New Composite Metallic Strip, or How to Enhance Modern Ground Grids

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***Abstract*—This technical publication explores the benefits of a new "ground grid enhancing technology" for improved transmission of electrical fault energy into the earth during a high-power ground fault before the circuit breaker trips or power fuse blows.**

There is a need for ground conductors that perform at least as well as traditional ground conductors and are comparably easy to work with, store, and transport, but also 1.) improve the resistance to ground via contact with the soil, 2.) reduce the probability of being stolen, and 3.) increase the probability of a longer service life underground.

A new family of composite metallic strip conductors, with ratio of width-to-thickness of their cross-sectional area being 15:1 or greater, are shown to outperform the electro-thermal performance (I^2t) of copper cables ranging from 2/0 AWG to 500 kcmil. They are also shown to have suitable exothermic connectors and workability during installation without special tools. Further are demonstrated to outperform the service life of copper cable in any soil condition, extending the usable service of copper by 5 years, while reducing the likelihood of theft, and significantly reducing the resistance to ground during transmission of fault energy in any soil condition.

Keywords— Grounding contact surface area, resistance to ground, and grounding conductors

I. DEVELOPMENT OF GROUND GRIDS

The modern copper ground grid is first found mentioned in the available literature in 1953 by Dr. Eric T. B. Gross, who explained that *"grounding grids are used in high-voltage stations when rocky ground makes the use of driven ground rods impractical.*"

Gross created a new mathematical model of effective ground grids using the resistance and capacitance of the earth. His analysis suggested ground grids made of 0.03-foot radius copper (500 kcmil) cable. He also recommended that the buried depth of the ground grid for most high voltage electrical applications should be 2 feet deep. [1]

In 1954, the predecessor to IEEE Standard 80 (Std-80), released as "AIEE Grounding Guide", provided some relief to electric substation designers by establishing the now-familiar 4/0 copper ground grid on twenty-foot centers buried twelve to eighteen inches deep with a ground rod electrode set at each of the four corners of the overall system. [2]

The 1954 AIEE Grounding Guide also documented the common use of buried copper strip as an alternative to buried 4/0 copper for the creation of efficient ground grids and electrode networks.

Perhaps surprisingly, a counter argument to those who assume the predominance of 4/0 copper grounding is based on technical reasons is found as recently as the 1976 version of IEEE Std-80. [3]

> *"Mechanical ruggedness will set a practical minimum conductor size. The earlier AIEE Grounding Guide, in effect, recommended minimum sizes of 1/0 and 2/0 copper for brazed and bolted joints respectively. It further stated that 'a large segment of the industry has set the 4/0 copper as a minimum for mechanical reasons.' On the other hand, many utilities have successfully used smaller sizes (down to No. 3 AWG in at least one case) with no appreciable mechanical trouble."*.

II. OVERLOOKED ADVANTAGES OF STRIP CONDUCTOR

H. B. Dwight of both Massachusetts Institute of Technology and New England Power Company (National Grid) introduced mathematical expressions for the calculation of resistance to ground for cables, plates, rods, and flat strips in 1936. [4]

Expanding upon Dwight's work, Reinhold Rudenberg of Harvard University wrote in 1945, *"we see that a flat strip follows a relation quite like that of a circular rod, and a strip thus is equivalent to a rod or a wire of a diameter equal to half the width of the strip."* His diagram is shown in Fig. 1. [5]

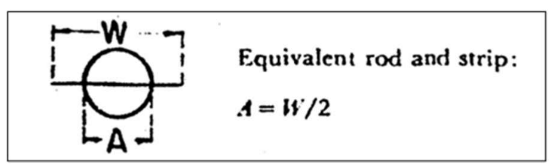

Fig. 1. Rudenberg's 1945 equivalencies for rod and strip.

In other words, to make an equivalent ground grid from metal strip, Rudenberg suggested that the strip selected must be twice as wide as the substituted copper cable. Following this logic, one could reason that a more efficient conductor could be made if the strip was more than twice as wide. Such a conductor would have increased contact surface area with the soil than any cable could reasonably provide. The contact with soil is material especially in high resistivity soils, except under very high current densities where soil ionisation takes place.

Subsequent publications of Std-80 ended the discussion. The 1961 version of Std-80 even indicated that *"resistance of a long electrode depends only to a slight extent on its diameter... it is therefore useless to depart from the circular type of conductor which is the sturdiest mechanically",* This assertion is believed to be an oversimplification, which this technical publication aims to dispute. [2].

