# Module Wiring 101

by John Wiles

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Photovoltaic systems require wiring methods not normally found in residential or commercial electrical systems. Do-it-yourselfers and installers alike should become familiar with the *National Electrical Code (NEC)* sections that pertain not only to PV systems but to electrical systems in general, and become confident in distinguishing the basic types of conductors and knowing their proper use. While conceptually simple, joining PV modules together and making the connections to the rest of the system's components should be carefully done with a solid working knowledge of electrical systems.

## PV Wiring & Conductor Types

Usually, single-conductor, exposed cables are used to connect individual PV modules in the PV array, a technique permitted by Section 690.31 of the *NEC*. Conductors permanently attached to the PV module are part of the listed module assembly and have been certified by Underwriters Laboratory (UL) as meeting the necessary safety requirements. In most cases, the cables are marked USE-2 or USE-2/RHW-2. Some are also marked "Sunlight Resistant," indicating better ultraviolet light resistance than the basic USE-2 cable, which is tested for UV resistance but not marked as such.

PV modules are typically connected in series strings. After making several connections, the positive and negative conductors at the ends of each string lie some distance apart. To bring these two points to a common location, a single conductor is used. Although Section 690.31 of the *NEC* allows USE, SE, and UF cables, installers typically use a USE-2 or USE-2/RHW-2 cable to bring the negative and positive negative conductors to the same spot. Because PV modules may heat up to 80°C (176°F), wiring touching or near the backs of modules should have 90°C (194°F)-rated insulation. In outdoor applications, "-2" conductors (USE-2, RHW-2, THWN-2) also should have a 90°C, wet–rated insulation, whether they're exposed or run in conduit.

The cable may be purchased with matching connectors attached, or a cable and connector may be assembled if the necessary crimping tool and required factory training are available. At this connection point, which must be under or very near the array, the exposed conductors are transitioned, using a junction box, to one of the common wiring methods stipulated in Chapter 3 of the *NEC*.

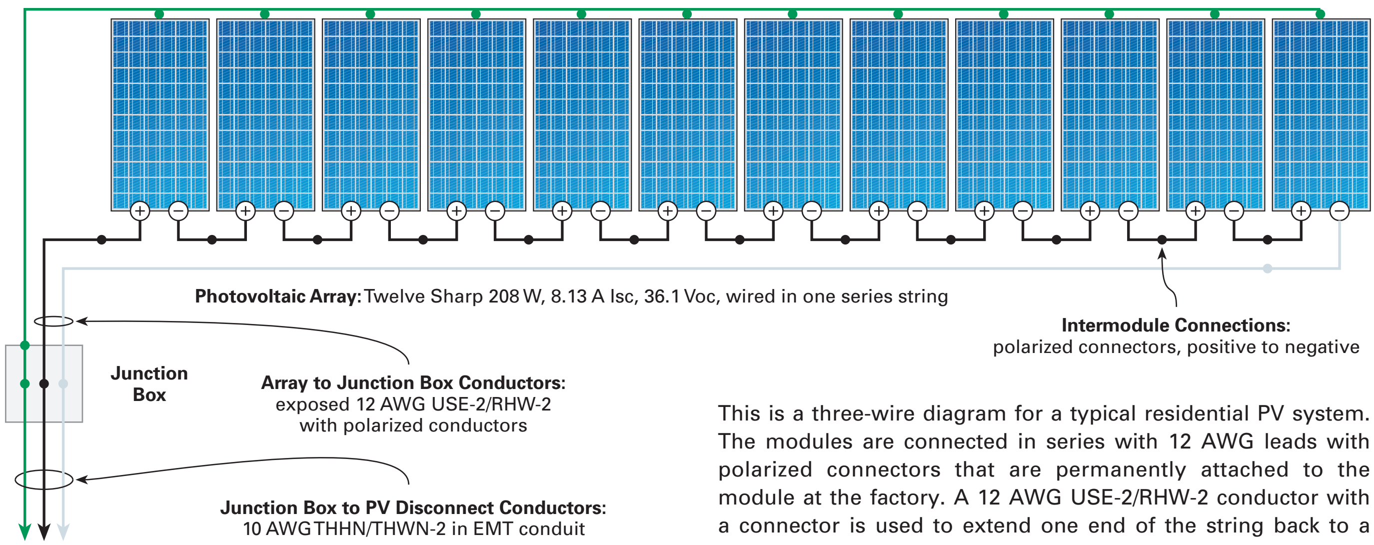
Where exposure to the weather is possible, especially in hot and wet conditions, THHN/THWN-2 or RHW-2 conductors are typically installed in conduit. Electrical metallic tubing (EMT) is commonly used, and, where allowed by local codes, rigid nonmetallic conduit (RNC) may be used. However, in very hot climates, the plastics used in RNC may not age well. In some cases, liquid-tight flexible nonmetallic conduit can be used, but is acceptable only when properly attached to the supporting structure. PV output conductors routed through the building to the DC PV disconnect must be installed in metal conduit. Nonmetallic conduits are not acceptable because of their limited fire resistance, lack of ground-fault indication, and lower degree of physical protection for the enclosed cables.

