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CFX ITS Inspection Reference & Training Manual

Chapter 4

Conductors

4.0 OVERVIEW OF CONDUCTORS

Conductors contain conductive materials, typically metals such as copper, which allow the flow of electrical current from one point to another. Conductors are utilized in CFX's ITS infrastructure as a means of providing power to ITS equipment and devices installed throughout CFX's system. This Chapter will introduce the basic concepts and terminology needed to understand how conductors are constructed, the different sizes and types of conductors, installation techniques and requirements for conductors being installed in CFX's ITS infrastructure.

4.1 CONDUCTOR CONSTRUCTION

The word conductor is a broad term which can include a wide range of different conductive strands or cables being used to provide power to equipment. The actual type and size of conductor being used will vary based on application, typically being dictated by factors such as: indoor or outdoor installation, planned load on the circuit, and distance of the circuit. In this Section, we will review basic conductor terminology and go into detail on how a typical conductor is constructed.

4.1.1 Conductive Material – Electrical conductivity is a measure of how easily a material allows the movement of electrically charged particles, or in other words, how well a material allows the flow of electrical current. Conductors make use of the high electrical conductivity inherent in metals. Metals such as silver, copper, gold, and aluminum are among the most highly conductive metals. Since silver and gold are expensive precious metals, their use as the conductive material in conductors is not practical. Instead, copper and aluminum are the most commonly used metal as conductive materials in conductors.

Comparatively, aluminum is much lighter than copper so its use in certain applications such as overhead installations, where weight needs to be considered, can be advantageous. Copper however has a better electrical conductivity than aluminum allowing for the use of a smaller gauge of conductor for the same installation. Historically, aluminum conductors have had issues and are not as easy to work with as copper. The rest of this Chapter will focus primarily on conductors that use copper as the conductive material as this is what CFX requires for installation in their ITS infrastructure.

It is also worth mentioning here that alloys such as tinned copper, where a thin tin coating is placed over an inner copper core, can also be used as the conductive material in conductors. The tin coating strengthens the copper's natural properties making the conductor better equipped to resist humidity, high temperatures, and wet environments. For this reason, tinned copper can be advantageous in underground direct bury installations where the conductor will be exposed to the elements.

4.1.2 Insulation – To be useful and safe, conductors must be constructed such that the electrical current they are carrying is forced to flow only where it is needed. Conductors must be constructed to prevent the current-carrying copper strands from coming into contact with one another or personnel working near them and to protect the conductive material from the elements. To achieve this, the conductive material will be coated or wrapped with an exterior insulation as shown in Figure 4.1 below.

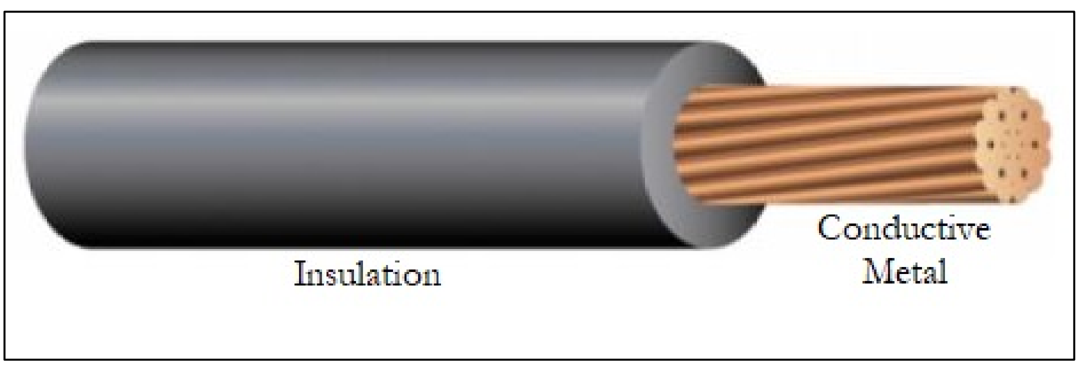

Figure 4.1: Typical Conductor Construction

The insulation material will have a high electrical resistivity to prevent current leakage through the insulation. Electrical resistivity is the opposite of electrical conductivity, it is a measure of how well a material opposes the flow of electrical current. There are a wide variety of insulating materials used on conductors, the most common are various plastic or rubber compounds. The safety and effectiveness of a conductor and their use in different applications will depend on its insulation.

