STEP 2: PV SYSTEM ELECTRICAL CODE INSTALLATION REQUIREMENTS

Electrical Review of PV System (Calculations for Electrical Diagram)

1. Major electrical components including PV modules, DC-to-DC converters, and inverters, are identified for use in PV systems.

PV utility-interactive inverters must be specifically listed and labeled for this application [NEC 690.4(B)] (numbers in brackets refer to sections in the NEC throughout this document). Without this specific identification process, an unacceptable amount of review would be necessary to approve an inverter. Inverters that pass UL1741 and are listed as "utility-interactive" have met the requirement. An inclusive list of these inverters is available online at www.gosolarcalifornia.com/equipment/inverters.php. PV modules must also be listed and identified for use in PV systems [690.4(B)]. PV modules that pass UL1703 and have a minimum of 600-Volt maximum voltage meet the requirement. A list of these modules is available online at www.gosolarcalifornia.com/equipment/pv_modules.php. Source-circuit combiners must be listed and labeled to meet the DC voltage requirements of the PV system or be specifically tested for PV systems and clearly state the allowable maximum current and voltage [690.4(B)].

2. Array mounting system UL2703 certified for bonding and grounding. Alternatively, the array mounting system may incorporate UL2703 grounding devices to bond separate exposed metal parts together or to the equipment grounding conductor.

This requirement is to simplify the process of ensuring that the exposed metal of a PV array is well-grounded. First published in January, 2015, UL2703 now has numerous mounting system products on the market that are compatible with many of the PV modules on the market. One key aspect of these listings is that UL2703 certification for a particular mounting system is specific for the PV modules to which it has been evaluated. Generally, the specific type or family of PV module from a specific manufacturer is provided with the installation instructions to show to which PV module products the mounting system has been evaluated.

Alternatively, it is possible to install a PV array mounting system that is not fully listed to UL2703. In this case, each separate exposed metal part would need to have a UL2703 listed bonding device attached to it for it to be bonded to adjacent metal parts [690.43] or a UL2703 listed bonding device to connect the metal to the EGC. The only exposed metal parts not specifically required to be grounded are the roof attachments that attach the mounting system to the roof. These roof attachments and flashings are not likely to be energized and are often not exposed. The roof attachments are treated in a similar way that other mechanical fittings are treated in the NEC. The definition in Article 100 of fitting in the NEC is as follows:

"Fitting. An accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function."

3. The PV array consists of no more than 2 series strings per inverter input and no more than 4 series strings in total per inverter.

This requirement is to limit the number of circuits to those configurations that are common for current residential PV systems. Most string inverters today have two, three, or four separate DC inputs. By limiting the number of strings for each input to one or two, no string fusing is necessary. This greatly simplifies the installation process and keeps it consistent with current practice. By limiting the overall input to the inverter to no more than four series strings, this ensures that the conduit connected to an inverter will have no more than 8 current-carrying conductors, upon which the conductor sizing in this guide is based.

4. Field Installed PV array wiring meets the following requirements.

This requirement is to simplify PV array wiring. Residential PV system wiring can be reduced to two main categories: (a) exposed string wiring is 12 AWG PV Wire [690.31(C)(1); and, (b) PV source circuit wiring is 12 AWG THWN-2, XHHW-2, or RHW-2. These simple rules work for any PV system with four source circuits or less using PV modules with a rated short circuit current of no greater than 12.8 amps.

☐ ***a. All exposed PV source circuit wiring is a minimum of 12 AWG PV Wire.***

The calculations used to arrive at these conservative conductor sizes are based on the hottest locations in the United States (Yuma, AZ and Palm Springs, CA). The NEC provides some insight on what to use for continuous ambient temperature for conductor sizing. Continuous is defined in the NEC as a 3-hour period [Article 100]. ASHRAE (American Society of Heating, Refrigeration, and Air Conditioning Engineers) has performed statistical analysis on weather data from the National Weather Service. These data include design values of 0.4%, 1%, and 2% for each month signifying that the temperature only exceeds the recorded value up to the specified time for a given location with temperature data.

