Grounding Principles

Introduction

Grounding and bonding are an integral part of any modern electrical protection system design.

An effective, low-impedance ground system is a key element of this system. It is crucial in ensuring personnel safety, as well as providing reliable protection for vital equipment and to minimize interruptions of service and costly downtime.

With almost a century of experience in the design and manufacture of bonding and grounding products, ERICO®, a single source provider, offers what we believe is the best range of long lasting and cost-effective grounding products available.

The following pages of this catalog detail these products and their respective applications.

Definitions

Ground: A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

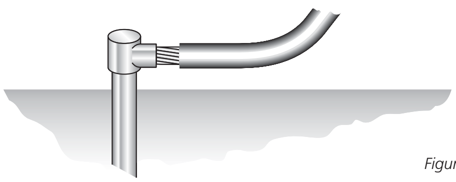

Figure 1.

Earth: The conductive mass of the earth, whose electric potential at any point is conventionally taken as equal to zero. (In some countries the term "ground" is used instead of "earth.")

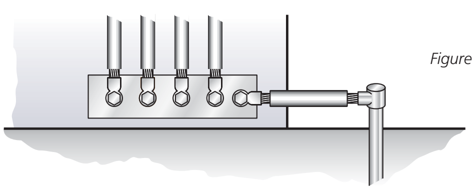

Figure 2.

Bonding: The permanent joining of metallic parts to form an electrically conductive path that will ensure electrical continuity and the capacity to conduct safely any current likely to be imposed.

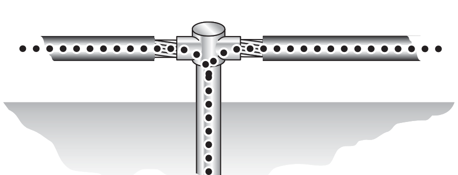

Figure 3.

The need to ground!

There are important reasons why a grounding system should be installed.

1 The most important reason is to protect people!

2 Protection of structures and equipment from unintentional contact with live conductors.

3 Ensure maximum safety from electrical system faults and lightning.

It is a fundamental fact that electricity ALWAYS flows to the point of lowest potential. The task is to ensure that electricity, including faults, lightning and electronic noise, flows to this point with maximum safety to people, while maintaining the reliability of equipment. Therefore we must ensure the safe, controlled flow of electricity with minimum voltage drop to earth in all cases.

Grounding Codes and Standards

Grounding needs vary according to function. The grounding requirements of a power system will vary from those of electrical equipment, lightning protection or for the proper function of electronic equipment.

Proper installation of appropriate grounding systems requires knowledge of the needs and layout of the facility. Soil characteristics, grounding conductor materials grounding connections and terminations, ***are significant factors determining the design of a grounding system. Applicable standards and codes must be applied.***

While many codes and standards contain minimum grounding and bonding requirements, the design and installation of electrical grounding systems is one of the most important aspects of any electrical distribution system. However, codes and standards are often misunderstood and grounding systems subsequently installed improperly.

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Introduction

The facility electrical ground system must:

- Efficiently dissipate lightning surge energy that may arrive via down-conductors of the lightning protection system;
- Efficiently dissipate electrical surges and faults to minimize the chances of injury from either “step potentials” or “touch potentials”;
- Provide a stable reference for electrical and RF circuits at the facility to minimize noise during normal operation;
- Be properly bonded to provide an equipotential plane under fault conditions;
- Be electrically and mechanically robust to assure performance over the “life” of the facility (nominally 40 years from construction date).

Applicable Codes and Standards

European	American	Australian
IEC 10234-1	IEEE Std 80	AS3000--AS2307
IEC 61364-5	NFPA 70 (NEC)	AS 1768-
ENV 61024-1	UL 96A	
BS 1400	CSA C22.1-94	
BS 7430	NFPA 780	
BS6651	IEEE 837	
	IEEE 1100	
	IEEE 142	
	IEEE 81	

The primary functions of grounding can be defined as follows:

1. Personnel Safety

Avoid hazardous Step and Touch Potentials (shock) or even death by low impedance grounding and bonding between metallic equipment, chassis, piping, and other conductive objects so that currents, due to faults or lightning, do not result in hazardous voltage rise.

