Minutia

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Understanding and applying the minutia of the National Electrical Code(NEC) has been the primary reason that for the last 100 years, the United States has had one of the safest electrical power systems in the world. Since PV systems are electrical power systems and must be safe, we (the people involved in all phases of PV system manufacture, design, and installation) must strive for complete understanding of the NEC.

While the NEC is not as clearly worded as some would like, there is a wealth of information contained in the various chapters—information that applies to PV systems just as it does other electrical systems. Ignoring this information or maintaining that it does not apply to PV systems dooms us to repeat the mistakes that led to the various sections of the code being developed in the first place. The PV industry, in it's relative infancy, cannot afford to make mistakes. A fire or electrical problem that damages property or causes loss of life in a highly visible PV system will attract the attention of the insurance industry. Such attention may be more than the PV Industry can stand. We must work together to understand and apply the various codes and standards to prevent this from happening. I welcome the dialog that the Code Corner Columns generate.

In 1990, there were PV installers who were not putting fuses or disconnects between the batteries and the inverters on PV systems, even though the NEC and common sense required them. Fortunately, the word has reached most in the PV industry that the NEC represents a minimum set of safety requirements and that fuses and disconnects are good ideas that don't result in significant performance penalties.

Feedback

In response to the letters that appeared in Home Power 61 (Code Curveballs) and other letters, e-mail, and telephone calls concerning the Code Corner Column in Home Power 60, I would like to address some of the details that are involved in understanding and applying the NEC to achieve safe PV systems. The information presented below is obtained from the NEC, the NEC Handbook, and various UL and IEEE Standards. The NEC Handbook is published by the National Fire Protection Association and is written by the electrical engineers at NFPA who are responsible for editing the NEC and making formal interpretations of it. The appeal process for differences in interpretation between electrical inspectors and the PV installer ends at the NFPA if the differences cannot be resolved at a lower level. Local codes supplement the NEC and may impose different requirements.

Cable Ampacities and Temperature Deratings

The Insulated Cable Engineers Association (ICEA) in conjunction with Underwriters Laboratories (UL) and the Institute of Electrical and Electronic Engineers (IEEE) have developed detailed cable standards (e.g. ICEA T 22-294 on testing cables in wet locations). If the cables are built to the published standards, tested and listed to those standards, and installed in accordance with the appropriate codes, they are designed to last at least 20-years. An important aspect of conductor life is the insulation temperature. If the insulation temperature is allowed to increase above the design specification, then the life of that insulation will be reduced and the cable may fail unexpectedly.

PV Module Cable Sizes

Most PV modules less than 100 watts in size have terminals or lugs that can accept cables in the range of number 14–8 AWG. Some modules come with number 16–10 AWG conductors that are attached as pigtails. Contrary to the opinion that no one would use cables that are too small to meet code because they don't want to waste valuable PV power, I have worked with several large PV module manufacturers and PV systems integrators that were trying to use cables as small as number 18 AWG to save money on copper costs and connectors. In large (50–100 kW) PV arrays, there is a lot of wiring and the costs mount up rapidly if oversized cable is used.

The NEC requires that cables be sized based on the ampacity of the cable because it is amperage that causes cables to overheat and overcurrent devices to trip. Voltage drop, important in RE systems, is not directly addressed in the NEC except as a non-directive Fine Print Note. I have found that after the proper temperature deratings have been applied to the ampacity of a PV module cable, the voltage drop for the minimum size code-compliant cable is usually acceptable. Of course, voltage drop should always be checked. When dealing with the cables that can be connected to the 100 watt and smaller modules, the number 12 and 10 AWG cables are most common.

Temperature Derating Cable

Ampacities start with the conductor material, the insulation material, the number of cables in close proximity, the installation method, and the ambient temperature in the vicinity of the cable. NEC Tables 310-16 and 310-17 give the starting points for the ampacities and these values are further modified by a series of footnotes and other restrictions. An engineer can also make detailed ampacity calculations (real arcane minutia) and not use the tables in the NEC.

