"GUIDELINES ON THE USE OF GROUNDING PRODUCT WITH REFERENCE TO CODE & STANDARDS OF THE USA"

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Summary: This paper explains the compliance of ERICO Electrical Products with American Grounding Standards. The paper covers various topics related to the most important aspects of designing reliable and long-lasting grounding systems.

Keywords: Grounding System Design, Permanent Connections, Service Life, Step & Touch Potentials

Introduction

ERICO Engineers and Product Managers participate in Technical Committees and Working Groups of many Standards listed in this document. Through this effort ERICO remains on the leading edge in this industry, supporting changes that enhance performance, improve reliability and addresses working safety.

Definition of a Grounding System

A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the Earth, or to some conducting body of a relatively large extent that serves in place of the Earth.

Purpose of Grounding System

Used for establishing and maintaining the potential of the Earth (or other conducting body) or approximately that potential, on conductors connected to it, and for conducting ground current to and from the Earth (or other conducting body).

Parameters of any Grounding System

- Provide a low impedance path to ground for personnel and equipment protection and effective circuit relaying by maximizing contact of the grounding components with the earth
- Withstand and dissipate repeated fault and surge currents, minimize transients induced on the electrical system by lightning activity in the area or by faults on the transmission lines
- Provide corrosion resistance to various soil chemistry and insure continuous performance for the life of the equipment being protected
- Provide rugged mechanical properties of all components used in the grounding system
- Comply with international and local standards
- Be cost effective

Parameters of Grounding Systems used in Substations

The two main goals to be achieved by any substation grounding system under normal as well as fault conditions.

- Provide means to dissipate electric currents into the earth without exceeding any operating and equipment limits
- Assure that a person in the vicinity of grounded facilities is not exposed to the danger of electrical shock that will not exceed limits outlined in Standard IEEE 80.

The following site-dependent parameters have been found to have substantial impact on the substation grid design:

- Maximum grid current (I_G) – maximum design value of ground fault current that flows through the substation grid into the earth
- Fault duration (t_f) and shock duration (t_s) – normally assumed equal, unless the fault duration is the sum of successive shocks. The selection of (t_f) should reflect fast clearing time for transmission substations and slow clearing time for distribution and industrial substations
- Soil resistivity – grid resistance and voltage gradients within a substation are directly dependent on the soil resistivity
- Resistivity of surface layer – layer of surface material helps in limiting the body current by adding resistance
- Grid geometry – based on economics and physical limitations

1. Grounding System Design

Considerations in designing a grounding system

- Perform soil resistivity tests
- Determine conductor size
- Determine tolerable step and touch potentials voltages
- Design should include a conductor loop and adequate grid conductors
- Calculate grounding system resistance
- Determine I_G - only the portion of the fault current that flows through the grid to remote earth should be used in designing the grid
- Evaluate if the ground potential rise (GPR) of the initial design is below the tolerable step and touch voltage, no further analysis is necessary
- Perform permanent Connections
- Consider underground Corrosion

The aspects of each step are described in the following paragraphs

The purpose of any grounding system installation is to maximize the surface area in contact with the surrounding soil. This helps lower the resistance of the grounding system. It also greatly improves the surge impedance of the grounding system, which helps to dissipate a lightning impulse with a fast rising front edge and a fundamental high frequency.

a) Soil Resistivity Testing

The Resistance of a grounding system is heavily influenced by the resistivity of the soil in which the grounding system is installed and as such, soil resistivity measurements are the first important step to design grounding systems. Knowledge of the soil resistivity at the intended site, and how it varies with parameters such as moisture, mineral content, temperature, and depth, provides valuable insight into how the desired ground resistance value can be achieved and maintained over the life of the installation with minimum cost and effort.

One of the main objectives of grounding electrical systems is to establish a common reference potential for the power supply systems, building structures, plant steelwork, electrical conduits, cable ladders and trays and instrumentation systems. To achieve this objective a suitable low resistance connection to earth is desirable. However, this is often difficult to achieve and depends on a number of factors including:

- Soil resistivity
- Size of the property intended for the grounding system installation
- Size and type of electrode used
- Depth to which the electrode is buried
- Moisture and chemical content of the soil
- Target resistance of the installed grounding system

Standards **IEEE 81** [1] and **IEEE 81.2** [2] are the most commonly used standards in the United States for measuring soil resistivity and grounding system resistances. For the more information refer to these standards.

i. Calculations of Resistance and Soil Resistivity

Resistance is that property of a conductor, which opposes electric current flow when a voltage is applied across the two ends. Its unit of measure is the Ohm (Ω) and the commonly used symbol is R. Resistance is the ratio of the applied voltage (V) to the resulting current flow (I) as defined by the linear equation **from Ohm's Law:**

$$V = I x R$$

where:

V — *Potential Difference across the conductor (V)*
I — *Current flowing through the conductor (A)*
R — *Resistance of the conductor in (Ohms)*

"Good conductors" are those with low resistance. "Bad conductors" are those with high resistance. "Very bad conductors" are usually called insulators.
The Resistance of a conductor depends on the atomic structure of the material or its **Resistivity** (measured in Ω-m), which is that property of a material that measures its ability to conduct electricity. A material with low resistivity will behave as a "good conductor" and one with a high resistivity will behave as a "bad conductor". The commonly used symbol for resistivity is ρ (Greek symbol rho). The resistance (R) of a conductor can be derived from the resistivity as:

$$R = \frac{r \times L}{A}$$

where:

r — *Resistivity (W-m) of the conductor material*
L — *Length of the conductor (m)*
A — *Cross sectional Area (m^2)*

SOIL TYPE	OHM-CM
Surface soils, loam, etc.	100 - 5,000
Clay	200 -10,000
Sand and Gravel	5,000-100,000
Surface limestone	10,000-1,000,000
Limestone	500 - 400,000
Shale	500 -1 0,000
Sandstone	2,000 - 200,000
Granites, basalt, etc.	100,000
Decomposed gneisses	5,000 - 50,000
Slates, etc.	1,000- 10,000

Table 1. Typical Soil Resistivity Values

Resistivity is also sometimes referred to as "Specific Resistance" because, from the above formula, Resistivity (Ω-m) is the resistance between the opposite faces of a cube of material with a side dimension of 1 metre.
Consequently, *Soil Resistivity* is the measure of the resistance between the opposite sides of a cube of soil with a side dimension of 1 metre. In the USA, units of Ω-cm are commonly used. (100 Ω-cm = 1 Ω-m)

As grounding systems are usually installed near the surface of the earth. As such the topsoil layers being subject to higher current densities are the most significant and require the most accurate modelling. The Wenner test method is commonly recommended for use.

The purpose of resistivity testing is to obtain a set of measurements, which may be interpreted as equivalent model for the electrical performance of the earth, as seen by the particular grounding system.
However, the results may be incorrect or misleading if adequate investigation is not made prior to the test or the test is not correctly undertaken.

To overcome these problems, the following data gathering and testing guidelines are suggested:

- An initial research phase is required to provide adequate background, upon which to determine the testing program, and against which the results may be interpreted.
- Data related to nearby metallic structures, as well as the geological, geographical and meteorological nature of the area including geological data regarding strata types and thicknesses will give an indication of the water retention properties of the upper layers and also the variation in resistivity to be expected due to water content.

- By comparing recent rainfall data against the seasonal average, maxima and minima for the area it may be ascertained whether the results are realistic or not.

ii. Methods of Measurement

Wenner Array Method (Fig. 1) is the most efficient measurement method of ground resistance in terms of the ratio of received voltage per unit of transmitted current. All four electrodes are moved for each test with the spacing between each adjacent pair remaining the same.
If the earth is non-homogeneous and the electrode spacing varies, a different value of resistivity (ρ_a) will be found for each measurement. This measured value of resistivity is known as the apparent resistivity. The apparent resistivity is a function of the array geometry, measured voltage (Δv), and injected current (I). The apparent resistivity from the field measurements is calculated using the following formula:

$$r_{aw} = 2pa\frac{\Delta v}{I} \quad \text{or} \quad r_{aw} = 2paR$$

Where:

r_{aw} = *apparent resistivity (W)*
a = *probe spacing (m)*
Dv = *voltage measured (volts)*
I = *injected current (Amps)*
R = *measured resistance (W)*

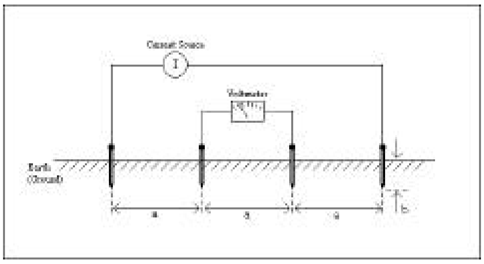

Fig. 1 Wenner measuring method

The Driven Rod Method (or Three Pin or Fall-of-Potential Method) (Fig. 2) is normally suitable for use in circumstances such as transmission line structure earths or areas of difficult terrain, because of the shallow penetration that can be achieved in practical situations, the very localised measurement area, and the inaccuracies encountered in two layer soil conditions. This method is the most commonly used for measuring resistance of the existing grounding systems. The apparent resistivity from the field measurements is calculated using the following formula:

$$r_{ad} = \frac{2plR}{\ln\left(\frac{8l}{d}\right)}$$

Where:

r_{ad} = *Apparent resistivity (Wm)*
l = *Length of driven rod in earth (m)*
d = *Driven rod diameter (m)*
R = *Measured value of resistance (W)*