2. Equipment and Building Protection

A direct, low impedance path to ground and bonding between electrical services, protective devices, equipment and other conductive objects so that faults or lightning currents are quickly dissipated and do not result in hazardous voltages within the building. Proper grounding also facilitates the operation of over-current protective devices.

3. Electrical Noise Reduction

Proper grounding aids in electrical noise reduction and ensures:

1. Minimal impedance between the signal ground points throughout the building.
2. Minimal voltage potential between interconnected equipment.
3. Minimal effect of electrical and magnetic field coupling.

STEP POTENTIAL

Step Potential is the voltage difference between a person’s feet caused by the dissipation gradient of a fault entering the earth.

TOUCH POTENTIAL

Touch Potential is similar to "Step Potential" except that the fault current passes through the person’s arm and torso on the way to the ground.

Another function of the grounding system is to provide a reference for circuit conductors to stabilize their voltage to ground during normal operation. The earth itself is not essential to provide a reference function; another suitable inductive body may be used instead.

The function of a grounding electrode system and a ground terminal is to provide a system of conductors, which ensures electrical contact with the earth.

STEP POTENTIAL   TOUCH POTENTIAL

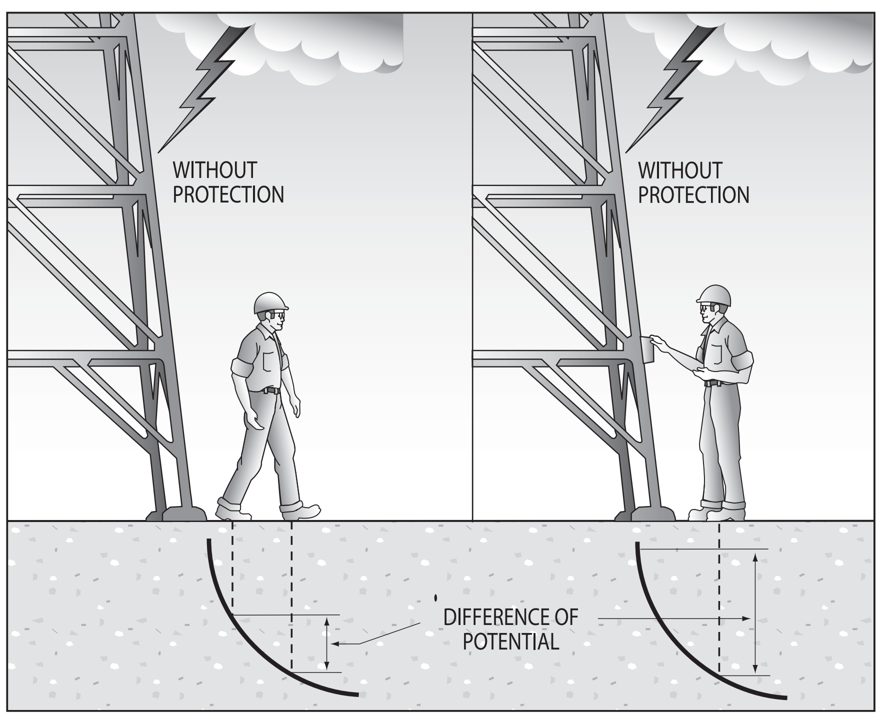

Figure 4. Typically, one meter from a fault entry point, voltage will be reduced by 50%. (e.g. A 1,000 Amp fault in a 5 Ohm grounding system will enter the earth at 5,000 volts. At a distance of less than one meter away, a fatal potential of 2,500 volts will exist).

Ground Resistance

When current flows from a ground electrode into the surrounding soil, it is often described as flowing through a series of concentric shells of increasing diameter.

Each successive shell has a greater area for current flow and consequently, lower resistance. At some point distant from the earth conductor the current dissipation becomes so large and current density so small, that the resistance is negligible.

