Clarifying Confusing Cables

John Wiles

Sponsored by The Photovoltaic Systems Assistance Center
Sandia National Laboratories

The National Electrical Code (NEC)® contains numerous references to different cable and conductor types. Some types are intended for fixed, non-moving installations. Other types are designated for installations where various parts must move. Some cable types can be used in either fixed or moving installations. Each cable type is designated by a series of letters and numbers that refer to the size of the conductor and the type of insulation. This Code Corner will attempt to shed a little light on the murky subject of conductors and cables.

Conductors, Cables, or Wires?

A conductor is something that is meant to conduct or carry electricity. It is normally made of copper, but can also be made of other metals like aluminum. Today, however, copper is the most commonly used conductor in both PV and residential electrical systems. It can be bare, with no covering or electrical insulation, or insulated.

The size of the conductor is expressed as an American Wire Gauge (AWG) with designations from number 27 AWG, the smallest size mentioned in the NEC®, to number 4/0 AWG or 0000 AWG (called "4 aught"). Conductors larger than 4/0 AWG are specified in kcmil (thousands of circular mils), a cross-sectional area designation, and range from 250 kcmil up to 2000 kcmil (with a diameter of about 1.6 inches).

Conductors may be solid copper (usually 6 AWG and smaller) or may be stranded. Stranded conductor is composed of several strands of a smaller conductor twisted together. Typical stranded conductors from 18 AWG through number 2 AWG have seven strands. Conductors from 1 AWG through 4/0 AWG have 19 strands. Conductors 250 kcmil through 500 kcmil have 37 strands. In each of these sizes, conductors are available on special order that have considerably more strands for added flexibility. For example, a 4/0 AWG conductor may have 437 strands of very small copper conductors rather than the 19 strands in the standard conductor.

Cables are usually defined as conductors covered by insulation, although in many cases, the term conductor and cable are used interchangeably. Cables may have only a single conductor, or may have multiple, individually-insulated conductors. Some multiple conductor cables have an external insulating outer covering or sheath. Others do not, and the individual conductors are just twisted together.

The term "wires" is used in the NEC® to refer to the general use of cables or conductors. Reference may be made to a wiring system, wire size, wire sag, and similar terms.

Grouping of Cable Types

In the NEC®, there are two distinct groups of cables. One group represents the building-wiring types of cables. They are primarily used in fixed, non-moving installations such as buildings and are the principle types of cables used in wiring PV systems. These types of cables are identified in Table 310-13 of the NEC®, and the proper methods of installing these cables may be found in Chapter 3 of the NEC®.

The second grouping of cable types is the Flexible Cords and Cables found in Article 400 of the NEC® and described in Table 400-4. These cables are used where there is motion between two parts that are electrically wired together. Such cables are used on appliances, tools, elevators, cranes, and other industrial applications. PV trackers represent a moving installation where flexible cords could be used.

These types of cables are specifically prohibited in Section 400-8 of the NEC® from being used as a replacement for fixed wiring. One of the reasons for this prohibition is that flexible cords have not been tested, evaluated, or listed for fixed uses such as being placed in conduit or run through walls. Another reason is that these flexible cables are generally installed in exposed locations where damage is readily visible and the need for replacement is evident. There are numerous other prohibited uses where the code says that if a fixed,

building-wire cable can be used, the fixed cable is to be used in lieu of a flexible cable.

Insulations and Cable Markings
Cables have insulations that are made of different materials for different applications. The letters and numbers of the outer covering of the cable provide information on the cable and where it can be used. The tables in Chapter 3 and Article 300 of the NEC® generally specify under what conditions each cable type can be used. Listed below are some of the cables that can be used in PV systems starting with the building-wire types of cables.

Cables for PV module connections
Exposed, single-conductor cables are allowed for PV module connections by NEC® Section 690-31. The following are the types allowed:

USE: Underground Service Entrance • 75°C, wet insulation rating • Heat and moisture resistant • Sunlight resistant, but not marked as such.

USE-2: As above, but with a 90°C, wet insulation rating. The most commonly recommended cable for PV module wiring.

UF: Underground Feeder • 60°C, wet insulation rating • Not sunlight resistant unless marked • Hard to find and not recommended due to the low, 60°C temperature rating.

SE: Service Entrance • Temperature rating is variable and is marked on the jacket • Sunlight resistant, but not marked • Hard to find in a single conductor.

PV modules may also be connected with conductors installed in conduit (metal, plastic, flexible, rigid, etc.). Since the conduits are exposed to the elements, they are considered to be wet locations (even in the hot, dry, sunny Southwest), and wet-rated conductors with 90°C insulation should be used for PV module wiring. The following types are the cables typically used.

THWN-2: Moisture and heat-resistant thermoplastic • 90°C, wet and dry insulation rating • May also be marked THHN. A cable marked only with THHN is not suitable for use in exposed conduits.