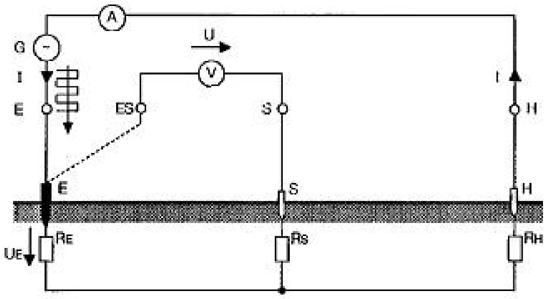

Fig. 2 Fall of Potential measuring method

b) Achieving a "Low" Value of Grounding System Resistance by Engineering Design

The proper grounding principles used by ERICO engineers as a guideline while designing grounding systems are outlined in standards **IEEE 80** [3], **IEEE 1100** [4], **IEEE 142** [5].

Despite the fact that grounding system impedance is an important design criterion, for practical reasons the grounding system is typically evaluated based on low frequency resistance measurements.

Grounding systems have to be designed for a particular value of grounding system resistance. For example, **25** W for residential applications, **5** W for telecommunications and **1** W for substation grounding. Those values might be required even when the soil resistivity is high (above 3000 Ωm) and the available space for installation of the grounding system is restricted to (say 100' x 100' [30.5 x 30.5 m]). The mentioned variables work directly against each other.

To provide low impedance to ground, a grounding system has to be designed with high conductivity, permanence and reliability. There can not be a weak link in the grounding system. Existence of high resistance electrical connections during the life of the grounding system cannot not be permitted.

ERICO recommends the use of copper-to-copper alloy system that assures permanent electrical connection. ERICO's ERITECH Products do offer such quality.

The U.S. National Bureau of Standards [6] tests show copper to be the most corrosion resistant of all materials tested. This topic is discussed in deeper detail later in this document.

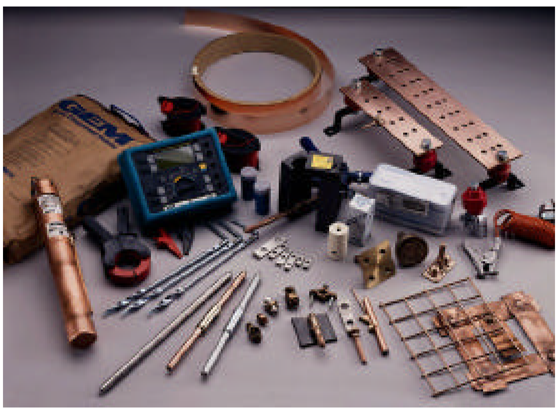

Fig. 3 ERITECH Electrical Grounding Products

Test parameters for connectors connecting ground rods to grounding conductors and ground rods to ground rods are outlined in **UL Standard 467 (ANSI C-33.8-1997)** [7] and **Standard ANSI/NEMA GR1** [8].

For instance the standards set minimum values on tightening force for mechanical connector screws and test procedures for testing ground rod couplers.
Some of the tests are:

- **Impact test**
- **Pullout test**
- **Bend test**

Preferred method for connecting conductors, conductors to ground rods and ground rods to ground rods is CADWELD® exothermic welding. This permanent connection is also very strong and provides lower resistance option than the mechanical coupler.

All ERITECH grounding products follow requirements established by Underwriters Laboratories, Inc. These requirements have served as the basis for approval for grounding of the **National Electrical Code (NEC)** [9]. The NEC in turn, provides the grounding premises of the **Occupational Safety and Health Act (OSHA).**

Given a certain land area to work with, and a desire to not exceed a certain installation depth, it is difficult to decrease the DC resistance value after a certain point is reached, no matter how much copper is placed in the soil. This is why each grounding system design is typically treated on a case-by-case basis, providing an effective and economical grounding solution considering the parameters.

Experience reveals that deep-driven ground rods and radial horizontal conductors covered with Ground Enhancement Material (GEM) are the most effective and economical approaches to effectively reduce the DC resistance of a grounding system. **Soil resistivity measurements help determining** if deep-driven, copper bonded steel ground rods or radial conductors enclosed in GEM should be used.

c) The attributes of an ideal grounding arrangement are considered to be as follows:

- Each grounding system (lightning, electrical, communications, and equipment room) must be of high integrity individually, as well as being considered a component of an overall grounding network. Separate grounds should be bonded together (especially under transient conditions). Bonding of all grounding systems is required by code in the United States.
- Because lightning is a multiple frequency event, it is the high frequency impedance that is the critical design element, not the D.C. resistance.
- A ground ring or grid should be considered as a first option because this is an effective means of reducing the risk of potential gradients across the facility.
- The lightning protection ground should be directly bonded to the facility ground ring.
- There should be a "single point" connection to the ground network from all equipment within a facility;
- The use of "crow's foot" radial grounding techniques for the lightning protection ground allows the lightning energy to diverge as each conductor takes a share of the current. This can lower the impedance and means that voltage gradients leading away from the injection point will be lower and there will be reduced danger from step potentials affecting people or/and equipment
- Electrolytically copper-bonded steel electrodes provide a cost-effective means of grounding for most standard applications. Solid ground plates, steel grates, safety mats, ground (mesh) grids, custom-designed terminals, braids and bridges are used in grounding and bonding applications for high-voltage or heavy current environments such as near industrial furnaces or around electrical substations.
- Special compounds can be used to reduce grounding impedances at locations where the ground resistivity is high such as in rocky, sandy or mountainous areas with large particle soil sizes. Ground impedances can be reduced by amounts in excess of 30 per cent when GEM (Ground Enhancement Material) is used to form conducting masses or non-soluble gels around grounding system.

2. Step and Touch Potentials

A direct lightning strike to the facility or to the ground in the vicinity of the structure will elevate the local ground potential and can give rise to dangerous levels of step and touch potentials. The step and touch potential can also be elevated by electrical fault in the substation or in the distribution system. These conditions can cause large differential voltages between the phase and grounding conductors, or the transformer windings. These potential differences can break down the insulation of the transformer windings or the power cables. The voltage differences can be greatly reduced by a properly designed and installed grounding system, as described above.
The lower the grounding system resistance and impedance, the lower the likelihood of such failures.

The basic shock situation is depicted in the following Fig. 4.

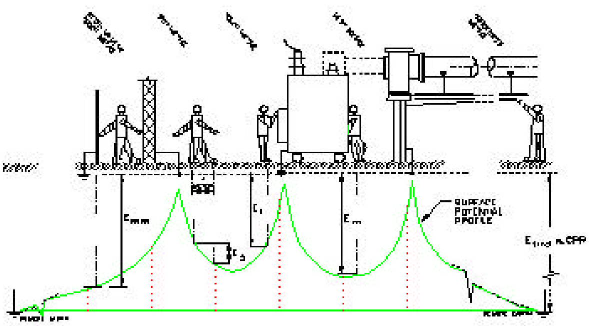

Fig. 4 Basic Shock Situation

Following is a summary of the important step and touch potential definitions, as defined in the **IEEE Standard 80** [3]:

Step voltage: a difference in surface potential experienced by a person bridging a distance of 1 m with the feet without connecting to any grounded object. [3]

Touch voltage: potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing while at the same time having a hand in contact with a grounded structure. [3]

Reducing the risk of electrical shock is an important consideration in the designing of any grounding system.
For more guidance on grounding system design and calculations of step and touch potentials refer to **Standard IEEE 80** [3].

3. Permanent Connections

Connections are often **the weak point** in grounding systems, especially if they are subjected to high currents and corrosion. Grounding connections must be permanent; they must be able to last the lifetime of the installation without corroding or increasing in resistance. One of ERICO, ERITECH's core product lines is CADWELD®, puts high emphasis on quality of permanent connections. Use of CADWELD connections in constructing grounding systems is strongly recommended. CADWELD represents molecular bonding processes, (copper-to-copper or alloys and copper-to-steel or alloys), that is superior in performance to any known mechanical or compression type surface-to-surface contact connectors. By virtue of its molecular bond, CADWELD connections provide specific features such as:

- Repetitive current carrying (fusing) capacity equal to that of the conductor
- Connections are permanent and will not deteriorate with age
- Connections form a permanent molecular bond that can not loosen or corrode
- Connections will withstand repeated faults
- Connections can be made with low labor costs
- Connections are made with inexpensive, lightweight and portable equipment
- No special skills are required for making the connections
- No external power or heat required
- The connections can be inspected for quality by visual inspection.

The CADWELD connections are **UL listed** and satisfy **Standard IEEE 837 [**10].

Historically, many studies have been conducted to determine the fusing currents of conductors and connectors manufactured from various materials. The tests reviled that connectors used in substation grounding, originally designed for power applications, would not carry as much current as the conductor under fault conditions.
Substation grounding criteria was first published in the USA in AIEE No. 80, March 1961, "Guide for Safety in Alternating-Current Substation Grounding". This standard later evolved to Standard IEEE 80-1986. This standard outlined the connection requirements by recognizing that exothermic connections have the same fault current and thermal capacity as the copper grounding conductor. Exothermic connections were not previously mentioned in the standard although some users recognized their capacity. **Grounding conductors were de-rated at that time to 250°C or 350°C when mechanical and compression connectors were used.**

As the 1986 revision of ANSI/IEEE Std. 80 was prepared, several manufacturers of connectors and members of the revision task force requested that a new standard should be prepared to test and qualify mechanical connectors for permanent high fault current usage in substations. This resulted in publication of Standard IEEE 837 in 1989. The standard has been revised to the current version in 2002. The 1986 revision of ANSI/IEEE Std. 80 recognized this standard and allowed **any connector that passed the requirements of IEEE Std. 837 [10] to be used without temperature de-rating of the grounding conductors**. The current revision of the Standard **IEEE 80** [3] still refers to Standard **IEEE 837** [10] for permanent connections and recommends that only connections that pass the requirements of the Standard **IEEE 837** [10] can be used in substation grounding.

