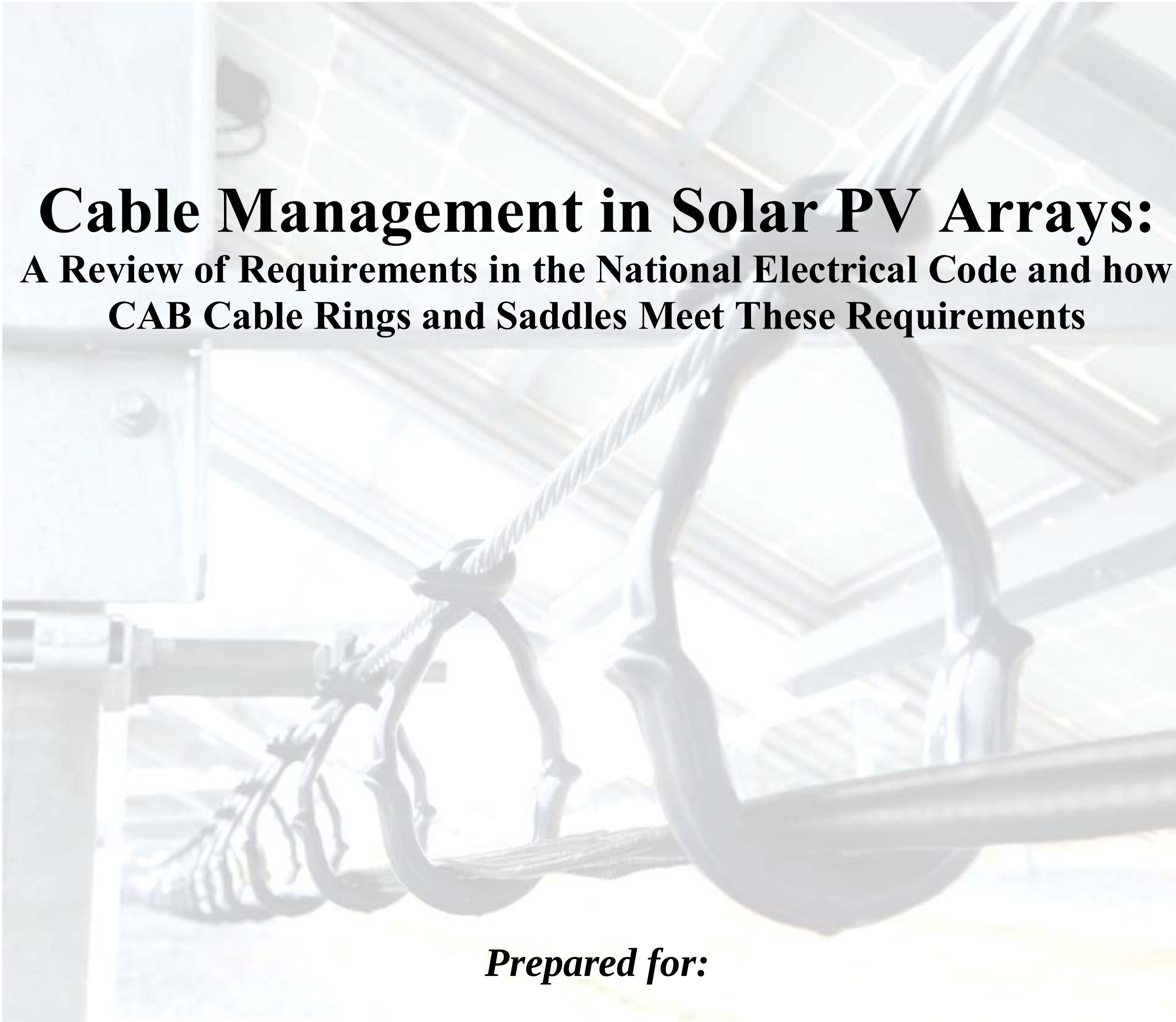

Cable Management in Solar PV Arrays:

A Review of Requirements in the National Electrical Code and how CAB Cable Rings and Saddles Meet These Requirements

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1 Introduction

Cable management is one of the most important aspects of the safety and longevity of nearly every photovoltaic (PV) system. This is primarily due to the extensive use of exposed cables used in the dc PV array. Since the equipment is installed outdoors on rooftops and in open fields, the electrical conductors must be rated for sunlight resistance and be supported and secured properly. Most electricians are referred to as “indoor wiremen” and are familiar with installing conductors in conduit, but have little, if any, experience working with exposed cables in power systems. These exposed cable power systems are common in the utility and petroleum industries and there are decades of experience with these types of systems. Since the National Electrical Code (NEC) does not regulate either of these industries, there is little in the NEC to guide these types of installations.

While the NEC may not have a lot of guidance on exposed cable management, there are several references to such systems and there are broad requirements for safe wiring practices that can be used to develop best practices for exposed cable systems in solar PV systems. This document will lay out the basic requirements found in the 2014 NEC and relate those requirements to Cable Rings and Saddles manufactured by the company CAB that are relevant to the NEC requirements and industry standard installation practices.

2 Review of NEC Requirements and Installation Standards

The primary aspects of this review will focus on the installation of the CAB Cable Rings and Saddles used for cable management in a solar PV array. Proper methods for exposed cable management is ultimately an issue of approval by the authority having jurisdiction (AHJ). That approval is generally based on the application of the National Electrical Code (NEC) and electrical installation standards. A common thread in the installation of electrical systems is that the work be done in a neat and workmanlike manner [NEC 110.12] and that conductors are not exposed to physical damage [NEC 300.4].

> ***110.12 Mechanical Execution of Work.*** *Electrical equipment shall be installed in a neat and workmanlike manner.*
>
> > *Informational Note: Accepted industry practices are described in ANSI/NECA 1-2010, Standard Practice of Good Workmanship in Electrical Construction, and other ANSI approved installation standards.*

> ***300.4 Protection Against Physical Damage.*** *Where subject to physical damage, conductors, raceways, and cables shall be protected.*

Physical damage is not specifically defined in the NEC or in ANSI/NECA 1-2010. However, it is generally understood as being self-defined. Preventing physical damage to electrical equipment in a parking garage may mean installing bollards or cages to keep cars from running into it [NEC 100 Enclosure, NEC 110.27(B), NEC 110.31(D)]. For conductors it is also highly location specific and physical damage would mean obvious items that could damage the insulation on a conductor. This would include chafing on sharp edges, car traffic, and vandalism depending on the installation. The NEC considers conductors and equipment below 8’ to be readily accessible in general. By placing cables or equipment above 8’, it may be possible to prevent damage due to accidental damage or vandalism in a public area. In a large PV power plant, the perimeter fencing and security system that keeps unqualified people out of the facility is sufficient to prevent physical damage due to unqualified persons. However, since vehicles often need to be used within the PV array, care should be taken in the design to prevent damage from vehicular traffic. This would include following rules for overhead conductors should vehicles be required to travel under cable management systems.

Given the large amount of exposed cable used in PV arrays, it is understandable that wiring methods are as simple and cost effective as possible to keep installation and maintenance costs to a minimum. This often creates differences of opinion as to whether exposed cables are installed in a neat and workmanlike manner that is free from physical damage. During the past 15 years when PV systems have predominantly used exposed dc cabling systems—many of the disagreements over installation practices revolve around exposed cable management in the PV array.

2.1 Installation Standards in ANSI/NECA 1

Since the NEC references ANSI/NECA 1-2010 in the informational note for NEC 110.12, it is helpful to review that installation standard for any information that may be relevant to industry standard practice in this area. Chapter nine of this standard in entitled “Wire and Cable” and includes the relevant information. In the opening clauses in chapter nine there are several simple and clear statements regarding cable management:

c) Wire and cables shall be installed so as not to damage the insulation or cable sheath.

h) Cables that are installed exposed shall be run parallel and perpendicular to the surface of the building or exposed structural members and follow the surface contours as much as practical.

i) Running boards shall be used where necessary to provide sufficient support and a neat installation. Care shall be taken to provide sufficient mechanical protection for exposed cables.

j) All wires and cables, whether exposed, concealed or in raceways, shall be sufficiently supported using devices intended for the purpose.