For example, a number 10 AWG conductor may have insulation rated at 90°C and may be installed in a conduit. Table 310-16 of the NEC gives data that infers that if the current in the conductor is at or below 40 amps (the ampacity) and the ambient temperature around the conductor is 30°C, then the temperature of the insulation will go no higher than the 90°C rating.

If the ambient temperature around the conduit is 40°C, then the temperature derating factor of 0.91 reduces the maximum allowable current to 40 x 0.91 = 36.4 amps. Currents at this level coupled with an ambient temperature of 40°C allow the insulation temperature to remain at or below 90°C.

If the conductor is connected to a PV module (by connecting it to terminals in the PV module junction box), the conductor can be exposed to temperatures of 70°C and higher. Temperatures in PV junction boxes have been measured as high as 73–80°C when the ambient temperature has been 40°C (104°F) and the solar irradiance at 1050 watts/meter squared (W/m2). It should be noted that in many portions of the country ambient temperatures can exceed 104°F and irradiance, on clear days, is usually above 1050 W/m2 for several hours. Modules mounted close to dark roofs with little air circulation can be exposed to temperatures higher than the ambient temperature of the surrounding air.

At the 70°C temperature, the ampacity derating factor for the conductor rated at 90°C is 0.58 which limits the ampacity of the number 10 AWG cable in conduit to 23.2 amps (0.58 x 40). If the current in the cable exceeds 23.2 amps under these conditions, then the insulation may be exposed to temperatures higher than the rated 90°C which will shorten the life of the cable. Keeping the current at or below 23.2 amps allows the insulation temperature to remain at or below 90°C and the cable will meet longevity specifications.

In a similar manner, cables with insulations rated 60°C and 75°C can also have their ampacities derated for temperatures higher than 30°C.

It is generally assumed that if a cable with a 90°C insulation is operated at a current that is equal to the rated ampacity of the same size cable with a 60°C insulation, then the insulation will remain at or below 60°C. For example, the ampacity of a number 10 AWG cable with 60°C insulation is 30 amps at 30°C (compared to the 40 amps of the number 10 AWG cable with 90°C insulation). If the 90°C insulated cable is operated in conduit at 30 amps, it is assumed that its insulation temperature will be 60°C or lower. While this assumption is generally made, it has not been extensively verified through tests. The insulation materials, thickness, and thermal conductivity on 60°C cables can be quite different than the same factors in 90°C cables.

However, it should be noted that ambient temperature also affects the 90°C conductors being operated at 60°C. If we take a 90°C rated, number 10 AWG conductor and operate it at 30 amps in an ambient temperature of 40°C, the insulation temperature will probably exceed 60°C. Table 310-16 shows a temperature derating factor of 0.82 for 60°C conductors operating in 36-40°C ambient temperatures. The derated ampacity now becomes 0.82 x 30 = 24.6 amps. If operated under these conditions at 30 amps, the insulation temperature would probably exceed 60°C. Some installers have suggested that the temperature derate factor be only 0.91 (the number associated with the 90°C conductor actually used), but there is no general agreement on this from the people that wrote this section of the NEC. Some think that the non-linear nature of the heat transfer equations (See NEC Section 310-15(b) and Appendix B) suggests that the higher derate factor associated with the 60°C cables be used.

There is some question about the value of the ambient temperature that should be used to derate the ampacity of conductors that are in conduit which is exposed to sunlight. The NEC, in earlier editions, had solar-gain tables to assist in calculating this temperature. These were removed for unknown reasons several years ago. However, most people know that it is unwise to touch a steel or gray plastic pipe that has been sitting in the sunlight on a hot day. The external and internal temperatures of such conduits are considerably hotter than the ambient temperatures of the surrounding air. Solar water heaters work well because of solar gain. However, the NEC requires that only the ambient temperatures be used in the ampacity derating calculations. This might indicate that PV installers be somewhat conservative when using conduits and cables exposed to sunlight.