In order to provide **reliable** and **impartial** test results to the standard committee in preparation of the Standard IEEE 837-1999 ERICO, Inc. commissioned laboratories of two different power utilities in North America to conduct connection testing. In 1996, at that time Ontario Hydro Technologies (OHT) of Toronto, Canada conducted a complete IEEE Std. 837-test program. The results were published in a final test report under the name **"Substation Grounding Connectors IEEE STD 837-1989 Test Series".** Also, in 1996, at that time the Southern Electric International's (SEI) Georgia Power Research Center conducted a current-thermal cycling test modified to be more stringent than the current– temperature segment of the **IEEE Std. 837** [10]. The results were published under the name **"Comparative Grounding Conductor Test Project No. C94901".**
Multiple types of connectors cable to cable and cable to ground rod manufactured by ERICO Inc. and other manufacturers were tested.

The typical compression and CADWELD exothermic connections are depicted in Fig. 5 and Fig 6.

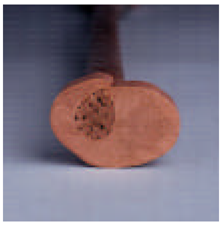

Fig. 5 Compression Connection

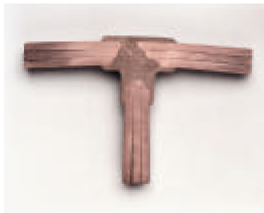

Fig. 6 Exothermic Connection

The OTH test followed test regiment consisting of four tests:

- Mechanical Pullout
- Electromechanical force
- Sequential Test Series

Results revealed that the performance of mechanical and compression earth-connectors are not equivalent to exothermically welded connections. Results also show that only exothermically welded connections passed the complete requirements of **IEEE 837** [10]**.** Results from both programs indicate that only the exothermic connections provide a permanent and reliable connection for substation grounding.

4. Service Life of Ground Electrodes

a) Underground Corrosion Theory

Corrosion is the deterioration of a metallic substance caused by a reaction with its environment. Most environments are corrosive to some degree. Soil is corrosive because of the presence of moisture, dissolved mineral salts and bacteria.
In particular low resistivity soils tend to be highly corrosive.
Generally high levels of moisture, dissolved salts, presence of oxygen and temperature changes are responsible and encourage corrosion. The requirements for corrosion to take place are that an anode (positive) and cathode (negative) must be present and form an electro-chemical cell and complete path for direct current to flow must exist. On the surface of many metals, anodic and cathodic areas are present because of impurities, grain boundaries and orientations and localized stresses exist. These positive and negative charged regions are on electrical contact through the body of the metal. For corrosion to occur, an additional current path through the electrolyte (conducting liquid) must exist. In the presence of moisture in the soil, the circuit is completed and current will flow from the anode to the cathode of the corrosion cell with the subsequent erosion of the anode.

Another type of corrosion of metals occurs during the transfer of electrons from metal to oxidizing agent. In this process of oxidation, an electromotive force (EMF) is established between the metal and the solution contacting the oxidizing agent. A metal in contact with an oxidizing solution contacting its own metallic ions establishes a fixed potential difference with respect to every other metal in the same condition. The set of potentials is determined under standardized set of conditions, including temperature and ion concentration in the solution and is known as the EMF or electrochemical series. The importance of the EMF series is that it quantitatively shows the relative tendencies of pure metals to corrode. Metals high in the series such as **aluminum, zinc and iron**, react more rapidly in a conducting solution and thus are more prone to corrosion than metals such as **copper,** which are low in the series. The metals by their EMF are organized in the following table [11]:

METAL	VOLTS
POTASIUM	-2.92
MAGNESIUM	-2.34
ALUMINUM	-1.67
ZINC	-0.76
CHROMIUM	-0.71
IRON & STEEL	-0.44
HYDROGEN	0.00
COPPER	+0.35
SILVER	+0.80
GOLD	+1.68

The ability of an electrical grounding component to resist corrosion determines its service life. The corrosion itself is a **complicated phenomenon** as can be seen in the previous paragraph with an entire engineering community dedicated to its study and prevention. Unfortunately, that knowledge and expertise has translated very little to the electrical community.

