REQUIREMENTS FOR EARTHING ENHANCEMENT COMPOUNDS

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ABSTRACT

This paper discusses standard IEC 62561-7 “Lightning Protection System Components (LPSC), Part 7: Requirements for Earthing Enhancing Compounds”. While IEC 62561 deals in particular with components for lightning protection, it is one of the only standards that have detailed information on prequalification of ground enhancement materials. Ground enhancing compounds have broader applications and, in particular, are used widely in telecommunication grounding in North America.

The IEC 62561 series of standards are written for qualifying lightning protection system components (LPSC) designed and implemented according to the IEC 62305 series of standards. Part 7 of IEC 62561 specifically details the requirements and testing of earthing (ground) enhancing materials and compounds. Information on other parts of IEC62561 and IEC62305 standard can be found under the general title Lightning Protection System Components (LPSC), and can be found on the IEC website.

The paper will discuss the tests required under IEC 62561-7, which include:

1. Leaching test which is performed according to EN 12457-2
2. Sulfur tests which is performed according to ISO 14869-1
3. Determination of resistivity
4. Corrosion test which is performed according to ASTM G59-97 and G102-89
5. Marking and indications

The paper will discuss the format of the report including report identification, signature and title of person(s) conducting the test, specimen description, description of test procedures, measuring instruments description and test parameters and results.

INTRODUCTION

Ground electrode resistance is the resistance between a ground electrode or ground electrode system and remote earth. A low resistance ground electrode system is important in order to provide a low-impedance path for the proper dissipation of lightning currents, and to protect personnel and equipment by minimizing and equalizing voltage potential differences. Both the National Electrical Code and the National Electrical Safety Code require the ground electrode resistance to be 25 ohms or less for facilities and systems[1]. Military Standards for grounding, bonding and shielding for communication

[1] If the installation one ground electrode does not meet the 25 ohm requirement, the installation of a second ground electrode is required.

systems require a ground electrode resistance of less than 10 ohms. Many telecommunications standards go beyond that, requiring a ground electrode resistance of 5 ohms (and sometimes even less).

While there are many factors involved with ground electrode system resistance, the resistivity of the soil is a major factor for determining the final ground electrode resistance of a particular facility. The soil resistivities of various soil types are shown in Table 1.

Description	Average Resistivity (ohm-meters)
Well-graded gravel, gravel-sand mixtures, little or no fines	600 to 1,000
Poorly-graded gravel, gravel-sand mixtures, little or no fines	1,000 to 2,500
Clayey gravel, poorly graded gravel, sand-clay mixtures	200 to 400
Silty sands, poorly graded sand-silt mixtures	100 to 500
Clayey sands, poorly graded sand-clay mixtures	50 to 200
Silty or clayey fine sands with slight plasticity	30 to 80
Fine sandy or silty soils, elastic silts	80 to 300
Gravelly clays, sandy clays, silty clays, lean clays	25 to 60
Inorganic clays of high plasticity	10 to 55
Sea water	1

Table (1) – Resistivity of Different Soil Types[2]

The resistivity of earth varies with the type of soil, mineral content and compactness. Resistivity also varies with moisture content and temperature. As a result, the ground electrode resistance of a facility or system varies seasonally and throughout the life of the installation.

[2] For further information, see IEEE 142 "Recommended Practice for Grounding of Industrial and Commercial Power Systems", Chapter 4

The required ground electrode resistance can often be achieved by the installation of the standard ground electrode system where the site's soil resistivity is low (especially if located within climate that receives a fair amount of precipitation). Other times, additional steps may be required in order to achieve the required ground electrode resistance. These steps may include the addition of grounding conductors or ground rod electrodes to help reduce the ground electrode resistance. Larger diameter ground rod electrodes can also be used, but an increase in diameter of ground rods and conductors only slightly reduces the resistance to earth. Driving ground rod electrodes deeper into the earth has a greater impact on the ground electrode resistance than the diameter of the ground rod, but in many instances this option is not feasible. Often, it is impossible to achieve the required ground electrode resistance even with these additional steps. In these cases, earthing (ground) enhancement materials can be used to augment the ground electrode system to help achieve the desired ground electrode resistance.

