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Flexible Cables

& Proper Termination

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Many off-grid and some larger utility-interactive renewable energy systems use fine-stranded, flexible cables. These flexible cables are easier to pull through conduit and to bend in tight spaces than large, stiff, standard cables. However, there have been reports of field-made connections that have failed when flexible, fine-stranded cables have been used with mechanical terminals or lugs that use a setscrew to hold the wire in the terminal.

Those of you who have used these flexible cables in your own PV systems (as I have) may have noticed that the terminals need periodic retightening. You torque them to specification when you first install them. After a few months, they may need another tightening to get the torque back up to specification. This can go on for a year of more. Overtightening these connections can result in sheared strands of the very fine individual wires in the cable, stripping the setscrew, or deforming the terminal. These problems don't only happen with the larger cables, but even in small, fine-stranded cables like two-conductor, #18 (0.8 mm^2) "zip cord" used for lamp cords.

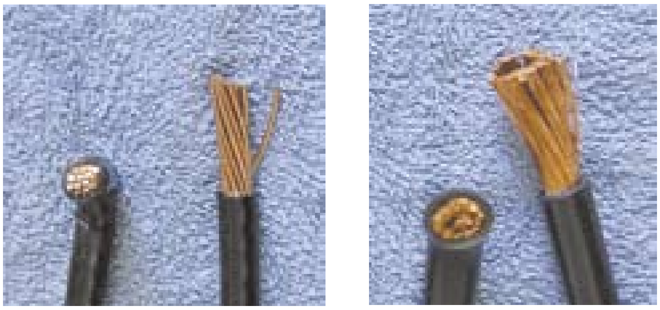
While some electrical equipment uses stud-type terminals that are compatible with fine-stranded wire (provided the correct lugs are used), many circuit breakers, fuse holders, disconnects, PV inverters, charge controllers, power distribution blocks, and some PV modules have setscrew terminals (see photo below).

Examples of mechanical, setscrew terminals.

Fine-Stranded Conductors

By definition, fine-stranded conductors and cables have stranding more numerous than Class B stranding. Class B stranding (the most common) will normally have 7 strands of wire per conductor in sizes #18 through #2 (0.8–33 mm^2), 19 strands in sizes #1 through #4/0 (42–107 mm^2), and 37 strands in sizes 250 kcmil through 500 kcmil (127–253 mm^2).

The photo below shows the differences between standard Class B cables and fine-stranded cables. Both cables pictured are #2/0 AWG (67 mm^2). The THHN Class B cables on the left have 19 separate conductors each with a diameter of 0.084 inches (2.13 mm). The fine-stranded cables on the right have 1,330 separate conductors, each with a diameter of 0.01 inch (0.25 mm).



Standard Class B conductors (left) and fine-stranded conductors (right).

Commonly used building-wire cables, such as USE, THW, RHW, THHN, and the like, are usually found with Class B stranding, but are also readily available with higher stranding. Fine-stranded cables are frequently used in PV systems for battery-interconnect cables, battery-to-inverter cables, and power conductors in large (100 KW plus) utility-interactive inverters.

Some PV modules are supplied with fine-stranded interconnecting cables with attached connectors (sometimes called "MC connectors"). While these crimped-on connectors listed with the module are suitable for use with the fine-stranded conductors, an end-of-string conductor with mating connector may also be supplied with the fine-stranded conductor, and the unterminated end of that conductor may not be compatible with some mechanical terminals. A simple and safe solution is to use end-of-string conductors with Class B stranding, which are readily available.

According to UL Standard 486 A and B, a terminal, lug, or connector must be listed and marked for use with non-Class B stranded conductors. With no marking or factory instructions to the contrary, the terminal should only be used with Class B stranded conductors, since they may not be suitable for use with fine-stranded cables. UL engineers state that few (if any) of the normal, screw-type mechanical terminals that the PV industry commonly uses have been listed for use with fine-stranded wires.

UL suggests three problems may arise when fine-stranded cables are used with inappropriate terminations. First, the turning screw tends to break the fine wire strands, reducing the amount of copper available to meet the listed ampacity. Second, some of the fine strands may slide past the side of the pressure screw and not be fully engaged in the connection. Third, the initial torque setting may not hold the cable, which continues to compress after the initial tightening.

Even after subsequent retorquing, the connection may still loosen. This creates a higher-than-normal resistance connection that heats both the copper and the lug, causing expansion and further loosening. The connection may eventually fail. The photo above right shows a failed mechanical terminal from a 225 KVA, utility-interactive PV system.

Ring Connectors with Stud Terminals

Crimp-on compression lugs in various sizes that are suitable for use with fine-stranded cables are available. Factory-supplied markings and literature indicate which lugs are suitable. An example is the ILSCO FE series of lugs in sizes #2/0 (67 mm^2) and larger. Burndy makes a YA series of lugs in sizes #14 (2 mm^2) and up. In both cases, the lugs are solid copper.

Crimp-on compression lugs must be installed on the cables using the tools recommended by the manufacturer. Common, low-cost, tin-plated aluminum, crimp-on lugs are not suitable for use with fine-stranded conductors. The photo below right shows an example of a typical lug that is not rated for use with fine-stranded cables.

Pin Adapters

Burndy and others make pin (aka pigtail) adapters that can be crimped on fine-stranded cables. The protruding pin of these adapters can be inserted into a standard screw-type mechanical connector. Again, not all pin or pigtail adapters are listed for use with fine-stranded conductors; some are intended for use with aluminum wire and others provide only a conversion to a smaller wire size for a Class B conductor.

Parallel Conductors

In some cases, it may be easier to parallel two smaller conductors to carry the same current as one larger conductor. The *NEC* only allows paralleling of conductors that are size #1/0 (53 mm^2) and larger. This may eliminate the need for fine-stranded cable. Of course, the terminals on the equipment must be designed to accept more than one conductor. Setscrew mechanical terminals are frequently listed for only one conductor per hole, while a stud-type terminal will usually accept more than one crimp-on lug.

Destroyed mechanical terminal and fine-stranded cable from a large, utility-interactive PV system.

Make It Fine

All electrical equipment listed to UL standards has terminals rated for the required current and sized to accept the proper conductors, sufficient wire-bending space to accommodate the Class B stranded conductors, and provisions to accept the appropriate conduit size for these conductors where conduit is required. It is therefore often unnecessary to use the fine-stranded cables.

Whenever fine-stranded conductors are used, they should be terminated properly. With owner-installed and operated systems, the owner can take responsibility for keeping all terminals tight. Otherwise, flexible cables should always be terminated with the appropriate connectors.

Fortunately, some manufacturers have recognized the termination issues related to fine-stranded wire, and modern designs use stud, rather than setscrew terminals on equipment typically used in conjunction with fine-stranded

A typical compression lug—*not* marked for fine-stranded cables.

cable. In these cases, fine-stranded cable can be safely used with the appropriate, rated ring lugs.

Access

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