Building Technologies and Urban Systems Division

Solar Photovoltaic (PV) Cable Management: Best Practices to Support DC-String Cables

Implications for new construction specifications and O&M

Purpose

Use of standard grades of plastic wire ties is by far the most common method used by installers to support and secure direct current (DC) string wiring in an array. At least some of these standard grades of ties fail well before the useful life of the solar PV system. The implications of failed wire supports can be seen in Figure 1 where significant fire-life-safety and performance issues could result from electrical faults. Complicating the specification and procurement decisions is the lack of industry consensus test standards that reflect the degradation forces stemming from the complex combination elements of heat, ultraviolet (UV), chemical reactivity, corrosiveness, and moisture. This content is meant to help agency managers specify wire ties that are more likely to safely and economically secure DC cabling for 25 years.

Figure 1. Photo from Gerald Robinson, Lawrence Berkeley National Laboratory (LBNL)

Background

Issues with DC-string cabling (wiring) on solar photovoltaic (PV) systems are emerging as a significant area of concern related to system failures, underperformance, and safety issues. The SolarGrade PV Health Report, produced by a large solar PV inspection company, Heliovolta, compiled 60,000 field inspection data points and found that 61% of inspected systems had major or critical conditions. Of these serious conditions, 91% are attributable to DC distribution system problems. Of these DC distribution system failures, 26% are due to poor cable management issues.

What Is DC-string Cable Management?

Overall, the objective of DC cable management is to route string wire in a manner that prevents damage to the insulation and conductor by avoiding sharp edges, abrasive surfaces (e.g., roof shingles), moving parts, and direct sunlight exposure. There are several aspects of cable management such as cable length, cutting/splicing, bundling, bend radius limits, installation of connectors, insulation selection, and supporting and securing. This content provides best practices related to cable management around supporting and securing DC-string cabling and focuses on related wire tie technologies. This content compares the cost and durability of common plastic cable ties versus metallic and high-grade polymer alternatives and provides specification language applicable for both new and existing solar PV systems.

Concerns With Plastic Cable Ties

Field inspectors have identified extensive failures of plastic cable ties, even for those labeled UV-stabilized for exterior use. Some last only a few months. Failed plastic cable ties can be seen behind modules and in places not exposed to direct sunlight, indicating that the degradation process is more involved than exposure to UV alone. Figure 2 shows an exterior-rated plastic tie with black carbon to resist UV degradation that failed and was found lying on the ground underneath the solar PV system.

Figure 2. Photo from Gerald Robinson, LBNL

Impacts and Effects of Failures

Figure 3. Photos from Gerald Robinson, LBNL

When cable ties fail, string wiring becomes unsupported and slack. Figure 3 is taken from field inspections, one roof, and another ground system. Slack cables are moved by wind, causing the cables to abrade against other materials (e.g., frame, fasteners, roof, ground) and can eventually lead to an electrical fault and or loss of power from the affected string. In some cases, the inverter is tripped off upon sensing a fault in the string, leading to loss of power and savings. Unsupported cable can put weight on module junction boxes causing the box to separate from module which will in turn result in a total loss of the module.

The worst impacts from cable failures are electrical shock, electrocution, structure fires, or wildfires. The issue of plastic pollution is another concern, as thousands of failed plastic ties can become liberated littering the areas under a system.

Replacing Failed Cable Ties – Cost and Risk

As shown in Figure 3 above, for some roof-mounted solar PV systems, the only way to replace failed cable ties is to substantially disassemble the system. A qualified contractor would need to be retained to perform the work at high cost. Given that the common basic grade of UV stabilized plastic cable ties often provide a few years of service (sometimes months), this action would need to be performed multiple times over a 30-year system life, resulting in high maintenance costs.

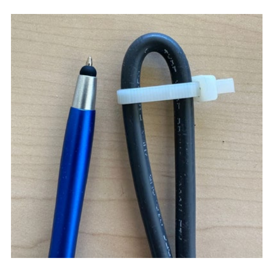

Figure 4. Photo from Gerald Robinson, LBNL

Each time a new cable tie is replaced, the installer may cause harm to the cable in two ways; 1) the bend in the cable may be too tight as shown in

Figure 4, causing damage to the wire strands and resulting in hot spots and 2) if the cable tie is pulled too tight around the wire, the insulation can be damaged.

Why Do Plastic Cable Ties Fail?

Field experience has shown that material degradation pathways are complex and likely involve compound effects of exposure to UV, heat, moisture, and salts (e.g., zinc chloride), among other factors. An exterior-rated tie with UV stabilizers or absorbers does not provide adequate longevity. The codes and standards from Underwriters Laboratory (UL), International Electrotechnical Commission (IEC), and the Canadian Standards Association (CSA) discussed below are not directly designed for the conditions seen in a solar array. However, these standards provide some correlation to cable tie longevity and can be used to develop technical requirements.