In theory, the ground resistance may be derived from the general formula:

$$R = P\frac{L}{A} \quad \text{Resistance} = \text{Resistivity} \times \frac{\text{Length}}{\text{Area}}$$

This formula illustrates why the shells of concentric earth decrease in resistance the farther they are from the ground rod:

$$R = \text{Resistivity of Soil} \times \frac{\text{Thickness of Shell}}{\text{Area}}$$

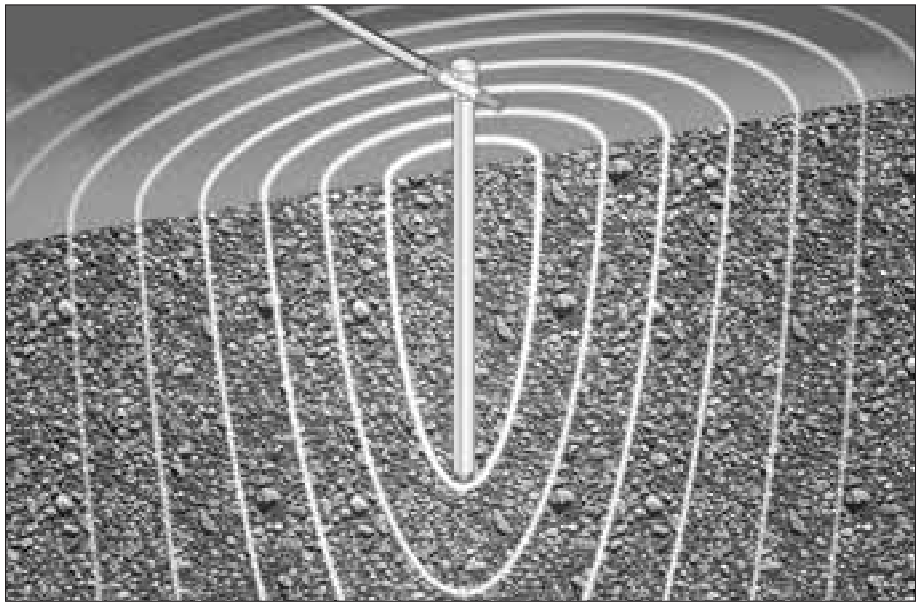

Figure 5. Sphere of Influence - electrical current flows from the ground rod into surrounding soil and progressively dissipates in waves of increasing diameter.

In the case of ground resistance, uniform earth (or soil) resistivity throughout the volume is assumed, although this is seldom the case in nature. The equations for systems of electrodes are very complex and often expressed only as approximations. The most commonly used formula for single ground electrode systems, developed by Professor H. R. Dwight of the Massachusetts Institute of Technology, is the following:

$$R = \frac{\rho}{2\pi L}\left\{\left(\ln \frac{4L}{r}\right) - 1\right\}$$

R = resistance in ohms of the ground rod to the earth (or soil)
L = grounding electrode length
r = grounding electrode radius
ρ = average resistivity in ohms-cm.

Conditions Influencing Soil Resistivity

The resistance of the earth itself (soil resistivity) can significantly impact the overall impedance of the grounding system. Several factors, such as soil composition, moisture content, mineral content, contaminants, etc., determine the overall resistivity of the earth (refer Table 1).

SOIL TYPE	Resistivity ohm-cm		
	Average	Min.	Max.
Fills – ashes, cinders, brine wastes	2,370	590	7,000
Clay, shale, gumbo, loam	4,060	340	16,300
Clay, shale, gumbo, loam with varying proportions of sand and gravel	15,800	1,020	135,000
Gravel, sand, stones, with little clay or loam	94,000	59,000	458,000

U.S. Bureau of Standards Technical Report 108

Table 1. Soil Resistivity.

Soil Composition

Soil types vary in content and consistency. Black dirt or soils with high organic content, are usually good conductors because they retain higher moisture levels and have a higher electrolyte level. Sandy soils, which drain faster, have a much lower moisture content and electrolyte level. Therefore they have higher impedance. Solid rock and volcanic ash contain virtually no moisture or electrolytes and hence high levels of resistivity.