EARTHING ENHANCEMENT COMPOUNDS AND MATERIALS

Earthing (ground) enhancement materials are high conductivity materials, which are designed to lower ground system resistance and improve grounding effectiveness in high resistivity soil conditions. They can be used in sites installed in areas with poor soil conductivity (such as rocky ground and sandy soil), or on sites where ground rod electrodes can not be driven to the desired depth. They are also often used when limited space makes achieving the required ground electrode resistance impossible with conventional methods.

Earthing (ground) enhancement materials are available in many forms. Bentonite clay is sometimes used as an earth enhancement material. Bentonite, a naturally occurring clay mostly comprised of the mineral montmorillionite, is hygroscopic and absorbs moisture from the surrounding environment. Because of this characteristic, bentonite requires the presence of moisture in the ground to maintain its properties and may not function well in a very dry environment.

Several commercially available forms of earthing enhancement materials are available, including powders, granules, pellets, gels and cementitious mixtures. Many are comprised of carbon-based materials or clays like bentonite (or a mixture of both). Others contain copper sulfate or other copper-based compounds, which may not be environmentally friendly. Some earthing enhancement materials also contain cement, which after installation sets up like concrete. This prevents the earthing enhancement material from leaching into the soil or washing away by groundwater. This type of earthing enhancement material is permanent, does not require any maintenance, and has been shown to significantly reduce the long-term resistance of grounding electrodes in a study commissioned by the National Fire Protection Research Foundation[3].

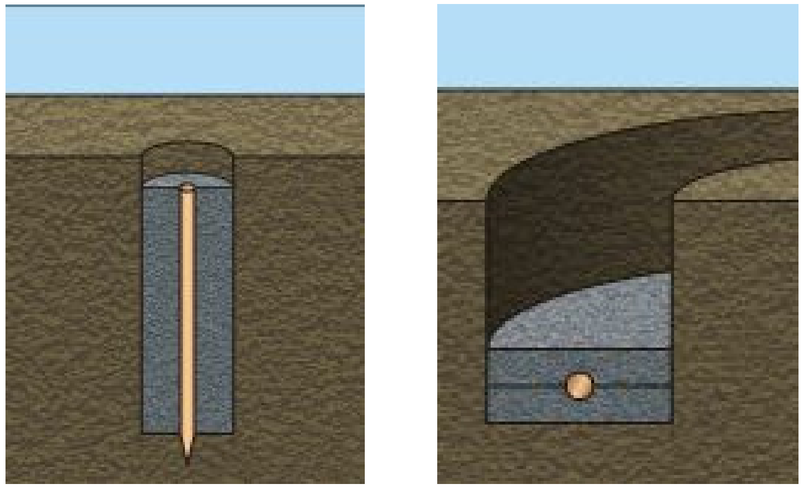

Figure 1 Ground Rod and Conductor with Earthing (Ground) Enhancement Material

Although earthing enhancement materials have been successfully used to reduce ground resistance for decades, a product or performance standard has not existed for these types of products until recently. In 2011, the International Electrotechnical Commission (IEC) published the first standard for ground enhancement materials IEC 62561-7 “Lightning Protection System Components (LPSC) – Part 7: Requirements for Earthing Enhancing Compounds”. The IEC 62561 series of standards covers lightning protection system components, including connectors (part 1), conductors and earth electrodes (part 2), isolating spark gaps (part 3), conductor fasteners (part 4), earth electrode inspection pits and housings (part 5), lightning strike counters (part 6) and earthing enhancement materials (part 7). IEC 62561-7 is one of the only standards that have detailed information on prequalification of ground enhancement materials.