As a result there is a general lack of understanding what **differentiates copper-bonded ground rod from galvanized ground rod.**
The answer lies primarily in the ability of two coating materials, namely **copper and zinc**, to resist all forms of corrosion. The following paragraphs discuss independent technical studies and practical field experience to demonstrate the difference in lifetime of copper-bonded and galvanized ground rods.

b) Requirements on ERITECH Copper Bonded Ground Rod

Many high current tests have been performed on ground rods to determine the parameters and the physical size. The tests concluded that the magnitude and the duration of fault current is one of the parameters directly related to the service life of the ground rods.
The choice of the material used to manufacture a ground rod also determines its service life.
ERITECH Ground Rods have a machined blunt point on one end and a chamfer on the other end to prevent mushrooming, when the ground rod is driven.

The most comprehensive specification developed for copper bonded ground rod is the "Standard for Safety" published by UL, Standard **UL 467 (ANSI C-33.8)** [7]**.**

This standard requires:

- Copper thickness being minimum 0.010" [0.254 mm]
- Diameter no less than ½" [12.7 mm]
- Length no less than 8' [2438.4 mm]
- A copper jacket adherence test
- A bending test with no cracking of the copper jacket

Requirements Regarding a Thickness of the Copper Layer

The required thickness of the copper thickness was determined after considerable engineering and research and stems from a study by the National Bureau of Standards regarding underground corrosion and other studies discussed in the following paragraphs.

The National Bureau of Standards underground corrosion data was first published in 1945 by the U.S. Department of Commerce, Circular No. 450 (superceded by the National Bureau of Standards, Circular No. 579 (contains a compilation of weight laws per year of copper specimens buried in 43 different soils for periods of 8 to 13 years). Dividing these values by the density of copper, an average penetration per year was established.

Extrapolating the average penetration figures to 30 years showed that specimens in 41 of the 43 soils would have an average penetration of 0.007" [0.18 mm] or less. Therefore, it can be concluded that ground rods consistently manufactured with a common thickness of 0.007" [0.18 mm] or greater, would result in ground electrodes with a nominal thirty years installed service life. ERICO's standard manufacturing process exceeds the 0.010" [0.254 mm] minimum coating requirement of UL Specification No. 467.

c) National Bureau of Standards Circular 579 [6]

From 1910 to 1955, The **National Bureau of Standards** [6] conducted an extensive underground corrosion study in which 36,500 specimens, representing 333 varieties of ferrous, non-ferrous, and protective coating materials were exposed in 128 test locations throughout the United States. **It is widely regarded as one of the most comprehensive corrosion studies ever conducted**.

The time required to remove 10 mils [0.0254 mm] of copper can be used to establish a ground rod's nominal service life. This study shows that **rods coated with 0.010 inches [0.0254 mm] of copper** can reasonably be expected to perform well in excess of **30 years** in most soil types. It also showns that galvanized rods coated with 0.0039 inches [0.00991 mm] of zinc should be expected to perform for **only** 10 to 15 years in most soil types.

The intent is to highlight the importance of choosing the proper electrode for a given application by showing the difference in life expectancy.

Although different soils were used, the data from 8 to 13 years shows that the rate of corrosion seems to lessen with time. This is probably due to the protective copper oxide film that develops on the rod.

d) "Field Testing of Electrical Grounding Rods" – Naval Civil Engineering Laboratory (NCEL) [11]

In cooperation with the National Association of Corrosion Engineers [12], the NCEL conducted a seven-year program of testing metal rods for electrical grounding. Copper-bonded, stainless bonded, and galvanized steel rods were included among other materials. Samples were buried individually and connected in pairs to determine the galvanic corrosion effect each rod had on other materials. This study does provide an independent source of information specifically relating to ground rods. The study set out to establish the best type of electrode as determined by the following:

- It should be easy to drive
- It should be resistant to corrosion
- It should not cause galvanic corrosion to nearby metals.

The following observations were made after samples were removed following seven years of exposure:

- **Galvanized steel rod:** "Most of the galvanizing had been lost. Rusting of the steel was greatest near the surface of the ground. Pitting was worst here and near the tip."
- **Stainless-claded steel rod:** "The dadding was free of corrosion, but at the tip, the steel core had corroded to a point about 1 inch inside the cladding."
- **Copper Bonded steel rod:** "The copper layer was virtually free of corrosion, but the steel core had corroded at the tip to a point 2 inches inside the layer."

The study concluded, "Magnesium, Aluminum, Zinc, mild Steel, and galvanized steel rods did not have the desired corrosion resistance".

e) National Electrical Grounding Research Project (NEGRP) [13]

This is the most recent study that is still actively going on and some aspects of the study are being evaluated at present.