III. Introducing the Modern Strip Grid

In the Spring of 2023, a small team of experienced hands-on product development engineers, including Exeter Ground, Southern States, Vincent Clad Metals, Hubbell Burndy, the University of Alabama, Georgia Institute of Technology, and Powertech Labs, explored the empirical development of 'European-style' flat strip grounding conductors made of composite metals that would deter copper theft—one common design for the U.S. and non-U.S. utilities. The team was led by the authors of this technical publication.

Theft-resistance can be achieved in many ways, but the easiest and most effective deterrent to grounding conductor theft is the incorporation of composite construction into its design. Like a tin can, which is actually a steel can plated with tin, a composite metal conductor can be recycled, but the cost of separating the metals consumes any value in the payout. By removing the financial incentive to sell it, the conductor simply becomes economically unattractive to steal. [6]

Top of mind was the need for a theft-deterrent conductor with sufficient flexibility for making 90-degree bends by hand in the field, during installation. The 90-degree bend, although not electrically ideal for conducting fault currents in substations, would permit tight and neat fitting from equipment along a concrete foundation pad and into the ground to avoid a trip hazard for most of time when the grounding conductor lies dormant. Equally important is the other infinitesimal minorityof the time when the conductor is being used for emergency grounding service, i.e. the attenuation of stray currents and the transmission of occasional potentially catastrophic high electrical fault current into the ground. [6]

In the Summer of 2024, a new extrusion technology was created to produce the desired strip conductor, a patent-pending design called Armor-965, shown in Table 1. [6]

TABLE 1: Summary of Strip Grid Performance in Context

	Electro-Thermal (I^2t)	Break Load Force (lbs)	Contact Circumference (inch)	Resistance to Ground (Ω/1000ft)
ARMOR-965™	**1,061**	**8,762**	**5.2**	**0.081**
4/0 Copper	965	4,933	2.6	0.091
350 Copper	2,497	8,161	3.1	0.090
500 Copper	5,096	11,614	3.9	0.890
3x 500s	14,524	34,842	7.7	0.084

The version shown in Table 1 is a thin and wide strip over four times wider than 4/0 copper but with the same cross-sectional area. The strip exhibits a ratio of width-to-thickness of 30:1. Other versions have ratios from 15:1 to 80:1. [7] Standard BB-07 exothermically molded connectors are available for ground grid fabrication. [8] High current test results demonstrate that the copper sheath of Armor-965 provides 10% higher electro-thermal capacity (I^2t), and the core provides 78% higher mechanical break load capacity than 4/0 copper cable. Resistance to ground is around 12% lower than that of 4/0 copper cable, assuming a ground grid made of 1,000 meters of conductor in contact with 100 ohm-meter soil and buried 0.5 meters deep, per Rudenberg's 1945 equations. [9]

While providing slightly better electro-thermal capacity (I^2t) than 4/0 copper, and for roughly the same market price as 4/0 copper, the new conductor has the break load strength of a 350 kcmil copper cable, and more significantly, it exhibits better resistance to ground than a traditional grid made of three-500-kcmil cables joined together in parallel, as shown in Table 1. [10]

IV. Improving Contact Surface Area

In the modern lexicon, the flow of electrical fault current away from a grounding conductor and into the soil is often called "leakage current", as in the current that flows out of or 'escapes' from the metal conductor. This, of course, is not an accurate description. The grounding conductor should be designed to drive the fault current into the soil as efficiently as possible. This effect is proportional to the potential gradient as a function of the conductor and its surface contact area with the soil.

Fig. 3 demonstrates a clear advantage for the composite metal strip ground grid over a round cable grid. Given the predominance of 4/0 copper cable as the historical ground grid conductor of choice, the benefit of thin and wide strip grounding conductor over round cable is presented in terms of multiples of 4/0 copper diameter. Here it is clear to see the cluster of various round cables in the upper left corner of the graph showing that there is little to no advantage for small strips. However, as the strip width approaches 3 times the diameter of a comparable cable, efficiencies do improve significantly. [11]

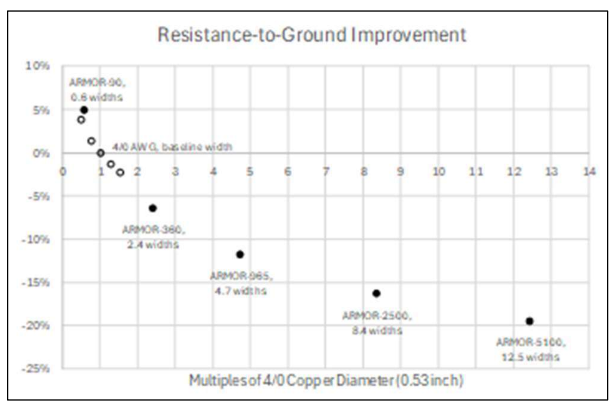

Fig. 3. Resistance to ground improvement from increased contact surface area with the soil.