Manufacturers' Claims

Manufacturers promoting specially engineered plastic cable ties for the solar industry claim that a specialized polymer mix with modifiers has a long service life of up to 20 years. While none of the manufacturers examined for this content advertised a product warranty (with one exception), one might be available if requested. However, any wire tie product warranty likely would not cover the resulting damage to the DC string wires and resulting life-safety issues. Complicating the procurement decision is that there is no industry consensus test standard and rating system that captures the conditions found in a solar PV array.

Accelerated Aging and Strength Studies

Two studies sponsored by manufacturers examined the exposure of proprietary engineered polymers to high doses of UV along with limited field exposures. However, without an industry-wide consensus test standard that is tailored to solar PV applications, there is no way to independently verify durability and longevity of a product.

Types of Plastic Cable Ties

A wide variety of compounds are used to synthesize plastic cable ties, each having tradeoffs in performance and price. Ties with a high percentage of nylon that are often milky white in color are not suitable for outdoor use (Figure 5). Manufacturers of cable ties add "modifiers" to the plastic compounds to help increase the products' lifespan. For example, adding carbon to nylon and other plastic polymers is a common means to make ties more durable to UV exposure (Figure 5).

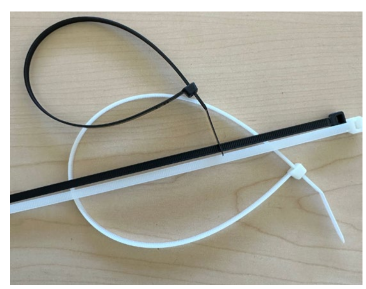

Figure 5. White nylon for indoor use and carbon black nylon for outdoor use. Photo from Gerald Robinson, LBNL

Two manufacturers of polyvinylidene fluoride (PVDF) ties claim 25+ year useful life and can somewhat substantiate the claim as PVDF compounds are used as metal roof coatings and have 30-year service lives. The two PVDF ties sold by distributors are very expensive, however. See Table 2 – Price Comparison below.

Applicable Standard – National Electric Code (NEC)

The NEC covers a wide variety of topics with some sections relevant to the exposed DC cabling systems used in solar PV arrays. As of the 2020 revision of the NEC (NEC 2020), all references to safe DC cable management in solar PV systems have been moved into section 690. Since many of the existing systems were installed under earlier versions of the NEC, it is important to understand requirements from earlier versions in order to assess existing arrays.

Summary of Relevant NEC Code Sections – Applicable to DC-string Cabling		
Section	**Citation**	**Details**
110.12 – Mechanical Execution of Work	*Electrical equipment shall be installed in a neat and workmanlike manner.*	Workmanlike manner is defined by ANSI NSI/NECA 1-2015, Standard Practice for Good Workmanship in Electrical Construction, and other ANSI approved installation standards.
334.30 – Non-Metallic Sheathed Cable (NEC 2017 and earlier) 690.31(C)(1) references Section 334.30 (NEC 2017 and earlier)	*1.Supported and secured by staples, cable ties, straps, hangers, or similar fittings at intervals that do not exceed 4.5 feet.* *2. Secured within 12 inches of each box, cabinet, conduit body, or other termination.*	Section also is applicable to residential non-metallic wiring (under tradename “Romex”) practices and has resulted in application confusion with solar PV systems.
690.31(C) (NEC 2020 and later)	*Exposed cables shall be supported and secured at intervals not to exceed 600 mm (24 in.) by cable ties, straps, hangers, or similar fittings listed and identified* *for securement and support in outdoor locations.*	Provides exceptions to these rules where multiconductor cables have sufficient strength and where support and securement systems are engineered.

The National Electric Code 2020 (NEC 2020) Article 690 now covers wiring materials and methods. This code provides guidance on securing and supporting DC cabling but does not include requirements regarding the composition or longevity of the supporting and securing systems. The standards covered below in Underwriters Laboratory (UL) and the International Electrotechnical Commission (IEC) address this to some extent but are not representative of the complex degradation pathways found in a solar PV system.

Cable Classification System – Underwriters Laboratory (UL)/ International Electrotechnical Commission (IEC) 62275 + Canadian Standards Commission (CSA) C22.2 No 62275 “Cable Ties for Electrical Installations”

Cable ties are broken into classes based on manufacturers' performance claims and lab testing verification (Table 1). The classification system was developed to help simplify the specification and verification process. None of the lab tests can be considered comprehensive enough to represent field conditions, though Type 2 ties appear to be tested under the most stringent conditions.