In 1992, a long-term grounding test study was established with the objective of addressing issues such as the anticipated performance of ground electrodes over time and the effect of environmental conditions on their performance. Called the "National Electrical Grounding Research Project" (NEGRP), this North American study was carried out under the supervision of the National Fire Protection Research Foundation (NFPA). The study focused on the evaluation of commonly used and commercially available ground electrodes. The study has provided performance data over a period of more than 10 years for a variety of soil and climatic conditions. It has been conducted in three phases – in Nevada (Phase 1) commencing in 1992, in Texas, Illinois, New York State, Virginia (Phase 2) commencing in 1997 and in NASA Mofette Field California (Phase 3) commencing in 2001. The specific objective of the test program has been to evaluate the performance and physical integrity of the electrodes over time, as determined by resistance measurements, in soils with varying resistivity values, geological, moisture and temperature conditions. Exothermic, compression and mechanical connections have been used to attach the insulated ground conductor (test lead) to the ground electrodes.

The Phase 1 sites were recently exhumed and are in process of being evaluated for corrosion and other parameters.

Pawnee site exhumation: in 2003, one of the original sites (Pawnee) was exhumed and the ground rod electrodes were removed. 5/8 inch copper-bonded and 3/4" galvanized rod samples were exhumed. The results are definitive.

The 5/8 copper-bonded rods were virtually **free of corrosion** while the 3/4" galvanized rod showed significant corrosion (see photos 1 to 6):

Photo 1
Copper bonded

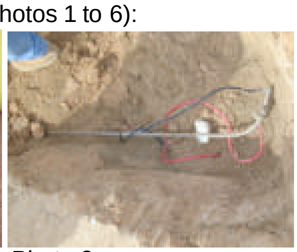

Photo 2
Copper bonded

Photo 3
Galvanized

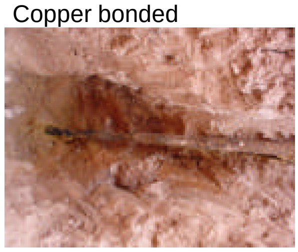

Photo 4
Galvanized

Photo 5
Copper bonded vs. Galvanized

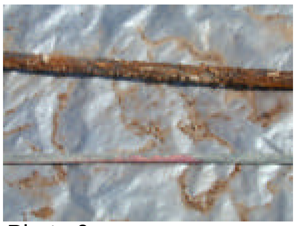

Photo 6
Galvanized

The same evidence has been discovered in the other three sites. (Balboa, Pecos and Lone Mountain).

Question being: 'What does prevent the steel from corroding, when enclosed in the copper jacket, does the transition region between the steel and copper forms obvious galvanic cell?'
The answer is: 'No, when the bond is integral'.

Although the thick copper coating on the ground rod provides superior corrosion resistance, it is also critical that the copper is metallically **bonded** to the steel core in order to achieve the long service life required.
With out this integral bond, any electrolyte that enters the copper-steel interface can implement rapid corrosion. This phenomenon exists with any un-bonded, bimetallic ground rod.
To assure the quality of this metallic bond, ERITECH ground rods are tested with the following test. The test states that a copper bonded ground rod shell be driven between two steel clamping plates or the jaws of the vise set 0.04" (1.016 mm) less than the diameter of the rod to expose the bond between the copper and the steel. It is required that there shall be no evidence of separation of the jacket from the steel core.
The bending test requirement states the ground rod shall be permanently bent through 30 degree angle and there shell be no evidence of cracking of the jacket. Both these tests are outlined on the **Standard UL 467** [7] .

5. Benefits of Ground Enhancement Material (GEM) [14]

As mentioned before **NEGRP** [13], a long-term grounding test study was established in 1992, with the objective of addressing issues such as the anticipated performance of ground electrodes over time and the effect of environmental conditions on their performance.

This paragraph presents the data and analysis for one specific part of the NEGRP, namely the study of the long-term effect of using an engineered ground enhancing material, called "GEM", in conjunction with ground electrodes. The results are presented for a total period of up to 12 years at each site. The resistance of ground electrodes enclosed in the GEM is compared with the results for standard ground electrodes. The data analysis also considers seasonal and longer-term variations in the resistivity of the soil, which can be correlated with the resistance measurements. Based on this long-term experimental study, the paragraph provides some quantitative conclusions regarding the relative benefit of using GEM.

GEM has a long history of usage in scenarios where a reduction in soil resistivity and hence grounding system resistance is needed, by virtue of the terrain in which the grounding system has to be installed. The following analysis of the NEGRP data was carried out in order to better quantify the "performance" of GEM.

Data from a total of 9 sites were analyzed:

SITE	TIME
Balboa – NEVADA	8.4 yrs
Charleston – NEVADA	4.6 yrs
Lone Mountain – NEVADA	11.8 yrs
Pawnee – NEVADA	9.9 yrs
Pecos – NEVADA	11.4 yrs
Dallas – TEXAS	5.5 yrs
Northbrook – ILLINOIS	5.2 yrs
Poughkeepsie – NEW YORK	2.9 yrs
Staunton – VIRGINIA	6.4 yrs

a) **Analyses** - The NEGRP long-term data were plotted, statistics were computed, and a correlation analysis was carried out as a function of the physical variables.