So, using the diameter of 4/0 copper, which is just over 0.5 inch in diameter, as the basis of comparison (where x-axis = 1), Fig. 3 shows that a strip with 4.7 times the diameter of 4/0 copper provides a 12% improvement in resistance to ground. Similarly, a strip with a width 12.5 times the diameter of 4/0 copper provides a 20% improvement. Beyond that, the benefit diminishes asymptotically. [11]

V. Improving Corrosion Resistance

The version of the new composite metal strip conductor shown in Table 1, which exhibits between 965 and 1061 A^2s 'I^2t' performance (better than the I^2t of 4/0 copper), has a copper sheath that is 0.024 inch (24-mil) thick, as shown in

Fig. 4. The copper sheath is 2.4x thicker than the 10-mil sheath on a standard CCS ground rod. Pitting caused by corrosion reduces the functional thickness by 6 mil, leaving 4 mil for corrosion resistance. In contrast, the composite metal strip conductor has 18 mil of corrosion resistance after considering the effects of pitting. As such, the strip with 24-mil sheath has 4.5x longer expected service life than the standard 10-mil ground rod. This is corroborated by copper loss rates published in the famous extensive NBS study.

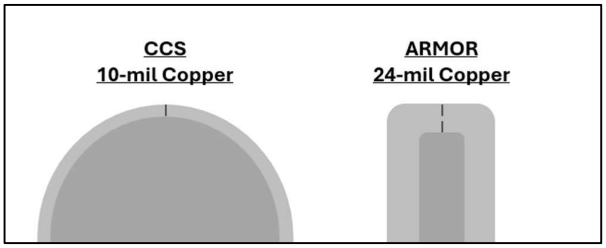

Fig. 4. Comparison of sheaths for CCS and Armor with dashes representing approximately 10-mil thickness.

In 1957, the National Bureau of Standards published a comprehensive study of soil related corrosion. The study was conducted over 14 years in 47 buried environments across the United States. The study was performed on 333 various grounding materials, including the effects on buried copper. Different sets of copper pipe samples were exposed to a range of soils from 1932. Losses quantified by the NBS in soil environments were initially measured in mass per year and were then converted to depth of corrosion in inches per year. [12]

For this technical publication, the data was then reduced by the authors into two broad groups: Standard and aggressive soils. Table 2 presents revised equations for corrosion in buried soils, based on empirical data. [6,8] We have labeled the lines on the chart by the following convention, used throughout this technical publication:

- SL_{STPC} = Standard Losses in Soil for common Tough Pitch Copper (TPC)
- SL_{SOFC} = Standard Losses in Soil for common Oxygen Free Copper (OFC)
- AL_{STPC} = Aggressive Losses in Soil for common Tough Pitch Copper (TPC)
- AL_{SOFC} = Aggressive Losses in Soil for common Oxygen Free Copper (OFC)

TABLE 2. PREDICTIVE CORROSION EQUATIONS

	Empirical Losses for Buried Copper from Corrosion	
	Environment	***Predicted Loss (inch)***
1	SL_{STPC}	= 0.00060 + (0.000026) * (No. of Years - 10)
2	SL_{SOFC}	= 0.00068 + (0.000034) * (No. of Years - 10)
3	AL_{STPC} *Soils of concern*	= 0.00756 + (0.001040) * (No. of Years - 10)
4	AL_{SOFC} *Soils of concern*	= 0.00625 + (0.000900) * (No. of Years - 10)

VI. DIMINISHING TENSILE STRENGTH

Standard 4/0 copper ground grids exhibit radial losses on each strand. Thus, loss of mass at rates presented in Table 1 can be converted to loss of strength as a function of reduction in cross-sectional area. Standard soils exhibit loss of 1-mil every 35 years or so. These are not soils of concern.