4.1.3 Jacket – A jacket is the outermost layer of a cable and serves the purpose of protecting the insulation and conductive material from mechanical damage during and after installation and from chemical deterioration. It should be noted that the jacket has little to do with the conductor's electrical performance. Like the conductor insulation, jackets come in a variety of types and styles and are mainly plastic or rubber based. For clarity on the difference between insulation and jacket, Figure 4.2 below identifies both on a multi conductor cable.

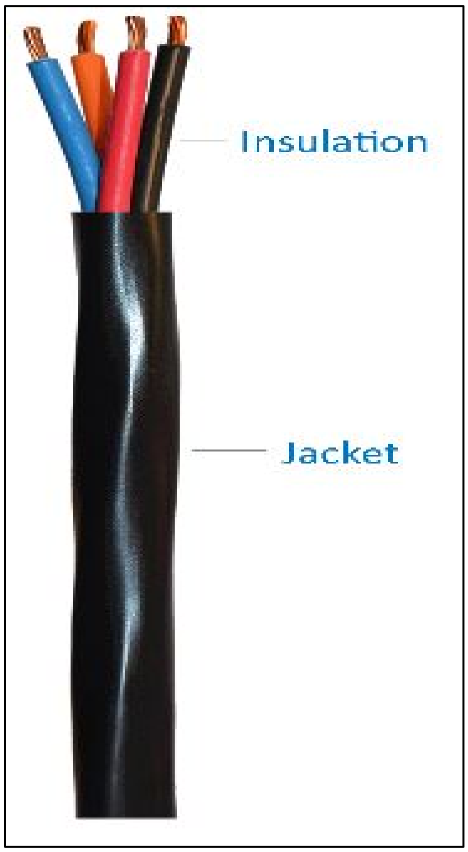

Figure 4.2: Jacket Versus Insulation

4.1.4 Conductor Size – Conductor size is determined based on the diameter of the innermost conductive material only and does not include the insulation or jacket. Conductor sizes are specified and will be given in construction plans according to the American Wire Gauge (AWG) system. The AWG system provides conductors with a numerical designation that runs opposite to the diameter of conductors, the smaller the AWG number, the larger the conductor's diameter. Figure 4.3 below provides a table of common conductor gauges and their corresponding diameter and cross-sectional areas. Note that 4-aught, shown as 0000 or 4/0, is the largest conductor size whereas 40-gauge is the smallest size conductor in the AWG system. As a rule of thumb, for every 6 AWG decrease, the conductor diameter doubles. Figure 4.4 below shows a wire gauge tool which is used to measure the size of a conductor to determine its AWG designation.

AWG #	Diameter (inch)	Cross Section Area (mm^2)
0000 (4/0)	0.4600	107.2193
0 (1/0)	0.3249	53.4751
2	0.2576	33.6308
4	0.2043	21.1506
6	0.1620	13.3018
8	0.1285	8.3656
10	0.1019	5.2612
12	0.0808	3.3088
14	0.0641	2.0809
40	0.0031	0.0050

Figure 4.3: Common AWG Sizes

Figure 4.4: Wire Gauge Tool

The size of the conductor dictates how much electrical current (ampacity) can safely pass through it. If a conductor is overloaded with too much electrical current for the size conductor, the conductors can overheat causing the circuit to fail, cause an electrical fire, or damage devices being powered by the circuit. While there will typically be circuit breakers or fuses in a circuit that should help protect conductors from being overloaded, these systems are not foolproof. As such, it is crucial that the correct size conductor is installed as designated in the construction plans. Figure 4.5 below shows the safe current carrying capacity for some AWG sizes that are commonly utilized in CFX's ITS infrastructure.

AWG #	Current Carrying Capacity
2	95 amps
4	70 amps
6	55 amps
8	40 amps
10	30 amps
12	20 amps
14	15 amps

Figure 4.5: Current Carrying Capacity for AWG Sizes

4.2 TYPES OF CONDUCTORS

As was outlined in the previous Section, there are many types and sizes of conductors available. The specific type and size of conductor used will vary based on the application and the project requirements. This Section will focus on the different types of conductors commonly utilized in CFX's ITS infrastructure and the applications in which they are used.

4.2.1 Bare – A bare conductor is simply a conductor that does not have insulation. Bare conductors are typically used for bonding and grounding which will be discussed in detail in the Grounding Chapter.

