FPL's Substation Use of Copper Clad Steel Conductor

A Theft-Resistant Grounding Alternative
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D. C. Schleicher, P.E.
Florida Power & Light

Historical Perspective

In the 1960s, Florida Power & Light Company (FPL) used various sizes of copper conductor in their substation grounding systems. In the mid to late 1960s, FPL began to experience increasing theft of the copper conductor, from both construction sites and in-service substations.

During the same time period FPL developed new low-profile substation standard designs primarily for distribution substations. Part of this development resulted in typical grounding plans that included ground wires buried several feet outside the substation perimeter fence to control touch voltages outside the fence. Wise decisions were made around 1968 to develop and implement new standards for ground grid conductor composed of copperclad steel (CCS) cable. The same CCS grounding standards were used in new, FPL designed, transmission substation and power plant switchyard projects. The CCS cable conductor sizes FPL chose and continue to use are shown in Table 1.

TABLE 1
FPL Substation CopperClad Steel (CCS) Sizes
40% Conductivity

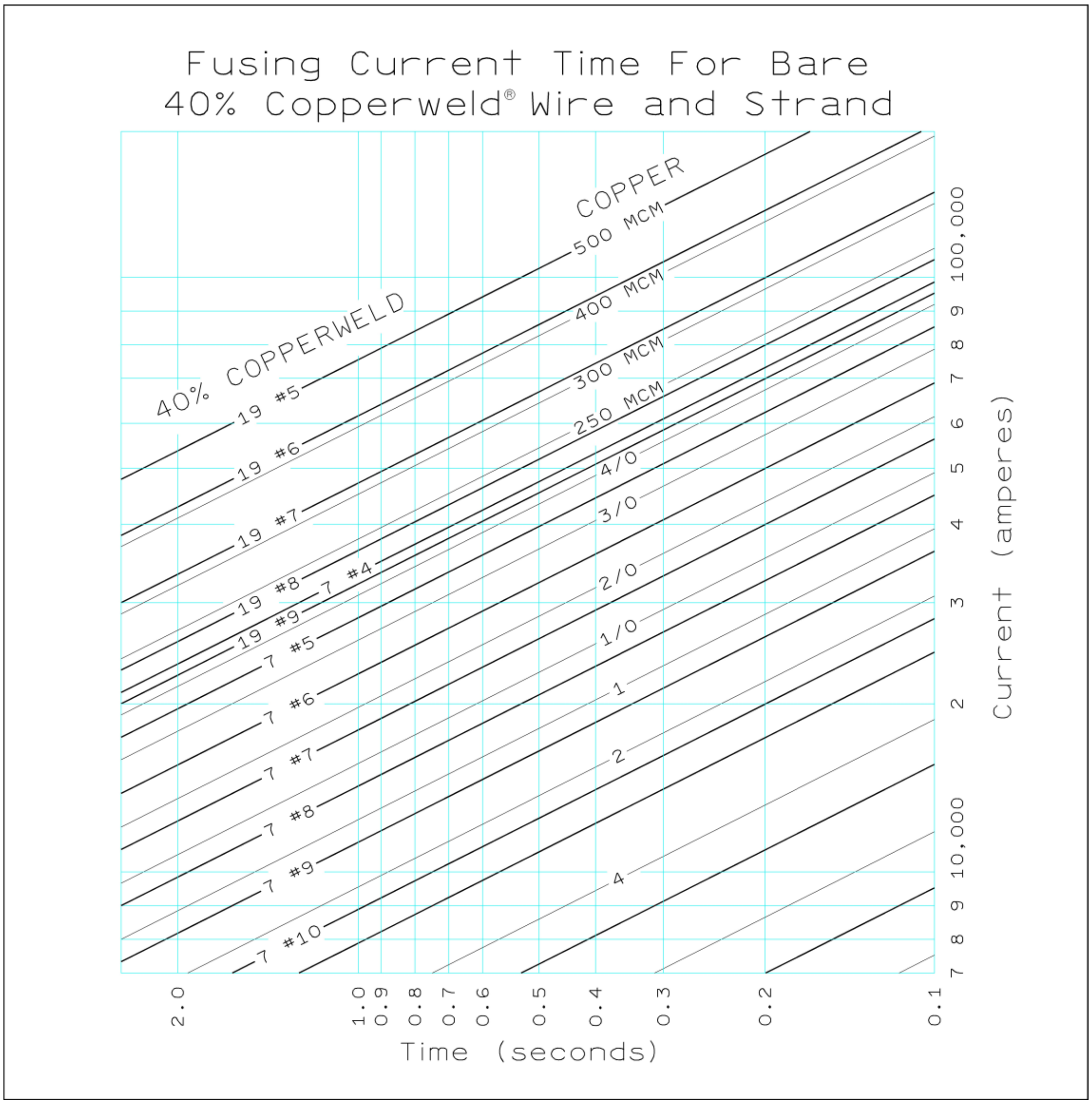
CCS Size (kcmil)	Stranding	Diameter (inches)	Fusing Amps (15 cycles) (1)	Copper Equivalent (fusing)
145.7	7 # 7	0.433	34,234	<# 2/0 AWG
248.8	19 # 9	0.572	58,458	# 4/0 AWG
395.5	19 # 7	0.721	92,927	300 kcmil
			$I=(C*A)/\sqrt{t}$	

References:
(1) Copperweld® Wire and Strand technical data sheets

Proper application of copper or CCS conductors in substation grounding must consider the conductor performance, type of relay protection systems, and fault current levels and duty cycles. Sufficient operational and engineering margins should be maintained between the conductor fusing current and the most likely worst case duty that may be imposed on the conductor. Technical data provided by CCS manufactures should be analyzed by the grounding designer.