Soils have generally been deposited in layers or strata. These strata can have different values of soil resistivity. By measuring the resistivity of the soil at varying depths, it is possible to develop a profile, which can be used to identify the most appropriate ground electrode design.

Moisture Content

Moisture content has the largest influence on soil resistivity because it helps chemicals in the soil that surround ground conductors carry the electric current. In general, the higher the moisture content the lower the soil's resistivity.

Moisture retention can be influenced by local climate conditions and electrolytic mechanisms such as mineral content, soil ionization, consistent grain size, even distribution and packing density.

Systems designed for areas which typically have very dry soil and arid climates may need to use enhancement materials or other means to achieve lower soil resistivity.

Temperature

High temperatures and drought, or temperatures below freezing and deep frosts, can cause high resistivity in soils that have much lower values in the preceding months. When moisture turns to ice, resistivity increases sharply. Areas with regular rainfall and no ground frost are more likely to have low soil resistivity, in comparison to those regions that are arid or have permafrost.

In areas subject to freezing winters driving the ground rod below the frost line is necessary to maintain a low resistivity.

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Soil Resistivity Testing

To properly design a grounding system, it is essential to test soil resistivity. Several methods can he used to measure earth resistivity: the four-point method, the variation in-depth method (three-point method) and the two-point method. The most accurate method and the one that ERICO® recommends is the four-point method.

The Four-Point Method

1. Four test stakes are positioned in a straight line an equal distance apart and are hammered into the ground to be surveyed to a depth of not more than 1/20 the distance between the adjacent stakes.

2. An earth resistance tester is connected to these four stakes as shown in Figure 6.

3. The DC test option on the tester is then selected and performed, and the resistance figure "R" recorded.

4. The soil resistivity level "r" (in ohms/cm) is then calculated using the formula: r=2paR where:

   R = the resistance figure, in ohms
   a = the separation of the test stakes, in meters.

$$p = \frac{4\pi AR}{1 + \frac{2A}{\sqrt{(A^2 + 4B^2)}} - \frac{2A}{\sqrt{(A^2 + 4B^2)}}}$$

Where:

A = distance between the electrodes in centimeters

B = electrode depth in centimeters

If A > 20 B, the formula becomes:

p = 2π AR (with A in cm)

p = 191.5 AR (with A in feet)

p = Soil resistivity (ohm-cm)

This value is average resistivity of the ground at a depth equivalent to the distance "A" between two electrodes.

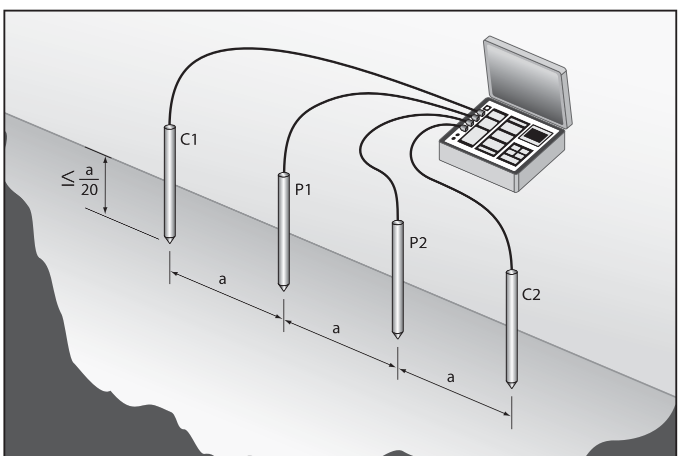


Figure 6.
Measuring Soil Resistivity using the "Four-Point" Method.

A Line Traverse Soil Resistivity Survey

Soil resistivity levels can vary significantly both with depth, and from one point to another on a site, and as such, a single soil resistivity measurement is usually not sufficient. To obtain a better picture of soil resistivity variations, it is advisable to conduct a detailed survey.

The Line Traverse technique is a commonly used method for performing soil resistivity surveys. In this method imaginary parallel lines are drawn across the area to be surveyed. Taking a number of measurements along each 'line' using different stake separations provide an indication of how the soil resistivity varies with depth, while measurements taken along different lines provide an indication of how the resistivity changes across the site.