Item “c)” above is self-explanatory. Cable damage is unacceptable because of the obvious hazards of energized conductors. Items “h)” and “i)” do not relate directly to cable hangers or CAB Cable Rings and Saddles, but they are relevant in that they address the neatness of an installation and the importance of mechanical support of exposed cables. Lastly, item “j)” focuses on the intended purpose of supporting devices. An installer may argue that a piece of coat hanger or bailing wire could support a cable, but these devices are not intended for the use. A similar issue could be made of an electrical support item not used in its intended use. For instance, a one-hole conduit strap designed to support a 1” EMT conduit could support an exterior cable. However, that device has sharp edges intended to help hold the conduit that can cause cable damage. The one-hole conduit strap device should not be used as a cable hanger since it is not intended for that use and can damage the cable insulation. This violates two directives of the installation standard.

Lastly, there is a specific directive in the ANSI/NECA 1-2010 standard related to securement and support with cable ties.

> *q) When using cable ties, do not over tighten, to ensure the cable tie does not cut the conductor's outer jacket. Cable ties shall not be used to support raceways or cables.*

It is the recommendation of this standard that cable ties not be used to support cables. It is common to see cable ties used in PV installation as the sole method of support. While it is not specifically disallowed in the NEC, this industry standard does not allow it. This clause also warns against the common mistake of overtightening cable ties to the point where they could damage the cable jacket. In summary, the requirements in the ANSI/NECA 1-2010 installation standard are common sense items that state that exposed cables should be supported and secured in such a way that the cables are undamaged, neat, and supported and secured by devices intended for cable support.

2.2 Requirements Relevant to Cable Management in the NEC

The 2014 NEC does have some direction on the support and management of exposed cables. Article 690 of the NEC, Solar Photovoltaic Systems, allows single conductor cable USE-2 and PV Wire to be installed in exposed locations within the array [NEC 690.31(C)(1)]. The installation methods for the exposed USE-2 cable is stated in NEC 338.10(B)(4). USE-2 cable is commonly used in PV array and is very similar to the PV Wire also used in many PV arrays which is why it is mentioned in the same section in 690.31(C)(1). Article 338.10(B)(4) refers the installer on to Article 334.30 for support methods. Article 334 is entitled Non-Metallic Sheathed Cable (often referred to by the trade name Romex) and includes these requirements for cable management in 334.30:

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

The provision for securement within 12 inches of a box is very well understood for NM cable in residential construction. The analogue in a PV array could be compared to the entry into a conduit system going underground or to a combiner box. These are subjective evaluation criteria and require the AHJ to provide their approval of the support methods.

A new section in the 2014 NEC in Article 690.31(C)(2) for cable tray also illuminates the intent of cable management in a PV array.

> ***(2) Cable Tray.*** *PV source circuits and PV output circuits using single-conductor cable listed and labeled as photovoltaic (PV) wire of all sizes, with or without a cable tray marking/rating, shall be permitted in cable trays installed in outdoor locations, provided that the cables are supported at intervals not to exceed 300 mm (12 in.) and secured at intervals not to exceed 1.4 m (4.5 ft).*

This new section is quite relevant to products such as the cable hangers or Cable Rings and Saddles manufactured by CAB. While the code would allow up to 4.5 feet between cable supports according to article 334.30, this new provision for cable trays provides a distinction between cable support and cable securement. In a cable tray that has ladder-type rungs for cable support, the distance between rungs can be specified when purchased. Typical distance between ladder rungs is 12” to 18”. Since the new NEC provision in Article 690.31(C)(2) allows for any size conductor, the provision requires a maximum distance of 12” between supports.