The graphs in Figure 1 show fusing current times for common CCS and copper conductor sizes. Fusing is recognized as the time duration and ampacity combination that causes the conductor to melt and vaporize like a fuse.

FIGURE 1



Grounding Philosophy

FPL's philosophy includes a requirement that all below grade grounding connections shall be exothermic. This includes connections to couple multiple, ground rod sections together. All hand and motor operator locations include a switch operator ground mat to reduce the potential differences between the operator's hands and feet during manual switch operation. FPL's switch operator ground mat is also composed of CCS conductors, sizes 145.7 kcmil and #6, that are joined with silver brazed connections. The ground mat is buried several inches below grade, exothermically connected to the ground grid, secured to the soil, and covered with loose rock cover.

Above grade connections to structures and components also utilize CCS conductors. Connections to structures and components are made with a combination of exothermic, bolted, and compression connections. CCS conductors are also utilized as the relay vault main ground conductor and are routed in and connected to all cable tray sections. FPL's substation ground grid is typically connected to all transmission OHGWs and all feeder neutral conductors. The exothermic connected CCS ground grid also serves as the neutral bus connecting feeder neutrals to distribution power transformer neutral. In order to maintain FPL's feeder fault current level limits, a neutral reactor is typically applied in the distribution power transformer, wye-connected, neutral bushing ground connection. The CCS conductors used for continuous current application are sized and bundled appropriately for the specific substation application. See Table 2 for one engineering method to determine continuous ampacity for CCS conductors.

TABLE 2
FPL Substation CopperClad Steel (CCS) Sizes
40% Conductivity

CCS Size (kcmil)	Stranding	Fusing Amps (15 cycles) (1)	Copper Equivalent (fusing)	DC Resistance Ohms/1000 ft	Approx. Copper Equivalent (continuous)	Amps @ 80°C Continuous Bare (2)
145.7	7 # 7	34,234	<# 2/0 AWG	0.1833	# 2 AWG	209
248.8	19 # 9	58,458	# 4/0 AWG	0.1078	# 1/0 AWG	282
395.5	19 # 7	92,927	300 kcmil	0.0678	# 3/0 AWG	382
		$I=(C*A)/\sqrt{t}$				

References:
(1) Copperweld® Wire and Strand technical data sheets
(2) National Electrical Code (NEC) 2005, Table 310.21

Special Copper Flexible Leads

There are several specific grounding applications where the flexibility of fine copper strands is needed and the stiff, large strand CCS is not appropriate. One application is the grounding of the gate leaves, where the flexibility of a braid or welding-type cable is necessary for the swing of the gate leaves. Another area where copper braids are used is to ground relay and communication panels; the braid provides a large surface area to dissipate high frequency transient overvoltages. The last area is portable safety grounds which are not permanently installed are outside the scope of this discussion.

CCS Connections

CCS conductors behave similarly to copper conductors in many connectors and on specific connections. For example, many bolted and compression terminal connectors normally used for 250 kcmil copper conductors can also be used with 248.8 kcmil CCS. Similarly an exothermic mold designed for 248.8 kcmil CCS with 0.572 inch diameter can also be used to connect an occasional 4/0 copper conductor with 0.522 inch diameter. A smaller conductor in a larger exothermic mold hole necessitates using shim stock, custom sleeves, or appropriate packing material to prevent weld metal from running out of the mold cavity. These types of dual usage material can prevent larger stores of standard exothermic molds and connectors.

When aluminum clad steel or aluminum conductors are attached to CCS, similar corrosion precautions need to be taken as when connecting copper to aluminum.

Advantages / Drawbacks with CCS

The primary advantage of CCS over copper conductors is the theft resistant nature of CCS wire. CCS wire has essentially no scrap value compared with copper equivalents. Another advantage of CCS conductor over copper conductor is that the equivalent fault capacity CCS conductor is often less expensive than copper conductor on a per foot basis. This depends on vendors, quantities purchased, conductor stranding, and market conditions.

CCS conductor is significantly stiffer than similar diameter soft drawn copper conductor. The CCS conductor is more difficult to bend, especially in tight quarters. Due to the stiff CCS conductors maintaining their reel bend more than copper, the conductor often has to be muscled in to fit an exothermic mold. This can be hard on the molds, can cause more wear on mold conductor openings, and can lead to more weld metal leakage. Early in the use of CCS, FPL decided to buy exothermic molds with wear plates. This practice has been successful in extending the exothermic mold life. It is one of the additional costs incurred in applying CCS. The differential additional cost of wear plates is considered a small, insignificant cost compared with significant theft reductions.

One CCS disadvantage is that there are no easy ways to procure 600 V insulated versions of CCS. It is only sold bare. FPL has a few standard grounding applications in which 600 V insulated 4/0 conductor is still used. Theft of this insulated copper conductor has been a problem at some locations.

The last disadvantage of CCS is that it is less forgiving than pure copper in a corrosion environment. In a high sulfur area where the copper is being attacked, there is only a layer of copper over the steel as opposed to the entire conductor. Also, if the CCS is poorly manufactured and the bimetallic process fails and exposes the steel core, under unusual conditions the steel can corrode creating a tunnel inside the copper where the steel used to be. This condition and failure is extremely rare when using quality manufactured CCS conductors and exothermic welds.