV modules are available from 4-5 manufacturers [110-3].

Conductors

- Conductor type-USE-2, UF, or SE if exposed [690-31(b)]; RHW-2, THWN-2, or XHHW-2 in conduit [310-15]. 90°C, wet-rated insulation is necessary [UL-1703].
- Temperature derated ampacity calculations should be based on 125% of short-circuit current (Isc), and the derated ampacity must also be greater than rating of overcurrent device (156% Isc -see below) [690-8,9].
- Suggest derating factors of 60-65°C in cooler areas, 70°C in hotter areas, and 75°C in desert areas be used for ampacity calculations.
- Portable cords are allowed only on moving tracker connections [690-31(c), 400-3].
- Strain reliefs/cable clamps or conduit should be used on all cables and cords [300-4, 400-10].

Overcurrent Protection

- DC-rated and listed fuses and circuit breakers are available from several sources. If device is not marked DC, then verify DC listing with manufacturer.
- Rated at 1.25 x 1.25 = 1.56 times short-circuit current from modules [UL-1703, 690-8, module instructions].
- Supplemental devices allowed, but branch-circuit devices preferred [690-9(c)].
- Located near the charge controller or battery [690-9(a) FPN].
- Must protect smallest conductor used to wire modules. Sources of overcurrent are parallel-connected modules, batteries, and backfeed through inverters [690-9(a)].

Charge Controllers

- Listed devices are available separately and inside listed PV load centers [110-3].
- There should be no exposed terminals—at least one listed unit has exposed terminals.

Disconnects

- Listed, DC-rated devices are available: Square D QO breakers for 12-volt DC systems, Square D Heavy Duty Fused Safety Switches up to 600 volts DC.
- Listed PV Load Centers by APT and Trace for 12, 24, and 48-volt systems contain charge controllers, disconnects, and overcurrent protection for entire DC system.
- Must provide disconnects for all current-carrying conductors [690-13].
- Must provide disconnects for equipment [690-17].

Inverters (Stand-alone Systems)

- Listed stand-alone inverters are available from three manufacturers [110-3].
- DC input currents must be calculated for cable and fuse requirements: Input current = rated ac output in watts divided by lowest battery voltage divided by inverter efficiency [690-8(b)(4)].
- Cables to batteries must handle 125% of input currents [690-8(a)].
- Overcurrent devices should be located within 4-5 feet of batteries.
- Overcurrent/Disconnects mounted near batteries and external to PV load centers are suggested if cables are longer than 5-6 feet to batteries or inverter.
- Listed, DC-rated fuses and circuit breakers are available. AIC should be at least 20,000 amps. Littelfuse marks DC rating, Bussmann and others sometimes do not [690-71(c), 110-9]. Verify listed, DC-rating with manufacturer if unmarked.
- 120-volt inverters connected to 120/240 load centers with multiwire branch circuits have the potential for neutral overloading in the branch circuit [100-Branch Circuit, Multiwire].

Batteries

- None are listed.
- Cables should be building-wire type cables [Chapter 3]. Welding cables and auto battery cables don't meet NEC. Flexible USE/RHW cables are available. Article 400 cables OK for cell connections, but not in conduit or through walls [690-74, 400-8]. See stand-alone inverters for ampacity calculations.
- Access should be limited [690-71(b)]. Install in well-vented areas (garages, basements, out-buildings, not living areas).
- Cables to inverters, DC load centers, and/or charge controllers should be in conduit [300-4].

Inverters (Utility-interactive Systems)

- Listed units are available from two manufacturers and should be used for safety of utility personnel by eliminating the possibility of energizing unenergized utility lines.
- Must be on dedicated branch circuit with back-fed overcurrent protection [690-64].
- Must have external DC and ac disconnects and overcurrent protection [690-15,17].
- Total rating of overcurrent devices connected to ac load center (main breaker plus PV breaker) must not exceed load-center rating (120% of rating in residences) [690-64(b)(2)].

Grounding

- Only one connection to DC circuits (ungrounded conductor) and one connection to ac circuits should be used for system grounding [250-21].
- AC and DC grounding electrode conductors may be connected to the same grounding electrode system (ground rod) [690-41,47].
- Equipment grounds are required even on ungrounded, low-voltage systems [690-43].
- If a 12-volt system is ungrounded [690-41], then disconnects and overcurrent devices are required in

both of the ungrounded conductors in each circuit [240-20(a)].

- Equipment grounding conductors for DC circuits from PV array may be run apart from other conductors [250-57 (b) Ex 2] and this routing is suggested to minimize damage from lightning surges.

Conductors (General)

- Standard building-wire cables and wiring methods can be used [300-1(a)].
- Wet-rated conductors should be used in conduits in exposed locations [100 Definition of Location, Wet].
- DC color codes should be the same as ac color codes—grounded conductors are white and equipment grounding conductors are green or bare [200-6(a), Ex 5].

Questions or Comments?

If you have questions about the NEC or the implementation of PV systems following the requirements of the NEC, feel free to call, fax, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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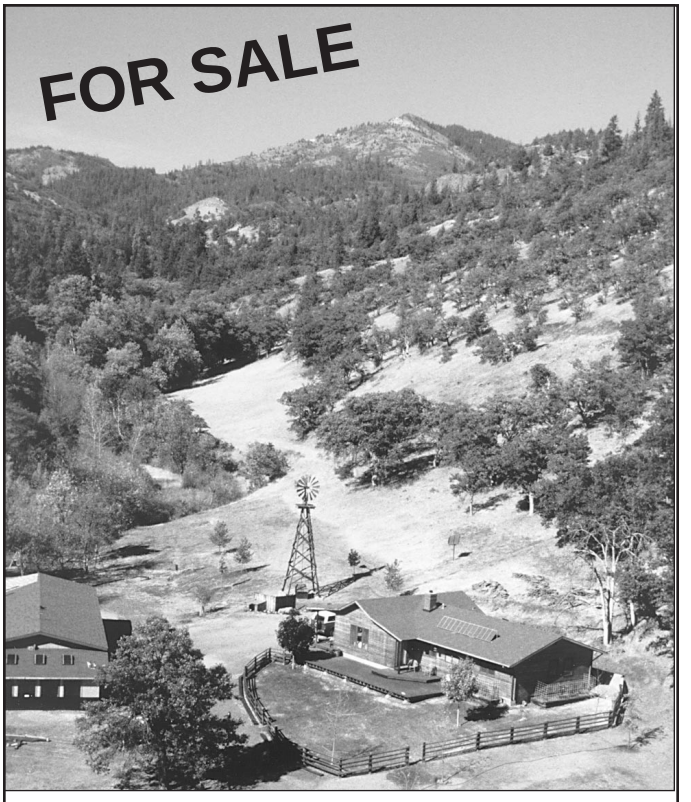

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