4.2.2 Solid – Solid conductors are manufactured with a single solid core, or single strand, of conductive material. Due to having only a single strand of conductive material, solid conductors tend to be very rigid leading to difficulties with installation in a raceway that has a lot of bends, particularly with larger diameter conductors. Because of this, solid conductors are commonly only sold in smaller diameters. It is worth mentioning that solid conductors also have advantages over stranded conductors, as they tend to have less corrosion and are easier to weld.

4.2.3 Stranded – Stranded conductors consist of multiple strands of smaller gauge conductors twisted together to create a larger conductor of specified diameter. Figure 4.6 below demonstrates the difference between solid and stranded conductors. Since stranded conductors are comprised of multiple strands of smaller gauge conductors, they tend to be more flexible and easier to install into a raceway than a solid conductor of the same diameter. Stranded conductors are susceptible to oxidative corrosion which can deteriorate the strands, but this is mitigated when using cadwelds. Stranded conductors are the most common type of conductor used in CFX's ITS infrastructure for powering their ITS equipment.

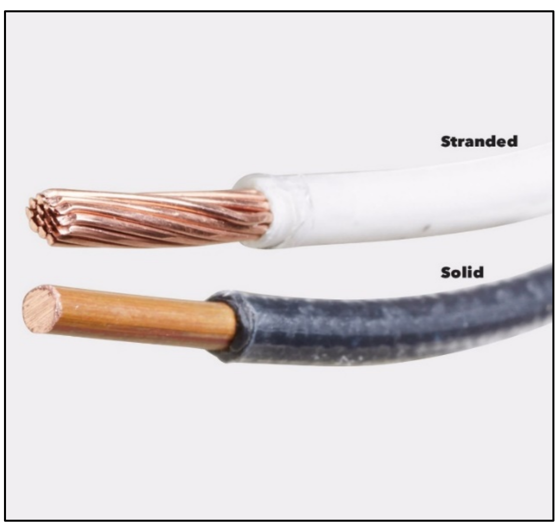

Figure 4.6: Solid and Stranded Conductors

4.2.4 Multi-Conductor - Multi-conductor cables are comprised of several conductors housed within a single outer protective jacket as shown in Figure 4.7 below. The conductors in a multi-conductor cable can be different gauges, bare or insulated, and have different color insulation for color coding purposes which we will discuss later in this Chapter. Multi-conductor cables can be used to provide both power and communications to ITS devices.

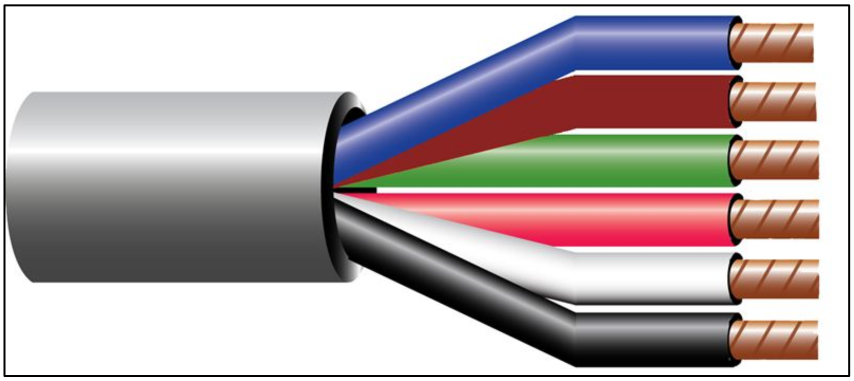

Figure 4.7: Multi-Conductor Cable

4.2.5 Insulation Type – As discussed in Section 4.1.2, there are numerous conductor insulation types available. We will by no means cover them all in this Chapter. Instead, this Section will focus specifically on: Thermoplastic High Heat-resistant Nylon (THHN) and Cross-Linked Polyethylene High Heat-resistant Water-resistant (XHHW).

4.2.5-1 THHN (Thermoplastic High Heat-resistant Nylon) – THHN are types of conductors comprised of an inner conductive material with a PVC insulation and an outer nylon jacket. The combination of PVC insulation and outer nylon jacket provides mechanical protection and protection from hydrocarbons such as oils and greases to prevent chemical degradation of the conductor. The thickness of the PVC insulation and outer nylon coating will depend on the gauge of the conductor. A #6 AWG conductor, for example, would have a PVC insulation and nylon coating thickness of 30 and 5 Mils, respectively. THHN conductors are very economical and are the most popular type of conductor used in construction. THHN conductors are offered in a water-resistant type that can be used in wet and dry locations known as THWN and THWN-2. The characteristics for these variations are given in Figure 4.8 below.