Table 1 - Cable Classification System

Classification(s)	Materials	Requirement(s)
Type 1	Nonmetallic (polymers) & composites	• Requirement that the tensile strength of the loop is 100% of the manufacturer's advertised strength when first taken out of the packaging. • Type 1 requires a heat aging process and a retest showing the loop strength at a minimum of 50% of the original advertised strength.
Type 11	Nonmetallic (polymers) & composites	• Same as Type 1 with long-term performance qualification of the polymer based on American National Standards Institute (ANSI)/UL 746B(2) and UL-QMFZ2. • Uses a heat based aging process.
Type 2	Metallic, nonmetallic (polymers) & composite	• Requirement that the tensile strength of the loop is 100% of the manufacturer's advertised strength when first taken out of the packaging and after the heat aging process. • Type 2 allows no strength degradation on the loop after aging.
Type 21	Metallic, nonmetallic (polymers) & composite	• Same as Type 2 with long-term performance qualification of the polymer based on ANSI/UL 746B(2) and UL-QMFZ2. • Uses a heat based aging process.
Type 2S & 21S	Metallic (2S only), nonmetallic (polymers) & composite	• The "S" designates that the cable ties have a specific prescribed loop or mechanical strength.

Alternatives to Standard Plastic Cable Ties

A variety of alternative methods can be used to support DC-string wiring, including metallic clips, hangers, and cable tray concepts. Figure 6 shows a sample cable support and securement hardware on display at the large annual international solar trade show (RE+ 2023) in Las Vegas in September 2023. A huge variety of support hardware is available for either single or a bundle of wires. These alternatives can be installed quickly without tools and should result in significantly improved longevity if of high grade (e.g. stainless 316 or PVDF) material. Examining large volume pricing reveals that some of these clips are significantly less expensive than some of the specialized plastic ties advertised for use on solar PV systems (see Table 2 below). Another good choice of cable support and securement systems can be through the racking manufacturers. There are several proprietary cable support products offered by racking manufacturers.

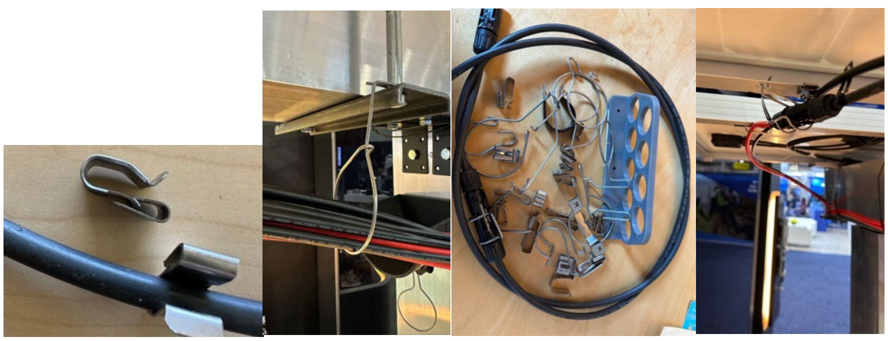

Figure 6. Samples of single and bundled wire support devices found at RE+ 2023. Photos from Gerald Robinson, LBNL

Material Cost of Cable Ties and Alternative Metallic Devices

For a 300-kW system, assuming the contractor follows NEC 2020 690 and supports the DC cabling every 24 inches, there would be about 2,100 cable ties. Table 2 shows the price per each tie and then for a 300-kW system. Note that the polymer-based cable ties are comparably priced or, in one case, substantially more expensive than metallic options.

The analysis below assumes that each solution requires about the same amount of installation labor as data was lacking on this facet of costs.

Table 2 - Price Comparison Table

Cost Comparison Between Cable Tie Hardware Options		
Volume Pricing (1,000 or more)	**$/Tie**	**Cost for 300kW System**
Solar-specific engineered polymer and composite cable ties	$.67- $.80/Tie	$1,407 - $1,680

Polyvinylidene fluoride (PVDF) tie	$1.50/Tie	$3,150
Stainless steel cable bundler	$.70-$.90/Bundler	$1,470 - $1,890
Stainless clips	$.14/Clip	$294

Life Cycle Cost Implications

While first cost is important, the cost of wire ties is a small cost of an installed systems yet greatly influences ownership costs and system longevity especially when electrical faults or life-safety conditions develop from unsecured DC cabling. Saving money by using low-grade plastic wire ties is likely to have significant life-cycle cost implications from loss of performance, system damage and costs to dismantle and reassemble (roof arrays).

Specifying Cable Ties

Use the following language (blue italic), which is based on the classification system in Table 1, in a solicitation. Note that many common cable ties are not labeled nor do product specification sheets refer to the classification system in Table 1 which complicates procurement and verification processes.

Cable ties shall be either Type 2, 2S, 21, or 21S. In addition to these allowed types, only ties that have a 25-year service life shall be used. No unlisted or unlabeled ties lacking markings shall be used. Cable ties or supports of stainless 316 shall be considered to have a 25-year service life.

Specifying Alternatives to Cable Ties

The blue italic language below can be used to specify alternatives to cable ties:

DC-string wiring shall be held using metallic or non-metallic alternatives to standard plastic cable ties such as friction clips, hangers, trays, hoops, and other similar concepts. These devices shall be stainless steel grade 316 or hot dipped galvanized, PVDF and, if near coastal areas, shall be stainless steel grade 316 on PVDF only.