An analysis of strength as a function of buried service life in soils of concern, whose loss rates are presented in item #3 and #4 of Table 1, is shown in Fig. 5. A downloadable engineering drawing XDWG-104 is available at ExeterGround.com under the "Technical Publications" section for further detailed examination. [10]

ASTM B910-compliant CCS performance, which sets the minimum allowable thickness for CCS cable, is best defined by 19#9 CCS conductor, which has a core of steel surrounded by a 10-mil copper sheath. When corrosion penetrates to the core, corrosion of the steel rapidly accelerates driven by the high electrochemical (galvanic) potential between copper and steel. [13]

For 4/0 copper cable and other copper able sizes, IEEE std-80 Annex B in IEEE Std-80 shows the calculation for the minimum conductor size of an application that results in No. 4 AWG copper. [14] Thereafter, it upgrades the recommendation to become 2/0, citing *"mechanical strength and ruggedness requirements"*. Thus, it seems reasonable to assume that 2/0 copper defines the minimum acceptable break load strength of a buried conductor throughout its service life. 2/0 copper cable has an electro-thermal (I^2t) withstand capability of 360 amp2-seconds and break load force of 3,105 (units) (i.e. equal to 90% * area * 33,000 psi). [6]

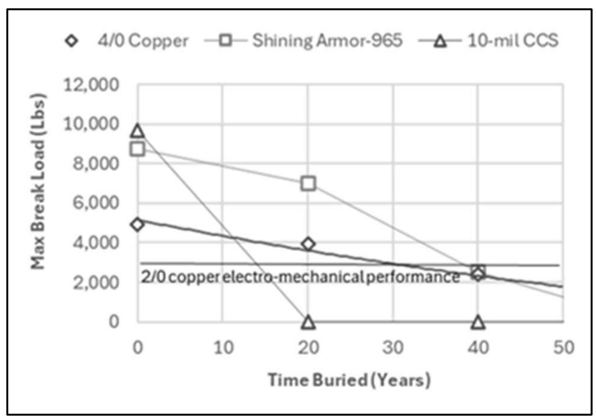

Fig. 5. Approximate Strength versus Time in Aggressive Soils

UL467-compliant [15] AND CSA-C22.2-NO.41-compliant [16] CCS ground rods are defined by their copper sheath that is a mere 10-mil thick. [15, 16]

Contrasting CCS cable, CCS ground rods, and 4/0 copper cable, one example of a new family of composite metal strip conductors has A 24-mil copper sheath. In aggressive soils, the composite strip remains significantly more rugged than 4/0 copper OR 10-MIL CCS because its 24-MIL copper sheath layer protects the core and strength is little affected until the steel is exposed and starts to corrode, as shown in Fig. 5. Thus, composite metal strip can extend service life by approximately 5 years over 4/0 copper. [12]

VII. End of Useful Service Life

The resulting comparison of expected service lives for commonly used and the newly developed flat grounding conductors and electrodes is shown in Table 3. The column on the right side of Table 2 labeled *"Max. Years Std Soil"* refers to standard soils (SL_{STPC} & SL_{SOFC}). Similarly, the column labeled *"Max. Years Agg. Soil"* refers to aggressive soils (AL_{STPC} & AL_{SOFC}).

TABLE 3. Predictive Useful Service Life

	End of useful service life for conductors and electrode				
	Type	***Metal***	***Limit***	***Max. Years in Std. Soil***	***Max. Years in Agg. Soil***
A	Armor-965	Cu-Fe	24-mil Sheath	>150	35
B	4/0 AWG	Cu	2/0 Equiv.	150	30
C	Ground Rod	CCS	10-mil Sheath	75	15
D	19#9	CCS	10-mil Sheath	75	15

VIII. Conclusions

A new family of composite flat metal strip conductors, having widths several times greater than traditional copper cable diameter, can be used to significantly reduce the resistance to ground in any soil condition. The benefits of composite strip ground grid conductors, when compared to standard 4/0 copper grounding cables, include better electro-thermal capacity (I^2t), superior mechanical break load strength, better theft resistance, improved flexibility for field installation, extended service life of at least 5 years in the most aggressive soils, and importantly, a 6%-20% lower resistance to ground compared to a ground grid of equivalent area round conductor. These advantages are quantified herein for use by substation designers in their ground grid modeling efforts that aim to mitigate risk to personnel and equipment. The improvement in reduction of electrode resistance over standard stranded cables, coupled with the superior service-life-to-cost of composite metallic strip conductors, renders them an optimal choice for the substation of the future and as an upgrade for existing stations.

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Vitae

Jeffrey T. Jordan, P. Eng, MBA, is the inventor of two families of modern grounding electrodes for high power electric substations: Copperweld's ArcAngel and Exeter Ground's Shining ArmorTM. Prior to forming Exeter Ground, Jeff led the development, validation testing, and launch of medium-voltage electric substation products for Southern States, Copper-weld, and Schneider Electric. Jeff started his career in the Department of Defense designing new warships for the US Navy. In addition to his professional experience, Jeff holds a Bachelor of Science in Engineering from The University of Michigan and an MBA from Vanderbilt University. He is also a registered Professional Engineer licensed in Machine Design.

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