THHN	THWN	THWN-2
T = Thermoplastic **HH** = High Heat Resistance **N** = Nylon Coated **Temp Rating:** 90° C in dry locations	**T** = Thermoplastic **H** = Heat and **W** = Water Resistance **N** = Nylon Coated **Temp Rating:** 90° C in dry locations and 75° C in wet locations	**T** = Thermoplastic **H** = Heat and **W** = Water Resistance **N** = Nylon Coated **Temp Rating:** 90° C in both dry and wet locations

Figure 4.8: THHN/THWN/THWN-2 Characteristics

Despite its popularity, CFX does not allow THHN/THWN/THWN-2 conductors to be used in the construction of their ITS infrastructure. **The CEI shall be diligent when conductors are being installed for ITS construction purposes to verify that the conductor is not THHN. Only XHHW conductors are permitted for installation on CFX Projects.**

4.2.5-2 XHHW (Cross-Linked Polyethylene High Heat-resistant Water-resistant) – CFX Technical Specification 639A requires all conductors utilized in CFX's ITS infrastructure to be XHHW. XHHW conductors are comprised of an inner conductive material and features a cross-linked polyethylene (XLPE) insulation. XHHW conductor insulation is thicker than THHN conductor insulation, as demonstrated in Figure 4.9 below for a #12 AWG conductor, making it less susceptible to current leakage, environmental impacts, and eventual breakdown.

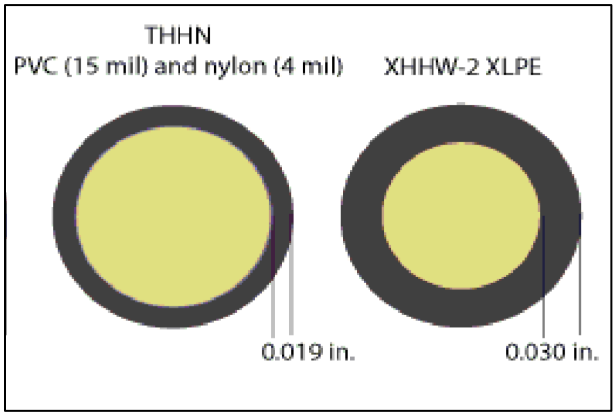

Figure 4.9: THHN and XHHW Insulation Thickness

The XLPE insulation is also a more flexible design that is easier to install than the THHN alternative. XHHW conductors are also offered in a 2nd generation known as XHHW-2, the characteristics for these variations are given below in Figure 4.10.

XHHW	XHHW-2
X = Cross-Linked Polyethylene (XLPE) **HH** = High Heat-Resistance **W** = Water Resistance **Temp Rating:** 90° C in dry locations and 75° C in wet locations	**X** = Cross-Linked Polyethylene (XLPE) **HH** = High Heat-Resistance **W** = Water Resistance **Temp Rating:** 90° C in both dry and wet locations

Figure 4.10: XHHW/XHHW-2 Characteristics

4.3 INSTALLATION OF CONDUCTORS

This Section will outline the installation requirements for conductors installed on CFX's system for ITS applications. In general, conductor installations for CFX's ITS infrastructure shall meet the requirements of CFX Technical Specification 639A and the National Electric Code (NEC).

4.3.1 Conductor Requirements – CFX Technical Specification 639A requires all current carrying conductors installed in their ITS infrastructure to be stranded copper conductor rated for 600 Volts in both wet and dry conditions with XHHW insulation with a thickness of 45 mils or greater (the increased mils is required to ensure that acidic conditions do not degrade the insulation over time). The plans will specify the specific size of conductor required for each installation. The CEI and contractor shall be diligent in continually verifying that the appropriate size and type of conductor is being installed on a daily basis. The type of conductor can easily be identified in the field by inspecting the insulation which will have the gauge and insulation type stamped on it at even increments as shown in Figure 4.11 below.

Figure 4.11: Conductor Identification Markings

4.3.2 Identifying Conductors – This section will discuss the importance of having conductors properly identified, how conductor identification is accomplished, and briefly cover requirements for conductor identification for CFX's ITS infrastructure. Being able to identify quickly whether a conductor is a "hot" (i.e. current carrying conductor) or simply a ground is of critical importance for any conductor installations to ensure a safe installation.