Figure 7 contains a plot of the data for one of the nine sites, Balboa, Nevada. The top graph shows the soil temperature, moisture and resistivity, and the bottom graph shows the electrode resistance as a function of time.

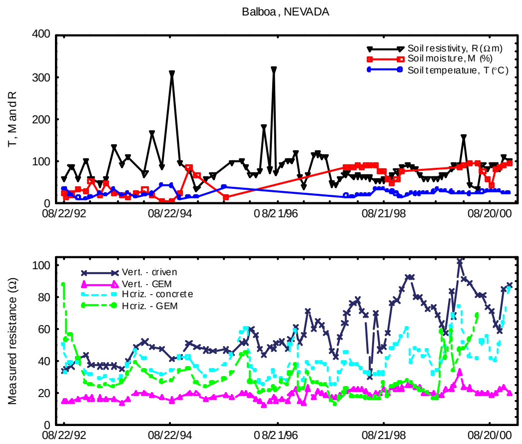

Figure 7 – More than 8 years of grounding resistance data for the Balboa site in Nevada, USA.

b) Specific conclusions about individual sites:

- Using the Nevada data only, the mean, long-term electrode resistance was:
  - 18 Ω for GEM-encased vs. 39 Ω for concrete-encased *horizontal* electrodes
  - 3.6 Ω for GEM-encased vs. 19.8 Ω for driven *vertical* rods

  i.e., a **53% and 82% reduction** in electrode resistance respectively.
  - Furthermore, there is a corresponding reduction in the *variability* (standard deviation) of the resistance of the electrodes with time, namely 60% and 67% respectively.
- Using the Phase 2 data (Texas, Illinois, New York and Virginia), the mean, long-term electrode resistance was 17.5 Ω for GEM-encased vs. 44.5 Ω for driven *vertical* rods, i.e., a **61% reduction** in electrode resistance.

- Furthermore, there is a corresponding reduction in the *variability* (standard deviation) of the resistance of the electrodes with time, namely 63%.
- It is also interesting to note that these reduction factors are relatively constant across different sites and hence soil types and resistivities.

c) **General conclusion can be made:**

- The results confirm the expected variation of soil resistivity with moisture or water content, i.e., a negative correlation (increased moisture ⇒ lower resistivity).
- The results show only a very weak correlation between soil temperature and resistivity, highlighting the fact that classical or textbook relationships between these variables are not necessarily obvious in long-term field data when other variables are also present.
- Interestingly, all of the sites displayed a net *decrease* in soil resistivity with time. It is not possible to tell from the data whether this decrease is real or due to measurement issues.
- On the other hand, almost all of the electrode measurements at each site showed a tendency of the resistance to *increase* over time. A decrease in soil resistivity would be expected to result in a decrease in electrode resistance measurements.
- Clearly, the performance of GEM in reducing electrode resistance and the seasonal and long-term variability in this parameter is very good. For all electrode types investigated, the reduction factor for grounding system resistance, seasonal and long-term variability is much better than 50%.

6. Final Conclusion

This paper has highlighted the benefits of using copper and copper alloys as opposed to galvanized steel for the purpose of electrical grounding. The use of Copper for constructing grounding systems has long history in the USA and is supported with a wealth of research data.
The data clearly shows the greater longevity of Copper in a variety of soil conditions. The use of Copper is also supported by many US Standards. It might seem that the use of galvanized steel is more economical than the use of copper. In reality, **this is not true**, if the projected service life of the grounding system is taken into consideration.
This paper clearly shows that a grounding system constructed from copper components has a projected service life of more than 30 years, while grounding system constructed from galvanized steel components has a projected service life of only 10 to 15 years.
Disregarding the labor cost's associated with replacing a grounding system, this 3 to 1 increase in service life greatly outweighs the approximately 35% increase cost of the components.
Also usage of exothermic connections is highly recommended to achieve a consistent approach for long-lasting networks.
In addition, optimisation of poor quality soils have been demonstrated by usage of GEM (ground enhancing material).

7. References

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[3] IEEE 80-2000 - Guide for Safety in AC Substation Grounding

[4] IEEE 1100 1999 – Recommended Practices for Powering and Grounding Electronic Equipment

[5] IEEE 142 1991 – (Green Book) Recommended Practices for Grounding of Industrial and Commercial Power Systems

[6] The National Bureau of Standards Circular 579

[7] UL 467 – Standard for Safety Grounding and Bonding Equipment

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[11] Naval Civil Engineering Laboratories (NCEL) – "Field Testing of Electrical Grounding Rods"

[12] National Association of Corrosion Engineers (NACE), 1984, Table 2.2, Corrosion Basics, An Introduction

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