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

The International Electrotechnical Commission (IEC), founded in 1906, is a non-profit organization that prepares and publishes international standards for the electrical and electronic industries. The IEC is part of the World Standards Cooperation (WSC), which also includes the International Organization for Standardization (ISO) and the International Telecommunication Union (ITU). IEC standards are written

[3] Lindsay, T., “National Electrical Grounding Research Project, Technical Report”

by technical experts, who participate in IEC member countries' National Committees through Technical Committees and Subcommittees. As of December 31, 2013, the IEC had published 6,178 standards[4].

IEC 62561-7 "LIGHTNING PROTECTION SYSTEM COMPONENTS (LPSC), PART 7: REQUIREMENTS FOR EARTHING ENHANCING COMPOUNDS"

IEC 62561 was published by the IEC in November, 2011 and was written by Technical Committee TC-81 for Lightning Protection. IEC 62561-7 specifies the product requirements including general, documentation, material and marking. The tests required by this standard include leaching, sulfur content, resistivity, and corrosion. Finally, IEC 625561 details the requirements on the structure and content of the test report.

Leaching Tests

One requirement for earthing enhancement materials is that they must be chemically and physically stable. They must be chemically inert to the surrounding soil and must not leach over time. Conformance is verified by testing in accordance to EN 12457-2 "Characterization of Waste - Leaching - Compliance Test for Leaching of Granular Waste Materials and Sludges - Part 2" and EN 12506 "Characterization of Waste - Analysis of Eluates - Determination of pH, As, Ba, Cd, Cl^-, Co, Cr, Cr VI, Cu, Mo, Ni, NO_2^-, Pb, total S, SO_4^{2-}, V and Zn".

Sulfur Tests

If an earthing enhancement material contains a significant amount of sulfur, it can corrode the ground rod electrode. IEC 62561-7 requires that any earthing enhancement material contains less than 2% sulfur. Conformance to this requirement is verified by testing to ISO 14869-1 "Soil quality - Dissolution for the Determination of Total Element Content -- Part 1: Dissolution with Hydrofluoric and Perchloric Acids".

Determination of Resistivity

Although the IEC does not require a minimum resistivity value for earthing enhancement materials, it does prescribe that all manufacturers of materials used for earthing enhancement test the resistivity in accordance to ASTM G57 "Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method". The sample box used for testing can be a commercially available four-electrode soil box, or one constructed of an inert non-conductive material with four mild or stainless steel electrodes. The measurements can be made by using a commercially available soil resistance meter, or by using a low-frequency AC source with a high impedance voltmeter and ammeter. The tested

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[4] International Electrotechnical Commission, Facts and Figures (http://www.iec.ch/about/activities/facts.htm)

resistivity value of the earthing enhancement compound must be clearly marked on the package, product data sheets, or installation instructions.

Corrosion Tests – Linear Polarization Resistance (LPR)

Background and Theory

An obvious requirement for earthing enhancement materials is that the material being used to lower the resistivity must not be corrosive to the earthing electrode. The pH of the material can be used as an indicator of a compounds' corrosiveness; but corrosion rate cannot be quantified by pH alone. A material with a pH of 4 is not very acidic, but can be quite aggressive towards mild steel. A highly alkaline compound would be very corrosive to some metals including zinc (i.e., galvanized steel earth electrodes).