4.3.2-1 Insulation Color – Conductor insulation color code requirements is the most common form of conductor identification. NEC, local agency requirements, and common trade practice for electricians all come into play when determining the appropriate color conductors to install. For CFX's ITS infrastructure, the CEI and contractor shall ensure the specific color code requirements of CFX Technical Specification 639A are followed. We will cover electric power service requirements in detail in a chapter 8, for now just note the following insulation color requirements for the corresponding Volts alternating current (VAC) circuits:

- **120/240 VAC** –
  - *Black* – Default hot conductor
  - *White* – Neutral conductor
  - *Green* – Ground conductor
  - *Red* – Second hot conductor
  - *Blue* – Third hot conductor

- **240/480 VAC** –
  - *Brown* – Default hot conductor
  - *Grey* – Neutral conductor
  - *Green* – Ground conductor
  - *Orange* – Second hot conductor
  - *Yellow* – Third hot conductor

4.3.2-2 Phasing – NEC recognizes the practice of phasing a conductor as an acceptable means of re-identifying conductors. Phasing is a practice where marking tape, paint, or other effective means are used to identify the conductor at all termination, connection, and splice points. The NEC gives specific circumstances in which phasing of conductors for identification purposes is allowable. However, for the purposes of CFX's ITS infrastructure, phasing of conductors #6 AWG or smaller is not allowed (also an NEC violation) and phasing of any conductors #4 AWG or larger is only permissible on black conductors where the tape used must be either green, white, red, or blue for 120/240 VAC circuits and green, grey, brown, orange, or yellow for 240/480 VAC circuits as is shown in the example in Figure 4.12 below. Any phasing tape used to identify conductors on CFX's ITS infrastructure shall meet the following requirements: UL Listed, UL 510, CSA Certified, RoHS 2002/95/EC, ASTM D1000. Additionally, when phasing of conductors is performed, the entire visible portion of the conductor shall be re-identified completely. This pertains to all phasing performed in pull boxes, cabinets, panels, etc.

Figure 4.12: Phasing of Conductors

4.3.3 Conduit Fill Ratio – When installing conductors in a conduit, the number and size of conductors shall not exceed the conduits allowable fill ratio. NEC Article 300.17 states that the number and size of conductors in a conduit cannot be more than will permit heat dissipation and ready withdrawal of conductors without damaging them. CFX has noted that issues with heat dissipation is a problem they have identified where there are more conductors than the fill ratio allows, especially in conduits installed underground that are filled with water. The allowable fill ratio can vary by raceway type and application. However, in general the below list (demonstrated graphically in Figure 4.13) provides the maximum fill ratio for a specific number of conductors installed in a conduit:

- 1 conductor - 53% maximum fill
- 2 conductors - 31% maximum fill
- 3 or more conductors - 40% maximum fill

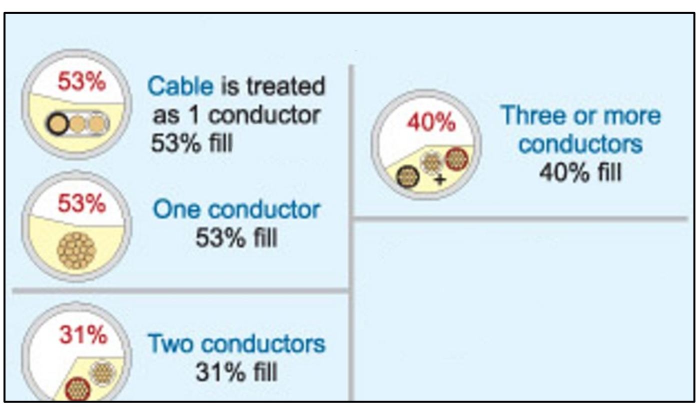

Figure 4.13: Conduit Fill Ratio

Note that a multi-conductor cable is treated as a single conductor when determining conduit fill ratio. The CEI and contractor should always be cognizant of the allowable conduit fill ratio and ensure that it is not exceeded.

4.3.4 Splices – Electrical splices are inherently a weak point in any conductor installation. For this reason, all splices of electrical conductors shall be made inside a pull or junction box such that they are readily accessible for inspection and maintenance personnel. CFX Technical Specification 639A requires the use of NSI Industries Easy-Splice Gel Splicing Kit Part #ESSLK-2/0, as shown in Figure 4.14 below, for all conductor splices except for locate wire splicing and splices within a transformer which will be discussed in future Chapters. The use of wire nuts or split bolts, as shown in Figure 4.15 below, for electrical splices are not permitted for CFX's ITS infrastructure.