Article 392 in the NEC, which covers cable tray installation, does not require additional securement of cables for horizontal installations other than those required by the wiring method [NEC 392.30]. This means that Article 392 would only require securement at 4.5 foot intervals for USE-2 which is consistent with NEC 334.30. This is why Article 690.31(C)(2) requires securement at intervals no larger than 4.5 feet for USE-2 and PV Wire.

Following both support and securement requirements outlined in Article 690.31(C)(2) for cable hanger installations is a well-founded approach. This means that cable hangers should be placed at 12” intervals and the cables secured to the hangers using cable ties at every fifth hanger (4 feet between securements). This basic approach is consistent with the requirement in Article 690.31(C)(2) for cable tray and would allow any size conductor to be used in the hanger [see Figure 1]. Given the mechanical strength of larger conductors (1/0 AWG and larger), it would be possible to use a greater distance between hangers for support while the securement distance should not increase past 4.5 feet. For example, if a group of four 4/0 AWG aluminum USE-2 cables were run in a cable hanger system, a distance of 18” between hangers would be sufficient for support while every fourth hanger would have cable tie securement (4.5 feet between securements). The reason 18" was chosen as a maximum distance between hangers is that it is consistent with commonly available cable tray rung spacing. The 12" support distance should be used for cable sizes less than size 1/0 AWG.

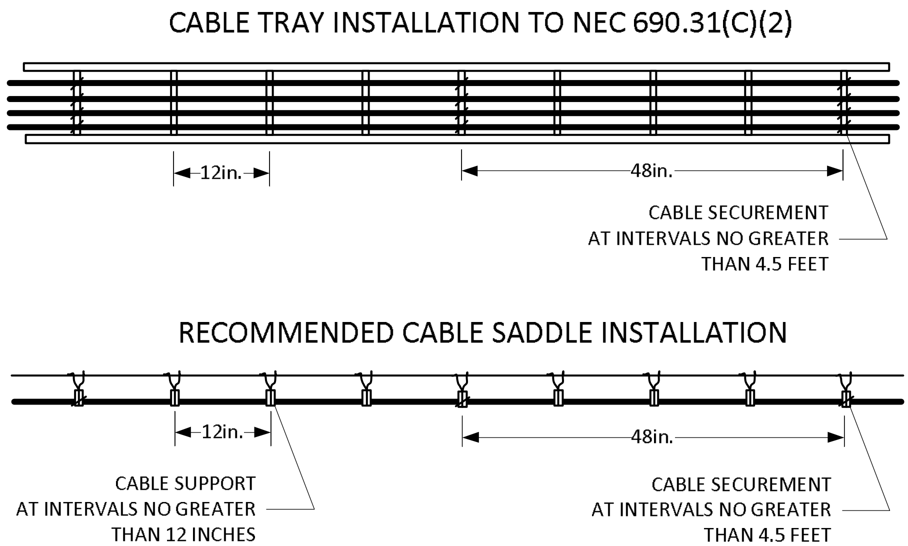

Figure 1: Cable Tray and Cable Saddle Installation Similarities

Since many ground-mounted PV arrays have tracking systems that use ac power to drive the tracker systems, an installer may want to install the ac conductors in the same cable support system with the dc conductors. In the 2011 NEC and prior versions of the NEC, it would be acceptable to have the cables in the same saddle as long as the conductors are bundled separately [2011 NEC 690.4(B) and NEC 690.4(B)(4)]. However, there is a significant change in the 2014 NEC that disallows dc and ac conductors, even when part of the same system to be installed in the same raceway or enclosure unless they are separated by a partition. The same messenger wire could be used, but a different type of ring or saddle would be necessary to separate the dc and ac cables. Figure 2 shows one method to separate the dc wiring from the ac wiring. Another ring design that would

Figure 2: Two Cable Systems on the Same Messenger Wire with Two Saddle Types

accomplish the same separation objective is shown in Figure 3. In Figure 3, the same cable ring is used, but the single ring has two separate saddles to separate dc and ac