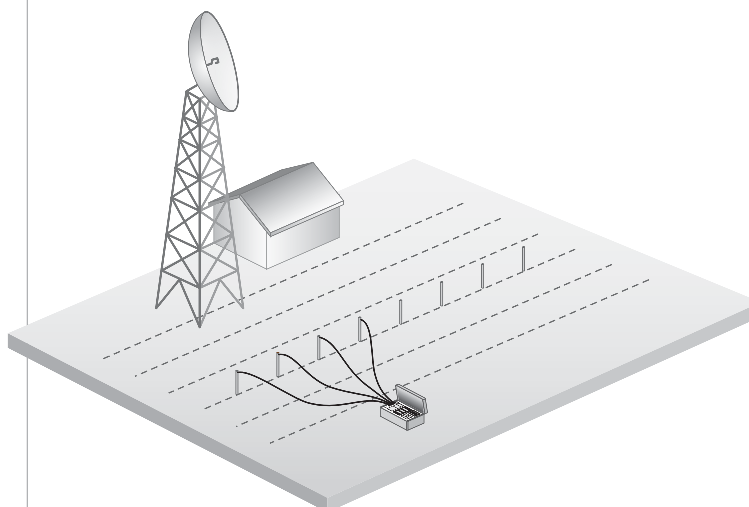


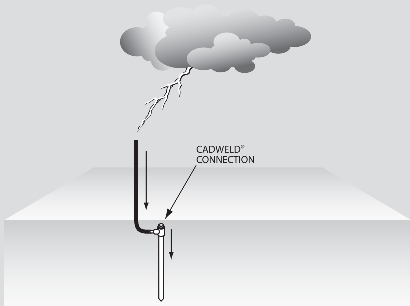
Figure 7. Performing a Line Traverse survey. A commonly used method for soil resistivity survey work.

Grounding Principles

Types of Grounding Systems

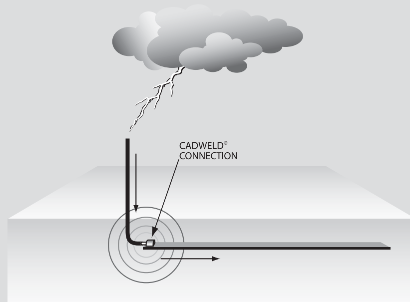
The basic philosophy of any ground electrode installation should be an attempt to maximize the surface area contact with the surrounding soil. Not only does this help to lower the resistance of the grounding system, but it also greatly improves the surge impedance of the grounding system due to the large capacitive coupling which is achieved.

The actual layout of the grounding system, and the number, length and depth of ground rods will vary with the usages, type of soil and space availability. Some common designs include:



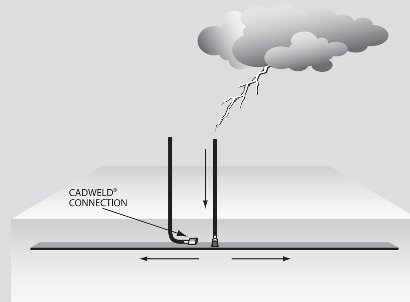
Single Ground Rod

One single ground electrode may be sufficient for an electrical installation in a built up area where the local supply authority utilizes a multiple or common multiple earth neutral (MEN or CMEN) system. However, it may not provide an adequately low impedance for lightning current injection.



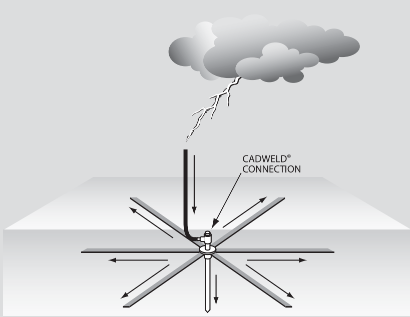
Single Strip End Connected

This is a common option for installations where, because of rock, driving an electrode is impractical. It is not recommended for lightning protection systems as there is only one path. Very high ground voltages will be experienced at the injection point.