A Test

I ran an informal test on a new, two-foot piece of 3/4 inch flexible non-metallic conduit. This conduit had a shiny, somewhat reflective surface and had not turned brown or chalky gray as these conduits do when exposed to sunlight and the weather. I inserted two number 10 AWG THWN-2 conductors and a thermocouple probe into the conduit. I partially blocked the open ends of the conduit to simulate the restricted air flow in a longer piece of conduit. I connected the thermocouple to a digital thermometer and placed the conduit in a shady area. It was a bright, clear afternoon and there was no wind. The solar irradiance was about 925 W/m2. The temperature of the ambient air was 30.5°C (87°F). This also was the temperature inside the conduit when the conduit was in the shade.

I then placed the conduit in the sunlight away from any other structure or body that might reflect sunlight or heat onto it. Within 30 minutes, the internal temperature of the conduit was 58.5°C (137°F). This represents a 38°C rise in conduit temperature above the surrounding ambient air temperature due to solar gain alone.

I have no doubt whatsoever that if the ambient temperature had been a few degrees higher and/or the irradiance had been nearer the peak noon-time value of 1075+ W/m2, the internal temperature of the conduit would have exceeded the 60°C wet rating. As the conduit ages, the color changes will result in even more solar energy being absorbed. Keep in mind that these temperatures were measured with no current flowing in the conductors that were inserted in the conduit. With aged conduit (non-reflective or darkened), current flowing in conductors, high ambient temperatures (40°C), and expected daily normal insolation values (>1000 W/m2), I would expect the internal temperatures of this type of conduit to exceed even the 80°C dry rating when exposed to sunlight.

Installations
Flexible conduit is exposed to sunlight in many PV installations. In some installations, there are gaps between the modules and sets of modules that allow sunlight to shine on the conduit. The conduit is also routed to junction boxes and down the poles of trackers exposing these sections to sunlight.

So What, I'm in the Shade
If the conduit is installed behind the modules, it appears that there would not be any direct solar heating. However, we must keep in mind that the back of module temperature and the j-box temperatures can be in the 60–80°C range when the ambient temperatures are at 40°C. If the conduit touches the back of the module or the conduit fitting is connected to the j-box, then the conduit and the fitting on the end may be exposed to temperatures above the rated value. The NEC does require that good mechanical connections be made when attaching the conduit fitting to the PV j-box. The code also requires that the conduit be well supported within 12 inches of the j-box and at not more than 3-feet intervals elsewhere along the maximum allowable six-foot length [NEC Section 351-27]. These mechanical constraints indicate that there is a possibility that one or more points on the conduit or fittings will be at temperatures higher than 60°C due to just thermal conductivity and convection in the shade without direct solar heating.

Wet Locations
All exposed, outdoor electrical installations are considered wet locations. Wet-rated conductors (types THWN-2, RHW-2, and XHHW-2 for 90°C wet ratings) must be used in conduits installed in outdoor locations. The conduits may not be used at the higher dry temperature ratings when used outdoors. This is fully explained in the NEC Handbook in Article 100 under the definitions of "location." Conduits attached to PV modules are in outdoor, wet locations. The NEC and the NEC Handbook are very clear on the point that outdoor exposed conduits frequently have water in them from wind-driven rain and condensation. The assumption is that they may have water in them at any time, even when the sun is and has been shining brightly. I have personally seen professionally-installed PV systems that had water in the module junction boxes and array-wiring conduits days after any rain. NEC instructions for installing conduit point to the requirement to install it in a manner that will minimize the collection of water. The NEC and the NEC Handbook mention sloping it downward at all points and making provisions for drains at low points [NEC Sections 100A., 225-22, and 230-53]. Of course, no one knows how to make it drain—do we leave the fittings loose (a definite no-no), or do we drill holes in it (another no-no)? These requirements indicate that the conduits in PV systems must be used at their wet temperature rating of 60°C.

