# Where To Use Which Conductor

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There are always questions about exactly which cable types can be used in each of the various locations in a PV system. This *Code Corner* will build on the information presented in my last column, and look at each part of a PV system with respect to the types of cables that might be allowed under the *National Electrical Code (NEC).*

**PV Module Interconnections**

Let's start at the PV module, where the electrical energy originates. PV modules get hot when they operate. Module junction box temperatures above 70°C (158°F) have been measured. The modules are also in exposed outdoor locations. Junction boxes have been found filled with water, even days after the last rain. With these things in mind, you can see why the *NEC* requires PV wiring to be rated for use in wet and high temperature environments. In fact, the code requires any wiring that will be exposed, or installed in conduit in exposed or underground locations to be wet rated.

The *NEC* permits module wiring to consist of single-conductor exposed cables between the module junction boxes and any array-mounted combiner/overcurrent box or array-mounted disconnect box. This allowance for exposed single-conductor PV module wiring is one of the very few places in the code where such wiring is allowed. In fact, local codes—particularly codes involving commercial and not residential installations—may prohibit such exposed conductors.

One of the best conductor types that meets the temperature and moisture requirements for this exposed PV module wiring is type USE-2. See *Code Corner, HP76,* for a description of this and other cables. Type USE cable is only rated for 75°C (167°F), and is not suitable for this application unless installed in areas where ambient temperatures stay below about 30°C (86°F). Type SE cable may also be used when it has an insulation rated for 90°C (194°F). Note that some types of SE cable have only 75°C (167°F) insulation—the rating will be marked on the cable. Although the code mentions type UF cable, this cable generally has only a 60°C (140°F) or 75°C (167°F) rating, which is not adequate for most module wiring.

The *NEC* also generally allows any other wiring method covered in the code to be used for module wiring. For example, type TC cable as a single-conductor exposed cable or as a two-conductor jacketed cable may be used when marked sunlight resistant. Other types of conductors may also be used if installed in conduit for physical and ultraviolet (UV) protection. Commonly available conductor types that can be installed in conduit and that are suitable for module wiring are THWN-2, THW-2, RHW-2, and XHHW-2.

Some of these cables may have additional markings such as the dual-marked THWN-2/THHN and USE-2/RHW-2. In these cases, the cable takes on the properties of each type, and the most strenuous rating can be used. Cables that do not have any of the markings listed in the previous paragraph should not be used. For example, a common type THHN conductor with no other type markings is not suitable for use in conduit for PV module wiring.

Note: A conductor marked with only type USE or USE-2 may not be installed in conduit inside buildings because it does not have the necessary flame retardant. In many cases, these USE-2 cables are also dual marked with type RHW-2, and type USE cable is accompanied by the RHW type marking. These dual-marked cables are suitable for use as exposed single-conductor cables and as cables inside conduits in buildings.

**Wiring In Conduit**

If conduit is used for module wiring, it should be electrical conduit. Such conduit comes in several rigid, flexible, metallic, and nonmetallic styles. Each style has matching fittings and/or cements that must be used. Plumbing PVC conduit is not allowed, nor is plumbing PVC cement to be used to cement electrical nonmetallic conduit.

Standard galvanized plumbing pipe and pipe fittings should not be substituted for rigid electrical conduit and electrical conduit fittings even though they are the same size. Threads and manufacturing methods are different for each. When using flexible nonmetallic conduit, the three-piece compression fittings should be used instead of the one-piece fittings. The one-piece fittings are only listed for 60°C (140°F) and there have been reports of them coming loose in PV installations.

**Wiring Between PV Array & PV Disconnect**
The wiring from the PV combiner/overcurrent box to the PV disconnect and charge controller located some distance away should use one of the other wiring methods allowed by the code for all electrical systems (not the exposed single-conductor cables allowed by Article 690). Conductors exposed to outdoor environments must either be in conduit or of a cable type listed for outdoor environments (such as type UF). Outdoor wiring systems include conductors installed in conduits as described above, sheathed (jacketed) multi-conductor tray cable (when installed in cable trays or other approved raceways), and sheathed multiconductor UF cable (where the 60°C (140°F) temperature limitations can be met).

Several less commonly used and available cable types described in the *NEC* may also be used in some situations, but they usually are more difficult to obtain and install. These include armored cable, electrical nonmetallic tubing, metal clad cable, and others.

When the wiring is run through indoor areas, several wiring methods may be used. Conductors in conduit are also appropriate in this area. In this case, the conduits are not exposed to wet, outdoor conditions and there are more conductor types allowed. In addition to the conductor types mentioned above, the following types are allowed in conduit: THHN, THWN, THW, THH, RHH, TW, XHHW, and XHH. Some of these conductors and type NM, nonmetallic sheathed cable, have only 60°C (140°C) temperature rating, which would preclude their use in hot attics. Type UF sheathed cables may also be used indoors. Each of these wiring methods has specific installation requirements detailed in the *NEC*.

**Power Center/Battery/Inverter Wiring**
Wiring between the battery and the inverter, power center, and charge controller is usually heavier than other wiring in the system. To meet *NEC* requirements, this wiring usually consists of single conductors installed in conduit for physical protection. In some cases, large-gauge type NM sheathed cable may be used where it has the physical protection required by the *NEC.*

The normal stranding for conductors in the #1/0 to #4/0 (53–107 $mm^2$) size range is seven to thirteen strands per conductor. This stranding makes for a pretty stiff conductor. However, all listed electrical equipment has sufficient wire bending room to deal with this cable, and commercial and industrial electricians routinely handle these and larger sized conductors without problems. PV installers who prefer not to deal with these stiff conductors may purchase flexible conductors at an added cost from PV and electrical equipment distributors. Types RHW and THW are usually available in high-stranded flexible versions.

**Equipment-Grounding Conductors**
Conductors used for equipment grounding may be bare (without insulation) or have green-colored insulation. If insulated conductors are used, the type of conductor must comply with the guidelines discussed above. Uninsulated conductors used as equipment-grounding conductors have no temperature or moisture limitations; however, they must be installed so that they meet code requirements for such conductors. Generally, these conductors must be run with the circuit conductors, and will therefore be run in conduit or manufactured as one of the conductors in a sheathed cable.

**Summary**
The PV designer/installer has a wide variety of conductors and wiring methods to choose from. Each method has advantages and restrictions. A thorough knowledge of the requirements in the *National Electrical Code* will provide insights that will enable safe, cost-effective PV systems to be installed.

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. 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 multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

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