Conductors and The Code

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It is sometimes difficult to find a suitable conductor with the proper insulation that can be installed using a method outlined in the National Electrical Code that will satisfy the electrical inspector. Numerous types of cables are available from sources as diverse as auto supply stores, welding shops, hardware stores, marine equipment stores, electrical supply houses, and building supply stores. The information presented below will assist in selecting the proper cable.

Interior wiring for load circuits, ac and DC, was addressed by David Doty in *Home Power* #27. He covered the use of non-metallic, sheathed cable (NM - Romex) rather completely. PV installers frequently use large cables to minimize voltage drop. If NM cable with number 10 AWG conductors (i.e. NM 10-2 w/gnd) protected with a 30 Amp fuse or circuit breaker is used, then 30 Amp receptacles are required. Fifteen and 20 Amp receptacles may be used only on branch circuits protected at 20 Amps or less.

Module Wiring

Inspectors usually have questions about exterior wiring. Section 690-31 of the 1990 National Electrical Code (NEC) allows the use of single conductor cable that is identified as sunlight resistant for PV module interconnections. UF (Underground Feeder) is identified as sunlight resistant. USE and SE cable are generally not marked sunlight resistant, but they have passed the sunlight resistance tests. The 1993 NEC will allow not only UF, but SE and USE cables as well. Most UF cables are made with PVC insulation. Problems have been identified with PVC insulation when used in direct current circuits where moisture is present. Under these conditions, the insulation turns to goo. It is unknown whether PV module wiring in wet climates provides the conditions necessary for PVC insulation failure. It might be wise to use another type of cable in locations where the cables are in contact with standing water. Furthermore, although passing the Underwriters Laboratories (UL) standards for sunlight resistance, UF cable has shown signs of deterioration after only four years in hot, sunlight-exposed installations. If USE or SE cable is available, it is preferred.

Most inspectors are familiar with the use of USE and SE cables outdoors in exposed locations. If the USE or SE cable has cross-linked polyethylene (marked XLPE or XLP) and is further marked RHW and RHH or RHW-2, it is one of the best commonly available cables. Standard USE cable has only 75°C insulation. The RHW designation indicates rubber 75°C insulation for use in wet conditions. RHH indicates rubber insulation, with 90°C insulation when dry. The new RHW-2 designation (1990 NEC) indicates rubber insulation with a 90°C rating even when wet. SE cable has a slight advantage over USE in that it has flame resistant additives. The Underwriters Laboratories label (UL) will ensure that the cable meets the highest quality standards and will be the most durable product.

Exposed, single conductor cable is only allowed for module connections. At some point near the modules, the wiring method must be changed to one of the other methods that meet the requirements of the NEC. The exposed, single conductor cables could be routed to a weather head and into conduit and then into the building and to the PV disconnect switch. Another alternative is to route the single conductor cables to a junction box where the cables can be spliced to a jacketed, multiple conductor cable like NM (Romex) or UF (Underground Feeder). These jacketed cables must then be installed with the required physical protection, and routed to the disconnect switch. NM cable, of course, can only be installed in indoor locations. UF cable has sunlight resistance and, with appropriate protection from physical damage, can be installed in outdoor locations.

Tray Cable (TC) is generally marked sunlight resistant. Some inspectors object to its use based on the NEC requirement in Section 340-4 that it is mechanically supported by a cable tray or other means. Section 340-5 prohibits the use of tray cable as open cable on brackets or cleats.

Temperature Derating

Modules in direct sunlight can get significantly hotter than

ambient air temperatures. The backs of the modules, the module junction boxes, and other nearby areas where the conductors must operate can have temperatures as high as 65°C to 75°C. The ampacity of the cables used to connect the modules must be derated for these higher temperatures.

After determining the temperature ratings of the module terminals (75°C or 90°C — marked on the back of UL-listed modules or from the manufacturer), the appropriate temperature derating factor can be selected from Table 310-16 or 310-17 in the NEC. Cable with 90°C insulation must use a 75°C conductor rating for the ampacity calculations, if the terminals are rated for only 75°C. The temperature derating must then be applied to this ampacity. Most installations should use a temperature of 65°C to derate the conductors. In hot locations, with no ventilation provided for the back of the modules (e.g. mounted directly on a roof), a 75°C temperature should be used.