THW-2: Moisture and heat-resistant thermoplastic • 90°C, wet and dry insulation rating • May also be marked THHW.

RHW-2: Moisture and heat-resistant thermoset (rubber) • 90°C, wet and dry insulation rating • May also be marked USE-2 and/or RHH.

XHHW-2: Moisture and heat-resistant thermoset (cross-linked synthetic polymer) • 90°C, wet and dry insulation rating.

In these and other markings on cables, the letters and numbers have meaning.

- **T:** Thermoplastic insulation
- **R:** Thermoset insulation (rubber or synthetic rubber)
- **X:** Cross-linked synthetic polymer insulation
- **H:** High temperature (usually 75°C when dry or damp)
- **HH:** Higher temperature (usually 90°C when dry or damp)
- **W:** Moisture resistant (usually 60°C when wet)
- **N:** Nylon jacket
- **-2:** High temperature and moisture resistance (90°C wet or dry)

Combinations of these letters and numbers change the definitions somewhat.

Wiring away from the PV modules must be one of the building-wire type of wiring systems. These methods are discussed in Chapter 3 of the NEC®. Single-conductor exposed cables are generally not allowed nor are unjacketed multiple-conductor cables.

If protected from mechanical damage and not exposed to high temperatures, a UF multiple-conductor jacketed cable might be used. However, since the cable is limited to 60°C by Section 339 of the NEC®, it is generally not applicable outside the structure where higher temperature ratings are required.

Inside the structure, the conductors listed above may be used inside conduit. Additionally, since the temperature requirements are less, and the conduits are no longer exposed, 75°C, damp-rated insulation versions of these conductors may also be used (THHN, THW, RHW, XHHW, or RH). Local electrical codes generally require conductors in conduit for all commercial wiring.

Non-metallic sheathed cable (Type NM) also know as Romex® is commonly used for interior residential wiring where it can be installed properly inside walls in accordance with NEC® Section 336. Note that type NM cable is specifically excluded from storage-battery room applications.

PV Trackers
Trackers contain moving parts and as such may be wired with flexible cables. However, the slow rotation rates of trackers (1300 revolutions per decade) generally allow the use of the stiffer building-wire types of cable, and are therefore recommended. Also available are building-wire types of cables with extra-fine strands for additional flexibility where required.

If flexible cables are to be used, then types identified in Article 400 of the NEC® are appropriate. The markings

shown below should always be accompanied with the letters “W-A” to indicate that the cable is suitable for outdoor use.

Flexible cords suitable for PV tracker connections on trackers are: SE, SEO, SEOO, SJ, SJE, SJEO, SJEOO, SJO, SJOO, SJT, SJTO, SJTOO, SO, and SOO. These are all hard-service or extra-hard-service flexible cords. With the “W-A” rating, they are also suitable for outdoor use. Again, each of the letters has meaning:

S: Hard Service Flexible Cord

SJ: Junior Hard Service Flexible Cord

E: Thermoplastic elastomer insulation

T: Thermoplastic insulation

O: Jacket is oil resistant

OO: Jacket and Conductors are oil resistant

Battery Cables

Battery-to-inverter cables are usually large in size. They should be installed in conduit when being used between the battery enclosure and other equipment. As mentioned above, extra-flexible building-wire cables are available that may make the installation somewhat easier. Extra-flexible types that are available include THW, RHW, and USE. Since most batteries are in sheltered areas, cables with only a damp-rated, 75°C insulation are required.

Section 690-74 of the NEC® allows the use of Article 400 flexible cables for inter-cell battery connections as well as the connections from the battery to a fixed-wiring system. Since single-conductor Article 400 cables (types SC and W-this is not welding cable) are not readily available, it is suggested that extra-flexible, building-wire types of cables be used for connections to the battery when it is deemed necessary to use flexible cables.

Welding cables and automotive battery cables are not recognized by the NEC® for use in wiring electrical power systems.

Listed Cables

All conductors (except bare) and all cables should have all size and insulation type information plus the listing mark printed on them. The listing mark will normally be the “UL”, indicating that Underwriters Laboratories, Inc. has evaluated the cable for the intended use.

Summary

The choice of the proper cables for PV installations is relatively straightforward. Most cables are available locally or are stocked by PV distributors. Using the correct cable in each application will ensure a durable, safe, long-lasting PV system.

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

Access

Author: John C. Wiles, Southwest Technology Development Institute, New Mexico State University, Box 30,001/ MSC 3 SOLAR, Las Cruces, NM 88003
505-646-6105 • Fax: 505-646-3841
Email: jwiles@nmsu.edu

Sandia National Laboratories Sponsor: Ward Bower, Sandia National Laboratories, Division 6218, MS 0753, Albuquerque, NM 87185 • 505-844-5206
Email: wibower@sandia.gov