Figure 4.14: Easy Gel Splice Part #ESSLK-2/0

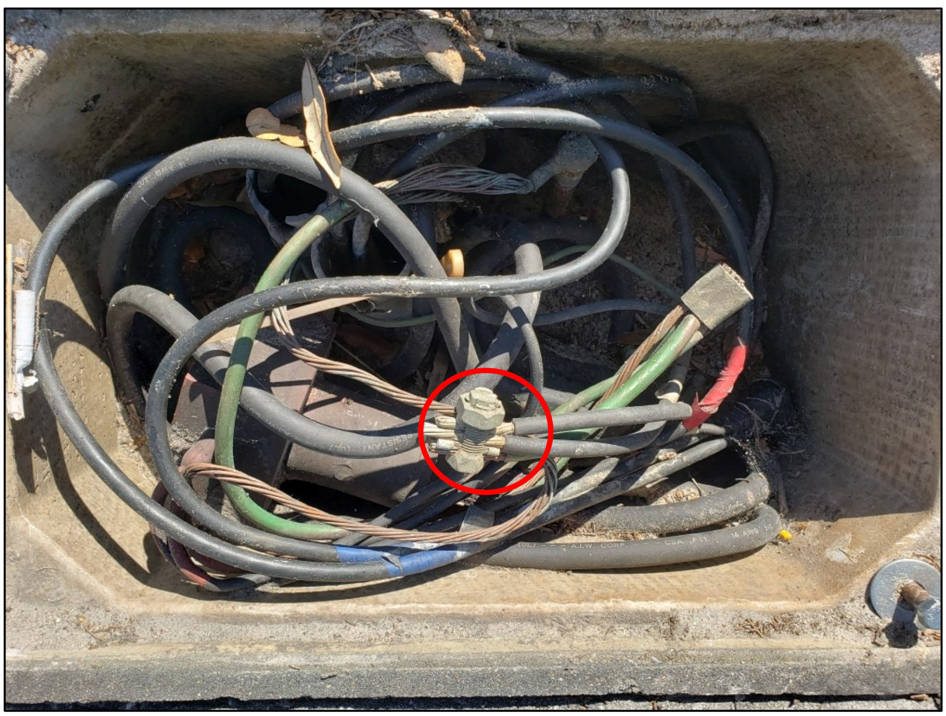

Figure 4.15: Split Bolt Electrical Splice

It is important that the CEI and contractor verify that when splices are being made using the NSI Industries Gel Splicing Kit Part #ESSLK-2/0 that they are installed according to the manufacturers recommendations. Figure 4.16 below shows an example of an improperly performed splice where two conductors landed in each terminal within the terminal block. These terminal blocks are only rated for a single conductor to land in each terminal so this particular splice would actually require two separate splice kits to be used for a correct installation.

Figure 4.16: Incorrectly Performed Splice

4.3.5 Slack – When conductors enter a pull box or other access point, it is best practice to have each conductor make one loop around the pull box such that approximately 3 – 5 feet of slack is available for each conductor in the pull box. Availability of this additional slack can be extremely beneficial for general maintenance purposes or if the pull box needs to be raised or relocated at any point in the future.

4.3.6 Pulling – Pulling conductors into a conduit can be a difficult task depending on how many bends are in the conduit path, how long the run is, or how many and the size of conductors being installed. All of these factors will determine how much friction and therefore how much resistance will be experienced for a particular installation. It is important however that the CEI and contractor ensure that the conductors are not being damaged during the installation process as shown in Figure 4.17 below. If conductor insulation is damaged during installation, the conductor is likely to still work, but exposed inner conductive material increases the risk of short circuit, electrical shock, or fire.