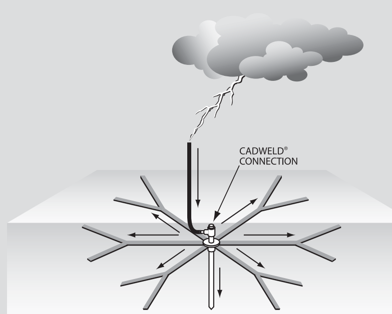
Single Strip Center Connected

Since the connection to the strip is at the center, any fault/injection current travels in two directions. This layout has lower impedance, but it is generally not adequate for lightning protection systems.



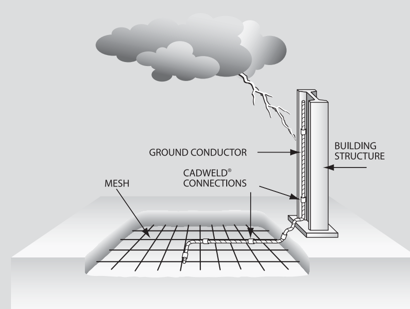
Radial Grounding, Single Radials

A design that is well suited to lightning protection in areas of medium resistivity. The radials can run to 100 feet in length.



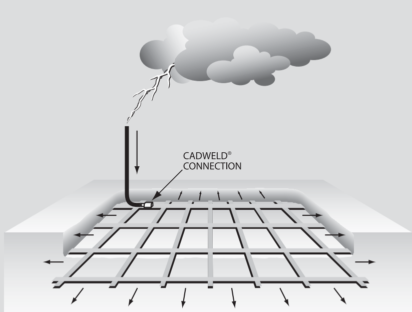
Radial Grounding, Multiple Radials

Crows foot design. Well suited to lightning as it allows energy to diverge as each conductor takes a share of the current, offering a lower impedance. Voltage gradients leading away from the injection point will be lower, reducing danger from step potentials.



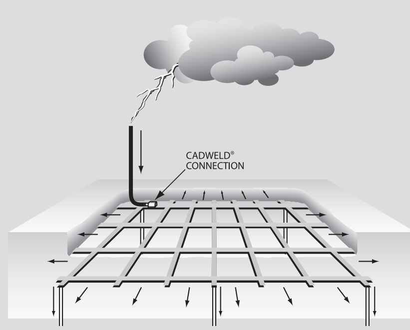
Equipotential Mesh Electrodes

Minimize the risk of step and touch potential hazard by positioning a mat and bonding it to the structure or operating handle at locations where personnel may be required to operate switchgear or stand in the course of their duties. Low ground impedance.



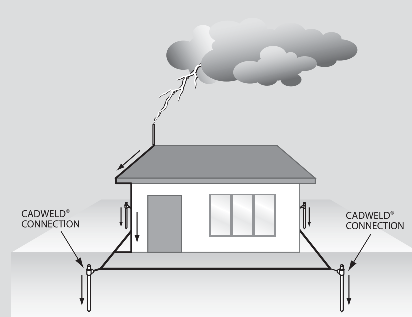
Grid Electrodes

Grounding for installations where there is concentration of electrical equipment, such as electrical substations, are often designed to meet a specific value of resistance (typically 1 ohm). Under fault conditions, a grid can dissipate currents over a large area.



Grid with Ground Rods

It may be advantageous to add ground rods to the grid. In doing so, it may be possible to access a low resistivity soil layer. Care must be taken to ensure each ground rod is spaced at least twice the installation depth.



Ring Electrode

Installations, including communications huts, pad mount transformers and fences surrounding high voltage installations, are generally surrounded by a ground ring. This practice also reduces the hazard of step and touch potential.

Figure 8.

Ground / Earthing System Design

Grounding systems are important. It is not expensive to build an appropriate ground system during initial construction of a facility, but it can be very expensive to add to it, enhance it, or replace it after the facility is complete. Care should be taken to design a system that is appropriate both for clearing ground faults and dissipating lightning energy. The system must have a long performance life, meet applicable codes / standards for safety, and have sufficient bonding points to make it easy to add new equipment / facility grounding to it easily.