Conductors run in exterior conduit exposed to sunlight on roofs should be given special consideration. For example, in climates that experience average high ambient temperatures of 40°C (104°F), conduit installed on a rooftop can easily reach temperatures of 62°C (144°F). For conductors exposed to these conditions, the *2008 NEC* calls for an addition of at least 17°C (31°F) to the ambient temperature correction. If the conduit is within a half-inch of the roof, the added temperature should be 33°C (59°F). Between 0.5 and 1.5 inches, the temperature added should be 22°C (40°F). To accommodate the reduced ampacity at higher temperatures, appropriate temperature deratings may dictate the use of larger conductors than would otherwise be used. (For more information, see the Fine Print Note #2 for Section 310.10 in the *2005 NEC*.)

For conduit run inside the building, conductors that only bear the USE-2 marking may not be used, since this cable does not contain the required flame and smoke retardants, but USE-2/RHW-2 conductor is acceptable. In the *2008 NEC*, the allowed use of cable types USE, UF, and SE was removed from Section 690.31 due to their temperature limitations and availability in the proper sizes (10, 12, and 14 AWG) for module interconnections.

A new PV conductor—a single-conductor cable designated "PV Wire," "Photovoltaic Wire," "PV Cable," or "Photovoltaic Cable"—will be allowed under Sections 690.31 and 690.35 of the *2008 NEC*. It will be marked "Sunlight Resistant," and will have the necessary flame- and smoke-retardant properties to allow its use in conduit inside buildings. However, this cable also will have thicker insulation than USE-2 conductor, and conduit fill will have to be calculated, rather than by using the tables in Chapter 9 of the *NEC*. This cable will be one of the wiring methods required in PV systems that operate ungrounded and use the new transformerless inverters.

## Example of PV Array Wiring




This is a three-wire diagram for a typical residential PV system. The modules are connected in series with 12 AWG leads with polarized connectors that are permanently attached to the module at the factory. A 12 AWG USE-2/RHW-2 conductor with a connector is used to extend one end of the string back to a junction/pull box where it and the other lead are transitioned to 10 AWG THHN/THWN-2 conductors in a 3/4-inch EMT conduit (see *NEC* Section 690.35).

### *Other PV Parts & Pieces*

Module short-circuit currents may range from 1 amp to about 17 amps (in unusual cases). Large (300-watt and greater) PV modules have short-circuit currents approaching 12 amps. The ampacity of the attached and any field-installed cables should be 1.56 times the module short-circuit current (Isc) after the "conditions of use" are applied, which include the external temperature that the cable will be subjected to and any factors associated with the number of conductors in a bundle or in a conduit. In most cases, the factory-attached cables have sufficient ampacity. However, in very hot climates, the conductor temperatures may be so high that the ampacity of the attached cables is insufficient to meet the 1.56 Isc requirement after temperature corrections are applied. The ampacity of these cables should be evaluated using *NEC* Table 310.17.

Equipment-grounding conductors connected to the PV module frames should be sized at 1.25 times the module Isc. On large PV arrays, where fuses are used to protect these conductors, *NEC* Table 250.122 should be used instead for proper sizing. This will result in a smaller, but adequate, equipment-grounding conductor that will be calculated using the 1.25 Isc value.

The backs of all listed PV modules are marked with a "Maximum Series Fuse" value or similar wording. An overcurrent device (fuse or breaker) protects the internal module conductors from damage from overcurrents that could be forced through the module from external sources. Although many residential PV systems do not require overcurrent protection in DC circuits, larger commercial systems usually do because the multiple parallel strings of modules are sources of potentially damaging fault currents. The *NEC* requires that any overcurrent device installed in the output of a module be rated at 1.56 Isc. There are a few modules being made (for unknown reasons) that have a maximum series fuse value of *less than* 1.56 Isc, which poses a code quandary. Section 690.8 says to use a fuse rated at 1.56 Isc, but Section 110.3 says to follow the product labels. Any installer facing this quandary should report the problem to UL via https://www.ul.com/consumers/conproddb.cfm.

### *Questions or Comments?*

If you have questions about the *NEC* or the implementation of PV systems that follow the requirements of the *NEC*, feel free to contact me. See the SWTDI Web site (below) for more detailed articles on these subjects. The U.S. Department of Energy sponsors my activities in this area as a support function to the PV industry under Contract DE-FC 36-05-G015149.

### *Access*

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