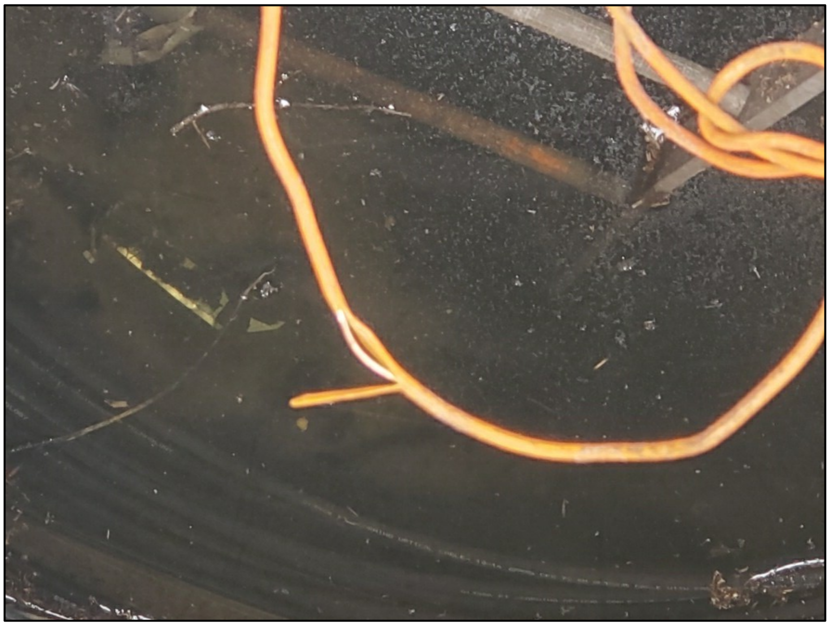

Figure 4.17: Damaged Conductor Insulation

Conductors are typically pulled into a conduit through the use of pull string or with the help of a fish tape. During conductor installation, some things to keep in mind are:

- Pull all conductors into a raceway at the same time.
- If replacing existing conductors, the existing conductors can be used to pull in new conductors.
- Use of an approved pulling compound as a lubricant can reduce friction and make conductor installation much easier.
- Hook up to the inner conductive material when pulling the conductor to avoid damage to the insulation.
- Inspect conductors after installation to ensure they were not damaged.

4.3.7 Copper Keepers – CFX Technical Specification 638-3.2.19 requires the use of Copper Keeper™ Cable Security System, as shown in Figure 4.18 below, for all conductor installations extending a distance greater than 100 feet. The Copper Keeper™ is a rubber stopper manufactured with four conductor pockets. The conductors are inserted into the pockets and the stopper is inserted into the end of a conduit. A specialized socket or “key” is used to tighten the compression bolt which expands the rubber stopper against the conductors and the conduit locking the conductors in place and preventing removal, thereby acting as an anti-theft system for the valuable copper conductors. Access to the Copper Keeper™ key for CFX projects is restricted to authorized personnel and is available on an as-needed basis via coordination with CFX’s Construction personnel.

Figure 4.18: Copper Keeper™ Cable Security System

4.4 PRE-ACTIVITY CONSIDERATIONS

This Section will serve as a checklist of items that the CEI and contractor shall consider prior to proceeding with installation of conductors on CFX projects:

1) **Pre-Installation Inspection –** Prior to installation of conductors, thoroughly inspect them to verify that the insulation is in good condition and does not have any nicks or damage creating a potential point of failure. Ensure on a daily basis that the conductors being brought to the project match the approved submittals. This insulation type can easily be verified by inspecting the markings on the conductor insulation. All conductors for CFX's ITS infrastructure shall be XHHW stranded copper conductors except for certain grounding and locate management system (LMS) applications.

2) **Verification of Conductor Size and Quantity –** Prior to installation, thoroughly review the plan requirements for the required size (gauge) and quantity of conductors to be installed. The conductor size can easily be verified by inspecting the markings on the conductor insulation.

3) **Conductor Identification –** The CEI and contractor shall review CFX Technical Specification 639A to determine the required conductor insulation colors and/or acceptable phasing of conductors for the particular VAC circuit being installed to ensure CFX's conductor identification requirements are being met.

4) **Verification of Separate Raceway –** Verify that a complete and separate raceway, including separate pull boxes, is available for conductor installation. For safety reasons, current carrying conductors shall never be installed in the same raceway as communications cables. The practice of mixing power and communications cables is strictly prohibited on CFX's system. Additionally, line and load conductors, to include conductors that are on UPS feeds, shall be installed in separate conduits.

5) **Post-Installation Inspection –** Following installation of conductors, thoroughly inspect them to verify that the insulation is still in good condition and was not nicked and damaged during installation. If damage to the insulation is observed, the contractor shall replace any damaged conductors and perform an insulation resistance test to assess the integrity of the conductors that remain in place.

6) **Verification of Splices –** The CEI and contractor shall ensure that all electrical splices are being made using the required splice kits (NSI Industries Easy-Splice Gel Splicing Kit Part #ESSLK-2/0) installed per the manufacture's recommendations and that all electrical splices are housed in a pull box such that they are readily accessible for inspection.