Some flexible, non-metallic conduits have a 70°C wet rating (Kaf-Tech brand), but I believe that even this temperature may be exceeded in many installations. The Carlon brand flexible non-metallic conduit has three-piece end fittings that are rated at 107°C (but the conduit is still rated at 60°C wet, 80°C dry). The cheaper Carlon one-piece fittings are only rated at 60°C (presumably wet or dry).

Flexible Nonmetallic Conduit—Can We Use It?
Maybe. Although I have not experienced mechanical failures of the conduit connectors coming loose from the conduit, I do have one report of such a failure to the extent that the installer will not use this product . While this report may be a simple problem of mismatched components or improper installation, it may also be due to a product being operated beyond its ratings.

As Bob-O Schultze and Redwood Kardon pointed out in their letter in Home Power 61, if we use 90°C, wet-rated cables and keep the current in the cable below the ampacity of a 60°C insulated cable (derated for any elevated ambient temperature), we can operate with the flexible non-metallic conduit. As shown above, the current in a number 10 AWG cable in a 40°C ambient temperature must be kept below 24.6 amps. While we can accomplish this, it appears that we cannot keep the temperature of the conduit due to sunlight heating from exceeding the 60°C wet rating. Conduit heated by sunlight to 60°C, plus additional conduit heating due to conductors operating at 60°C indicates to me that flexible, non-metallic electrical conduit should not be used in PV installations. To do so would violate the provisions of the National Electrical Code.

In moderate to cold climates (maximum ambient temperatures below 30°C (86°F)), with proper temperature deratings of the conductors, high-temperature fittings, careful mounting, and good ventilation to the backs of the modules, it may be possible to keep the conduit temperature below 60°C and not violate the provisions of the NEC in Section 351-23(b).

What Happens if I Do Use It?
If the flexible conduit is installed where the 60°C temperature limitation is exceeded, the effects will probably not be dramatic. The combination of moisture and temperature may result in some, none, or all of the following: conduit and conductor insulation deteriorating faster than specified, conduit separating from the fittings, or conduits deforming causing conductors to operated at even higher temperatures with possible accelerated insulation failures. The deterioration of the conduit and insulation are related to chemical changes in the compounds that make them up. Many chemical reactions are accelerated by a factor of two for every 10°C increase in temperature. The increased temperatures are the main cause for the shortened lives of cable insulation and conduits. Heat can also soften the conduit and insulation making them more subject to mechanical abuse and failure.

Other Options
Manufacturers like Heyco and T&B produce high-temperature tubing that is sunlight and moisture resistant. Unfortunately, it is only a recognized product and is not listed as a flexible non-metallic conduit. I will continue to search for a suitable product. Ideas from others are welcome and will be included in this column when appropriate.

I have heard about (from an IBEW member), but not seen, expansion joints that are used for rigid electrical PVC conduit. These gasketed, water-tight slip joints would make it easier to install rigid PVC conduit. They are available from Graybar and probably other suppliers.

Single-conductor USE-2 or Tray Cable (type TC) in the two-conductor version looks better and better all the time where conduit is not required.

Summary
We install PV systems with PV modules that will be producing energy day-in-and-day-out for 25 years or more. We install other balance of systems components that we hope will be equally long lived. I see no reason to use a product like flexible non-metallic conduit beyond its ratings. To do so only invites system failures and possibly worse.

We all would like to see PV become a real player in the energy supply of the United States and the world. The Department of Energy's Million Roofs Program (250,000 for PV, 750,000 for Solar Hot water) will be another addition to the hundreds of thousands of stand-alone residential systems already operational. As the number of PV installations approaches a million or more in all forms, we must be ready to address and deal with the failures that might happen once in 10,000 installations. Those one hundred failures may be prevented if we all carefully study and apply the minutia of the NEC.

Next issue I will address some more of the code and performance issues as they apply to the use of fuses, circuit breakers, and diodes to protect PV modules. Dave Katz made some very good points in Home Power #61 and I would like to elaborate on them.

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, email, 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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