Since corrosion occurs as a result of electrochemical reactions, electrochemical techniques are ideal for characterizing corrosion processes. "Potentiodynamic Polarization Resistance" (often referred to as "Linear Polarization Resistance" or LPR) is an electrochemical method that is widely used to determine corrosion rates. In this technique, a metal electrode is immersed in a solution typical of the metal's environment in the system being studied. Additional electrodes are immersed in the solution, and all the electrodes are connected to a potentiostat. The potentiostat allows the voltage to be varied in a controlled manner and measures the current as a function of voltage, resulting in a polarization curve. When the potential of the metal surface is polarized by the application of the current in a positive direction, it is anodically polarized. And when the metal surface is polarized in the negative direction, it is cathodically polarized. The magnitude of polarization is indicative of how the rates of the anodic and the cathodic reactions are affected by various environmental and surface processes (concentration and activation polarization). The polarization curve is used to study the affect of concentration and activation processes on the rate of anodic or cathodic reactions to determine the corrosion rate. The value of either the anodic or cathodic current is called the corrosion current, I_{corr}. This value cannot be measured directly, however, it can be related to the polarization resistance by the Stern-Geary coefficient:

$$i_{corr} = \frac{B}{R_p}$$

Equation (1)

Where: B = proportionality constant (mV)

R_p = linear polarization resistance (Ω.m^2)

i_{corr} = corrosion current (μA/cm^2)

The Stern-Geary constant *B* can be determined empirically from separate weight loss measurements or can be calculated from b_a and b_c, the slopes of the anodic and cathodic Tafel curves:

$$B = \frac{b_a b_c}{2.3(b_a + b_c)}$$

Equation (2)

The following equation can be used to convert the I_{corr} units of μA/cm^2 in Equation (1) above to units of μm/yr:

$$\frac{mA}{cm^2} = 3.28\frac{M}{nd}$$

Equation (3)

Where: M = atomic mass

n = number of electrons freed by corrosion reaction

d = density

Polarization Resistance Method Applied to Earthing Enhancement Materials and Earthing Electrodes

The Linear Polarization Method can be employed to determine whether or not an earthing enhancement compound is corrosive to a grounding electrode. The working electrode (in this case, zinc-plated (galvanized) or copper-bonded steel rod) is immersed in the earthing enhancement material sample being tested along with two other electrodes. These electrodes are then connected to a potentiostat. Once the polarization resistance is determined, the Stern-Geary constant, *B*, can be used for "aggressive" (corrosive) and "non-aggressive" (non-corrosive or inert) soil environments, to determine the maximum polarization resistance allowable for the system (i.e., copper-bonded steel in earth enhancement material or galvanized steel earth electrode in earth enhancement material).

Figure 2 – Photograph of LPR Test Cell

Earth Enhancement Materials – Determining Allowable Polarization Resistance for Use with Copper-bonded Ground Electrodes

The acceptable corrosion rate for copper-plated electrodes immersed in earth enhancement material can be determined by using Equation (3) above, where:

M = 63.546 g/mol

d = 8.84 g/cm^3

n = 2

Based upon the molar density of copper and the Faraday constant, the conversion of μA/cm^2 to μm/yr is:

1 μA/cm2 = 11.6 μm/yr for copper.

The corrosion rate C (μm/yr) is then determined by the following equation:

$$C = \frac{11.6B}{10R_p}$$

Equation (4)

Stern-Geary Constant for Copper

Studies have shown that the Stern-Geary constant B = 7 mV for copper buried in bentonite in a deep oxygen free environment. Studies have also shown that B = 25 mV in impermeable concrete, and it is often claimed to be 50 mV. As a result, the test procedure assumes B = 25 mV for "non-aggressive environments" and B = 50 mV for "aggressive environments". Based on previous underground corrosion studies (see references 5 and 13 below) and assuming a constant corrosion rate, 10 mils or 254 μm of copper assumes a lifetime of 35 years (10 mils or 254 μm is the minimum copper plating thickness for ground rod electrodes required by UL 467 "Grounding and Bonding Equipment" as well as European Standard (EN) and IEC Standards). It then follows that the corrosion rate for copper-bonded ground rods must not exceed 7.3 μm/yr. Using Equation (4) above, that means the polarization resistance must be greater than 4 $\Omega \cdot m^2$ for non-aggressive environments and greater than 8 $\Omega \cdot m^2$ for aggressive environments. It should be noted that this calculation does not predict rates for localized events.