7) **Verification of Copper Keepers -** The CEI and contractor shall ensure that the Copper Keeper ™ Cable Security System is installed and is properly securing the conductors within the electrical conduit for all conductor runs exceeding 100 feet.

Figure 4.19 below shows an example of a correct conductor installation within an electrical pull box. There is no visual damage to the insulation indicating that the conductors were not damaged during installation. The conductor insulation colors appear to be correct for a 120/240 VAC circuit installation. The conductors are installed in a dedicated electrical raceway and not mixed with communications cables. There is adequate conductor slack within the pull box and the appropriate NSI Industries gel splicing kits were used for the electrical splices. Finally, copper keepers are installed securing the conductors in place within the conduits.

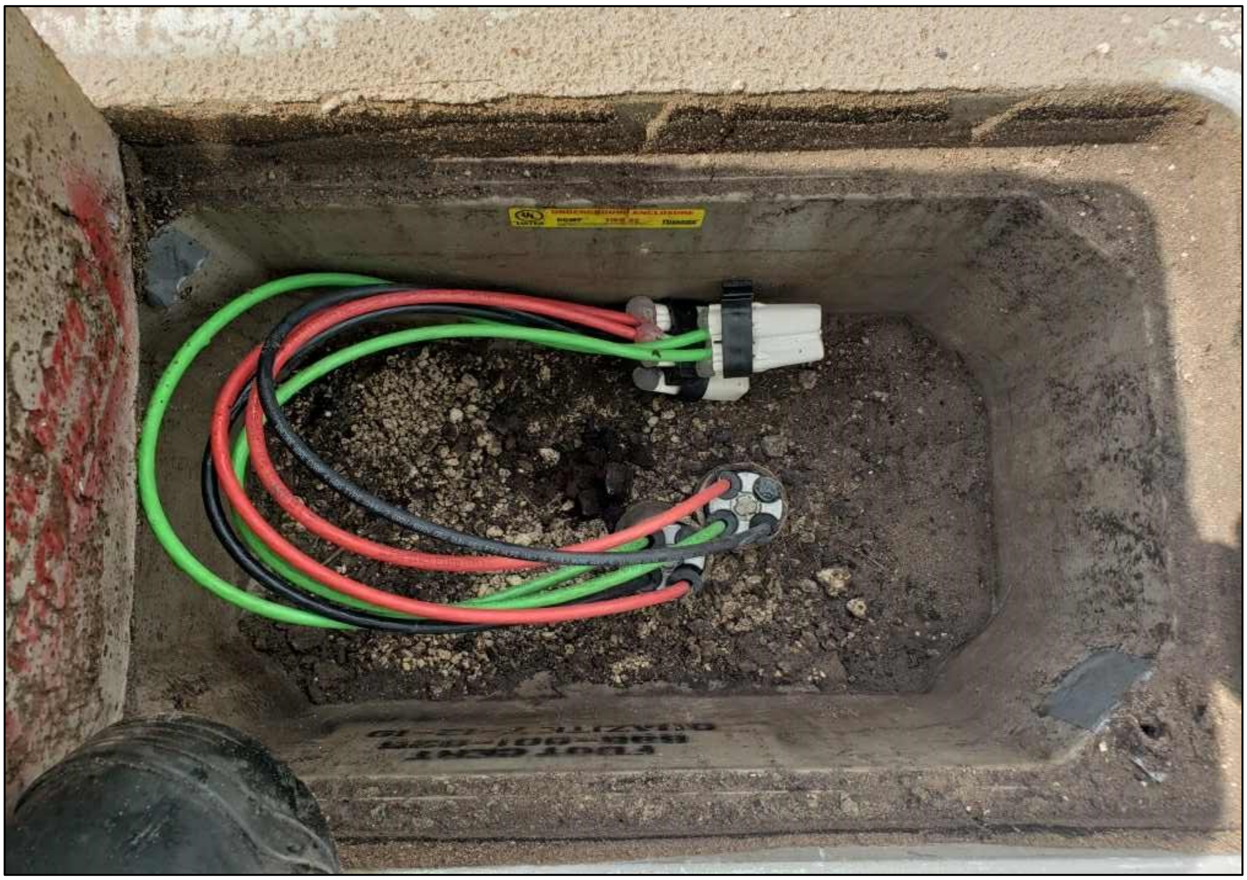

Figure 4.19: Correct Conductor Installation