The average for June, July, and August of the 2% value has been chosen by the Copper Development Association as the value that best represents a condition that would create the 3-hour continuous condition referred to in Article 100. Two percent of one month is about 14 hours. Since high temperatures usually last for several days in most locations, the assumption is that at least one or two 3-hour high temperature events will happen during a given month. These data are supplied on the website https://energyresearch.ucf.edu/solar-certification/solar-reference-map/ for reference. If a designer seeks a more conservative approach to temperature, the 0.4% data for hottest month of the year is an alternative value. 0.4% of one month is about 3 hours. Using the 0.4% value assumes that all 3 hours occur on the same day which would be the statistical worst-case scenario. Both the 3-month average 2% data and the hottest single month 0.4% data are supplied on website for reference.

☐ ***b. All PV source circuit wiring in raceway is a minimum of 12 AWG THWN-2, XHHW-2, or RHW-2 for 2017 and later NEC installations and is at least 7/8" above the roof surface***.

The rooftop temperature adder in 310.15(B)(3)(c) is not required as long as the conduit is mounted at least 7/8" above the roof surface (standard half strut height). Therefore, the design temperature correction would be 0.87, allowing the use of 12AWG conductors for a 20-amp circuit. If nine conductors or less are in the exposed conduit (4 pairs of conductors or less), then the conduit fill correction factor is 0.7 according to NEC Table 310.15(B)(3)(a). Putting all these correction factors together means that the 30°C conductor ampacity can be calculated as follows:

12AWG= 30A x 0.87 x 0.7 = 18.27A—sufficient for protection by a 20-amp device according to 240.4(B).

Since the highest I_{SC} for most PV modules commonly available are less than 12.8 amps, 12 AWG conductors will work for these modules regardless of location in the U.S. as long as there are no more than 9 current carrying conductors in the conduit and the conduit is at least 7/8" above the roof surface. For those PV modules with an I_{SC} above 12.8 amps, 10 AWG conductors must be used. These calculations are provided so that contractors and jurisdictions will not need to repeat these standard calculations over and over.

5. Equipment is rated for the maximum dc voltage applied to the equipment (put N/A in all blanks that do not apply to the specific installation).

This requirement addresses the need to check to make sure that all equipment that is connected together on the DC side of a PV system is properly configured to prevent equipment from having the DC voltage limits exceeded. This is important since so many different configurations are possible with PV modules and their associated equipment. Each line item is addressing different types of PV systems so several of the entries may not be relevant for a particular PV system. N/A will apply to those blanks that are not relevant.

The NEC includes an Informational Note to 690.7 that specifies the use of the ASHRAE mean extreme value for lowest expected ambient temperature when calculating maximum system voltage. ASHRAE has performed statistical analysis on weather data from the National Weather Service. These data include values for the mean extreme temperatures for the locations with temperature data. The mean extreme low temperature is the coldest expected temperature for a location. Half of the years on record have not exceeded this number, and the rest have exceeded this number. These data are supplied online at https://energyresearch.ucf.edu/solar-certification/solar-reference-map/.

6. PV system circuits on buildings meet requirements for controlled conductors in 690.12.

The 2017 and 2020 NEC require that PV system conductors on buildings be controlled to a safer condition when a rapid shutdown switch is operated. The controlled conductors outside 1 foot from the array must be shutdown to below 30 volts within 30 seconds and PV array wiring within the array be controlled to a safer condition when in rapid shutdown mode. Conductors in the array can meet the requirement by segmenting to 80 volt sections within 30 seconds or meet either of the other two requirements in 690.12(B)(2). As of 2021, a new array listing process is available called PV Hazard Control (UL3741). This new process allows array systems to be evaluated and meet the requirements with the PV array as outlined in 690.12(B)(2)(1) [2017 NEC] and 690.12(B)(2)(a) [2020 NEC].

7. The PV system disconnecting means meets the requirements of 690.13.

The 2017 and 2020 NEC require that the PV system disconnecting means separates the PV system from all other systems in a building. Details in 690.13(F) list the characteristics of a PV disconnect. Most commonly a PV system disconnecting means is a switch or circuit breaker. This switch or circuit breaker is marked “PV System Disconnect,” and must be installed in a readily accessible location [690.13(A)].

8. The standard electrical diagrams can accurately represent the PV system.

The basis for a simplified permit is the use of standard electrical diagrams. Clearly, PV systems can vary significantly in PV array layout and inverter selection. However, the majority of small-scale, residential-sized PV systems can be accurately represented by one of these diagrams. These diagrams include string inverters, DC-to-DC converter systems, microinverters, AC module systems, and energy storage systems (see Step 4). These diagrams also include several interconnection options including the 120% rule, the sum of breakers rule, and supply-side service connections. These diagrams must be completely filled out in order for the permit package to be considered complete.