Design considerations include:

- Purpose of facility
- Design life of facility
- Soil resistivity at 3 depths
- Corrosive nature of soil
- Shape and available area of facility site
- Existing structures and their grounding systems
- Seasonal variations in moisture and temperature for facility site
- Public access & personnel use
- Adjacent facilities and electrical systems
- Future uses, additions, equipment for facility

For proper operation of overcurrent devices, it is important to have a low DC ohmic resistance to remote earth. In many instances, this is best achieved by installing a deep ground electrode on site. It should be driven deep enough to reach the permanent water table.

For dissipation of direct or indirect lightning currents, it is better to have many horizontal ground conductors in the soil, preferably in a radial array. This provides a low impedance path of dissipation to the high frequency component of the lightning energy.

For safety of personnel, particularly where people congregate or where equipment operators will be located, it is important to have a grid system or other equipotential plane to reduce "step potential" and have equipment and metal structures bonded to the ground system to reduce "touch potential".

A proper facility grounding system incorporates these necessities in the most cost-effective manner that will last for the design life of the facility.

ERICO® is a manufacturer and marketer of grounding, bonding, lightning protection and surge protection products and systems. ERICO has many knowledgeable and experienced engineers on staff with the training and the tools (including some of the latest design software) to design appropriate grounding systems. These engineers can assist facility owners, engineers and contractors in designing the most appropriate system for the facility in question.

Grounding Chain

- Grounding Electrode Conductor
- Grounding Connections
- Grounding Electrode
- Electrode to Soil Resistance
- Soil

The Grounding Chain

The performance of the grounding system is determined by the quality of the following five components all of which are of equal importance.

1. The Grounding Electrode Conductor. Typically made from copper or copper-clad steel, the grounding electrode conductor must be large enough to withstand the maximum available fault current over the maximum clearing time.
2. The Grounding Connections. Often overlooked, the grounding connections are used to tie the elements of the electrode system together. Exothermically welded connections provide a molecular bond that will never loosen or corrode. Mechanical connectors, such as crimp, bolted, and wedge type, rely on physical point-to-point surface contact to maintain the integrity of the electrical connection. IEEE Standard 837 provides detailed information on the application and testing of permanent grounding connections. ERICO can provide an independent, third-party test report evaluating the performance of these connectors in accordance with the testing procedures set forth in IEEE 837 Standard for Qualifying Permanent Substation Grounding Connections.
3. The Grounding Electrode. The grounding electrode provides the physical connection to the earth and is the instrument used to dissipate current into it. There are two main types of electrodes. "Natural" electrodes are intrinsic to the facility and include metal underground water pipe, the metal frame of the building (if effectively grounded), and reinforcing bar in concrete foundations. "Made" electrodes are installed specifically to improve the performance of the ground system and include wire meshes, metallic plates, buried copper conductor and rods or pipes driven into the ground. The ground rod is the most widely used electrode.
4. Electrode to Soil Resistance. Amount of rod surface and rod replacement are the controlling factors. Doubling diameter reduces resistance by only 10% and is not cost effective. Doubling rod length, however, theoretically reduces resistance by 40%. The most common solution is proper placement of multiple rods that are driven to the required depths.
5. The Soil. The soil resistivity, measured in ohm-centimeters or ohm-meters, plays a significant role in determining the overall performance of the grounding system and must be known before a proper grounding system can be engineered. Measuring soil resistivity allows the design engineer to locate an area with the most conductive soil and to determine the depth of the conductive soil so that electrodes can be placed accordingly.

The grounding system will carry little or no current for long periods of time until a fault occurs or a lightning strike or other transient requires dissipation. At that point, the grounding system components will be expected to perform like new while conducting large amounts of current. Most of the grounding system is concealed below grade, making inspection of the grounding components difficult or impossible. The underground environment is a harsh one. The initial selection of the components used in the grounding system is of critical importance to its long-term effectiveness.