Earth Enhancement Materials – Determining Allowable Polarization Resistance for Use with Galvanized Steel Earth Electrodes

The acceptable corrosion rate for galvanized steel electrodes immersed in earth enhancement material can be determined as follows. Using Equation (3) above, where:

M = 65.39 g/mol

d = 7.13 g/cm^3

n = 2

Based upon the molar density of zinc and the Faraday constant, the conversion of μA/cm^2 to μm/yr is:

1 μA/cm2 = 15.0 μm/yr for zinc.

Therefore, the corrosion rate C (μm/yr) for zinc is given by:

$$C = \frac{15.0B}{10R_p}$$

Equation (5)

Stern-Geary Constant for Zinc

According to research completed by the US Department of Transportation, the Stern-Geary constant for zinc is:

B = 20mV for non-aggressive environments

B = 50mV for aggressive environments

Using the same methodology as above and based on the assumption that 3.9 mils (99 µm) of zinc must have a lifetime of 10 years, and assuming a constant corrosion rate (see references 5 and 13 below), the corrosion rate must not exceed 9.9 µm/yr. As a result, the polarization resistance must be greater than 3 $\Omega \cdot m^2$ for non-aggressive environments and 7.6 $\Omega \cdot m^2$ for aggressive environments for galvanized steel earth electrodes.

Marking and Indications

All earthing enhancement compounds that comply with IEC 62561-7 must be marked with the manufacturer's name, trademark or identifying symbol. In addition the standard requires a serial or lot number, installation instructions, the resistivity and test apparatus used to obtain this value, and a conformity statement to IEC 62561-7. If not included on the package, this information must be included on the manufacturer's product data sheet, catalog, or included in the installation instructions.

Structure and Content of the Test Report

The IEC 62561-7 requirements for the arrangement and content of the test report, which can be found in Section 6, are very clear and concise. The General Requirements states "*The results of each test carried out by the laboratory shall be reported accurately, clearly, unambiguously and objectively, in accordance with any instructions in the test methods*" and specifies the headings for each applicable section, which follow.

Report identification

The report must include a title or subject of the report, a test identification number, contact information of the testing laboratory, contact information of the manufacturer and a report issue date. The report must also include the signature and title of the person authorized to sign for the laboratory and the person who conducted the test.

Specimen description

The test report must also include a description of the samples, the date they were received, sampling procedures, photographs or drawings, and references to relevant standards and documentation, along with standard issue dates and documentation dates.

Description of Test Procedure, Testing Equipment, and Measuring Instruments

Details of each test procedure must be included in the test report including the justification for any deviations from the testing requirements of IEC 63561-7. Laboratory environmental conditions, test assembly configurations and descriptions of the measuring techniques and testing equipment must also be included in the final report.

Results, Parameters, and Passing Criteria

The results of each of the tests required by the standard must be clearly stated and shall include the measured and average values, or the observed or derived results as well as the passing criteria for each of the required test.

Pass/Fail Statement

Finally, a statement of pass/fail is required for each of the tests. For any failures, a description of the failure must be included. Drawings, photographs and notes of visual observations should also be included as appropriate.

CONCLUSION

Earthing (grounding) enhancement materials and compounds have been successfully used to lower grounding electrode system resistances worldwide for decades. These materials have been especially useful in areas with high soil resistivity or where site limitations prevent achieving the required ground electrode using conventional grounding methods. Although several standards such as IEEE Std 80 “IEEE Guide for Safety in AC Substation Grounding and TIA 607B “Generic Telecommunications Bonding and Grounding (Earthing) for Customer Premises“ recommend the use of earthing (ground) enhancement materials to achieve a required ground resistance under the circumstances noted above. IEC 62561-7 is the first international conformance standard for earthing (ground) enhancement materials published by a standards organization. The details and requirements of this standard were covered in detail, and aspects of this standard could be considered for inclusion in future US grounding and telecommunications standards.

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