Figure 3: Single Cable Ring with Two Saddles

cables. A third variation on this concept is shown in Figure 4. The cable ring design shown in Figure 4 provides for three different types of exposed cables. The same coated wire is used to create two main cable sections for the dc and ac conductors, but a third section at the top of the ring is provided to install a communications cable. This is key because the required communications cable may not be of the same voltage rating as either the dc or ac cables. Since the communications cable is kept separate from the dc and ac cables, the voltage rating of the communications cable need only be sufficient to withstand the voltage of the communication circuits. This third section can have a significant value for the support of exposed cables since the code would require that the communications cable have the same rating as any conductors it contacts. Finding communications cables with ratings above 150 volts can be difficult not to mention expensive. Both dc and ac circuits used in most large ground mounted systems are well above 150 volts. All three designs shown in Figures 2, 3, and 4 are available from CAB products.

Figure 4: Cable Ring with three Cable Sections

3 Grounding and Bonding of Cable Supports

The electrical industry, including code enforcement personnel, are heavily focused on grounding and bonding of metallic parts. The primary concern is contact of exposed metal parts with conductors having damaged insulation—thus energizing the metal parts. Consider a metallic cable hanger like the CAB Cable Rings and Saddles shown in Figure 3. These types of cable rings and saddles would fall under that definition of "fitting" in Article 100 of the NEC.

> ***Fitting.*** *An accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function.*

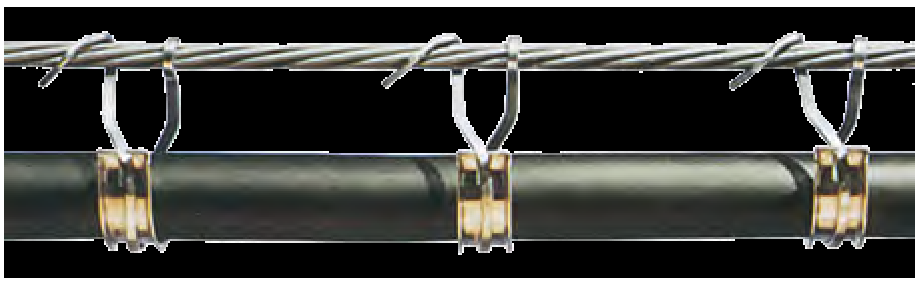

Figure 5: CAB Cable Rings and Saddles Installation

Some AHJs may request that exposed metal rings and saddles be evaluated for bonding, but this is not well substantiated in the NEC, nor is there a UL standard for evaluating such equipment. As an example, metallic cable staples for NM cable are not required to be bonded. The NEC simply states in Article 334.30 that, "*Nonmetallic-sheathed cable shall be supported and secured by staples, cable ties, straps, hangers, or similar fittings designed and installed so as not to damage the cable*…." Clearly, damage to the cable is the issue. Given this line of reasoning, a cable hanger or similar fitting such as CAB Cable Rings and Saddles could be installed without a listing for bonding and grounding. In Figure 5, the hangers are actually in full contact with a grounded steel messenger wire. It could be argued that even if the conductor insulation were ever to be damaged, the cable rings and saddles would stay at or near ground potential.

Ultimately, the AHJ must approve any equipment used in a PV installation under their purview. If an AHJ will not accept cable rings and saddles as being designed to prevent damage to the cable, a simple way to resolve the need for bonding this product is to coat the product with a durable non-conductive coating so that the metal of the rings and saddles never comes in contact with the cable. An example of CAB Cable Rings and Saddles with this type of coating is shown in Figure 6.