An Example

A particular PV module has junction box terminals rated at 75°C. Single conductor, number 10 AWG USE cable has been ordered with XLPE, RHW-2, and UL markings which indicate a 90°C temperature rating. The modules are mounted on a rack on a brown shingled roof, but for esthetic reasons, the spacing is only two inches. The wiring is to be in free air (not in conduit) so Table 310-17 in the NEC may be used. In this table, the 75°C temperature rating of the conductor must be used because the module terminals are rated at this temperature. If the 90°C rating was used, which matches the USE/RHH wire temperature rating, then the module terminals would operate at a higher than designed temperature and/or current.

According to Table 310-17, number 10 AWG cable with 75°C insulation has an ampacity (current carrying capacity) of 50 Amps at ambient temperatures of 30°C. A footnote to the table states that number 10 AWG conductors must not have an overcurrent device rated at more than 30 Amps. Because the modules have little ventilation space and the roof is brown, the area between the modules and the roof and in the module junction boxes can be expected to be as high as 75°C on hot, sunny days. The ampacity of the conductor must be derated for this temperature, which is the ambient temperature in which the conductors operate. Ampacity Correction Factors are presented in the lower section of Table 310-17. For conductors rated at 75°C, there is no correction factor because a 75°C cable operating at 75°C has no ability to carry current. Back to the drawing board.

If the modules were spaced six or more inches from the roof, the maximum operating temperature would drop to about 65°C on hot, sunny days. In this case, the derating factor is 0.33 which, when multiplied by the 50 Amp rating of the cable at 30°C, gives a derated ampacity of 16.5 Amps.

Furthermore, Section 690-8 requires that a 25% safety factor be used when sizing conductors. This calculation indicates that the maximum short-circuit current that this conductor can handle is 13.2 Amps. The sum of all short-circuit currents for all of the modules connected in parallel on this number 10 AWG USE cable should not exceed 13.2 Amps.

Flexible Cables

The NEC does not address the need for flexible cables for use with tracking module mounts or concentrating PV modules. The highly flexible cables such as rubber-covered SO and SOJ cables described in Article 400 of the NEC are to be used only in portable installations. They may not be used for fixed PV installations. Furthermore, they do not have the necessary temperature derating data that is presented for the more common cable types found in Article 310 of the NEC, and in many cases they may not be sunlight resistant. If flexible cables must be used, UL-listed cables that are type SEOO, SJOO, and SJEOO "hard-service cables", and identified as sunlight resistant, appear to be the most appropriate. The ampacity tables given in Section 400-5 of the NEC derated for temperature, according to Table 310-17, *might* be used to determine the ampacity of these cables. The electrical inspector will have to issue a waiver on the use of these flexible cables in fixed PV installations.

Battery and Inverter Cables

Large conductors such as 2/0–4/0 AWG cables used to connect batteries and inverters are very stiff if made with building wire, such as THHN or USE, with 19 strands of copper. The inspector may require the use of such cable because the NEC requires it to be used in fixed installations and the inspector frequently sees electricians using these stiff cables in standard ac power installations. The NEC also requires that space be allocated for wire bending and connection areas when installing equipment using these large cables. Use of these cables requires the proper tools to deal with the stiffness, which are available from electrical supply houses.

Most PV installers use either battery cable (controlled by SAE Standards) or welding cable for the larger cables. These cables have numerous small strands that provide a

degree of flexibility not found in more rigid building cables. Stand-alone inverters and large battery cells are being manufactured with flexible cables attached, but these products are generally designed for mobile applications or industrial applications, which do not fall under the NEC. The flexibility makes for ease of installation, but the NEC (in the same manner as outlined for flexible cables) does not make definite provisions for their use in fixed installations. If the flexible cables are used, they should be UL-listed and acid resistant, and installed in conduit. Flexible, Type W single conductor cables are available and identified for extra hard usage, but they still fall under Article 400 of the NEC.

There are restrictions in Section 400-8 that prohibit flexible cables from being run through walls or attached to building surfaces. Section 400-10 of the NEC also requires that strain relief be used wherever flexible cables are connected. This would indicate that if the inspector approves their use, it will most likely be for short runs to a nearby junction box where the flexible cables are connected to a standard, stiff cable.

Manufacturers of inverters and large battery cells might also consider the use of junction boxes and terminals that allow the use of the more rigid standard building cables. Underwriters Laboratories will address the cable and cable termination requirements as the standards are developed for the inverters and battery systems used in residential and commercial systems falling under the NEC.

Summary

Cables are available that can be used for PV installations. In some cases, waivers by the electrical inspector may be required. In other instances, new (to the PV installer) installation techniques may have to be used to deal with the existing, required cables.

Access

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