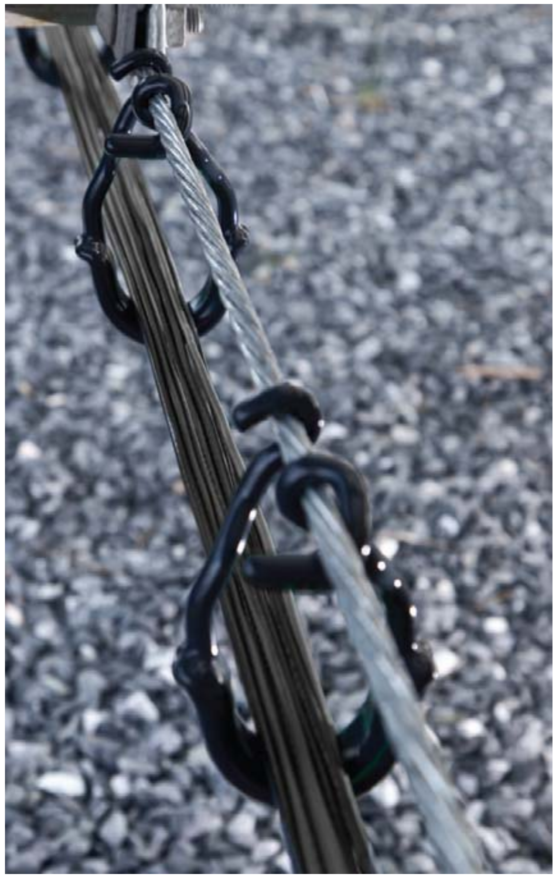

Figure 6: CAB Cable Rings and Saddles with PVC Coating

4 Ampacity of Conductors Bundled in a Cable Support

Another important concern of the AHJ is the ampacity of the conductors. Clearly, a USE-2 installation such as the one shown in Figure 3 should be considered as a free air installation and subject to the free air ampacity table, Table 310.15(B)(17), for ampacity values. However, as cables are bundled together, as in Figure 4, the inner conductors are not in free air and their ampacity is similar to conductors in a raceway. Therefore, to be conservative, a cable bundle of three cables should be subject to the ampacity limitations of Table 310.15(B)(16) which is used for up to three conductors in a raceway. Since outdoor ambient design temperatures are generally above 30°C for most of the United States, an additional correction factor for temperature should be applied according to Table 310.15(B)(2)(a). For more than three cables in a bundle, Table 310.15(B)(3)(a) should adjust the ampacity further.

This may be a conservative interpretation, but the NEC is not specific on this issue. Supporting evidence in the NEC for the above method is found in Article 392 for Cable trays. Uncovered cable trays with multiconductor cables [392.80(A)(1)] requires the use of Table 310.15(B)(16) as a starting point. When a cable has more than three conductors in a bundle, it requires using the adjustment factors for conduit fill in Table 310.15(B)(3)(a).

Given the above references in the NEC, it appears that it is appropriate to use the free air table [Table 310.15(B)(17)] only for unbundled single conductor cable. This may be slightly conservative, but it is difficult to justify another position from the language of the NEC. In the future, with supporting research on specific applications, it may be possible to use Table 310.15(B)(17) rather than 310.15(B)(16) for bundled conductors.

5 Summary

In summary, using purpose-built products like the CAB Cable Rings and Saddles for the exposed cable management in a PV array are well substantiated by the NEC and industry installation standards. Multiple sections, such as those in various configurations of CAB Cable Rings and Saddles, create effective separation of conductors that allow for dc, ac, and communications cables to be supported with a single ring type.

Whether or not uncoated metallic require bonding and grounding could be an item of dispute with various AHJs, so the cable management design should be communicated to the AHJ and approved prior to ordering the cable management equipment. Ampacity of bundled cables in a cable management system should follow Table 310.15(B)(16) and should be corrected by Table 310.15(B)(2)(a) for ambient temperatures above 30°C and adjusted by Table 310.15(B)(3)(a) when more than three conductors are in the bundle.

This concludes the Brooks Engineering assessment of the code compliance of the CAB Cable Rings and Saddles cable management equipment. Questions about the details of this evaluation should be addressed to Bill Brooks of Brooks Engineering at billbrooks7@sbcglobal.net.