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Third installment of the series:

Grounding 101

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In this installment, we focus on the importance of proper grounding for safety and the performance of sensitive electronic devices.

The idea of grounding is that the earth itself acts as the electrical ground, providing not only a common reference for all electrical devices, but also a standard between devices regardless of location. The earth is used as the common reference conductor.

The consideration that the earth acts as a constant conductor is the underlying principle, and in the larger sense, it does. However, the connection to the ground or "earthing" needs to have the lowest resistance possible. Any resistance due to improper or faulty connections will allow the presence of a current to flow. In the context of safety, current flowing through a vital organ is what causes injury or death. The frequency of the alternating current, the duration of contact, and the path of contact are all important factors in determining the severity of the shock (see page 22, table 2).

The connection to the earth consists of two basic parts: the grounding electrode and the connection (or bonding) to that electrode. Any resistance introduced in the grounding path could lead to a damaging or dangerous condition.

The relationship between resistance, current, and voltage is revealed in Ohm's Law[1]:

$I = V / R$

Where :

I = current flow

V = voltage

R = resistance[2]

Using this equation, if the resistance is 0, then the current flow will be maximized in the ground circuit. (This is what you want, not current flow in another path that does not include the ground, but may include YOU!)

The accepted National Electrical Code (NEC), standard for a grounding circuit is 25 ohms or less, but much lower values can be obtained using multiple grounding electrodes.

"A single electrode consisting of a rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less shall be augmented by one additional electrode of any of the types specified by 250.52(A)(2) through (A)(7). Where multiple rod, pipe, or plate electrodes are installed to meet the requirements of this section, they shall not be less than 1.8 m (6 ft) apart".

Section 250.56 of the National Electrical Code

Recently the following was added:

"In facilities with sensitive equipment it should be 5.0 ohms or less."[3]

[1] Named after George Simon Ohm, a German physicist who first published his findings in 1827.

[2] The resistance expressed in ohms is a simple number in DC circuits. In an AC circuit, there are also two other frequency dependent components, inductive reactance (found in coils, or inductors) and capacitive reactance (found in capacitors). For simplicity, we consider only the DC components in this article.

[3] Weighing system equipment is sensitive. We recommend 5.0 ohms or less.

The grounding electrode

The usual form of grounding an electrode is a copper rod, sunk into the earth at a point near the device or electrical service to be protected. NEC calls for a minimum of 8 ft of electrode to be in contact with the earth. However, not all "earth" has the same electrical properties. (See Table 1).

Table 1[4]

Type of Soil	Min R	Max R
Clayey Sand	1	156
Silty Sand	1	15
Clayey Silt with Sand	30	91
Sandy Gravel with Silt	30	102

To overcome this variable, sometimes a multiple number of rods can be placed in an area to lower the resistance to ground.

When using multiple ground rods, they are all connected in a "daisy chain" and one conductor is used to connect to the service or device to be grounded. This effectively places them in parallel and the resulting resistance is lower. Although it would seem the resistance is in direct proportion to the number of rods, the calculation is a little more complicated.

The total resistance of a multiple rod system is calculated by using the formula:

$$Rt = (Rs/n) \times F$$

Where:

Rt = combined ground resistance of the system

N = number of electrodes

Rs = typical resistance of one electrode

F = factor shown in table 4 for the number of rods

Table 4[5]

Number of Rods	F
2	1.16
3	1.29
4	1.56
8	1.68
12	1.80
16	1.92
20	2.00
24	2.16

Testing for earth ground resistivity requires the use of an earth ground resistivity meter and some additional stakes and cabling to measure the resistance between the grounding conductor and earth. One of the most accepted tests uses the Wenner method developed by Dr. Frank Wenner of the U.S. Bureau of Standards (now known as NIST) in 1915[6].

Table 2[7]

Current Level (in milliamperes)	**Probable effect on human body**
1 mA	*Perception level. Slight tingling sensation. Still dangerous under certain conditions.*
5 mA	*Slight shock felt; not painful but disturbing. Average individual can let go. However, strong involuntary reactions to shocks in this range may lead to injuries.*
6-30 mA	*Painful shock, muscular control is lost. This is called the freezing current or "let-go" range.*
50-150 mA	*Extreme pain, respiratory arrest, severe muscular contractions. Individual cannot let go. Death is possible.*
1000-4300 mA	*Ventricular fibrillation (the rhythmic pumping action of the heart ceases). Muscular contraction and nerve damage occur. Death is most likely.*
10,000 mA	*Cardiac arrest, severe burns and probable death.*

Table 3

Shielding Grounding Protection Schemes	Magnetic	Low f RF	High f RF	Ground loop	Comments
No ground	None	None	None	None	
Ground one end	Good	Fair	Good	None	Good for frequencies where cable length is greater than 1/8 frequency
Ground both ends	Good	Good	Fair	Dangerous	Ground loops currents can be damaging
Ground at send end and capacitor coupled to ground at the other end	Good	Good	Good	Insignificant	Capacitor should have a spark gap for transients and must be selected and placed correctly

[4] Excerpted and adapted from the National Electrical Grounding Research Project by the Fire Protection Research Foundation.

[5] From Practical Grounding, Bonding, Shielding and Surge Protection by G.Vijayaraghavan, Mark Brown, Malcolm Barnes, Butterworth-Heinemann, 2004.

[6] F. Wenner, A Method of Measuring Earth Resistivity; National Bureau of Standards, 12(4) 258, p. 478-496; 1915/16.

[7] From OSHA.gov website. This table demonstrates the general impact of a 60Hz hand-to-foot shock of one second duration.

The Wenner method involves placing four probes in the earth at equal spacing. The probes are connected with wires to the ground resistance test set. The test set passes a known amount of current through the outer two probes and measures the voltage drop between the inner two probes. Using Ohm's Law, it will output a resistance value which can then be converted to a resistivity value using the equation:

$P = 2\pi aR$

Where:

P = soil resistivity in ohm cm

a = spacing between probes in cm

π = 3.1416

R = resistance value measured by test set

Soil resistivity values vary depending on the soil type, temperature, and moisture content. Typically, data is collected to depths of one to ten meters with additional testing required for difficult (high or widely varying resistance) sites.

Finally, testing of the grounding system is important to determine whether ground resistance targets are met. Grounding professionals should be called to perform the ground resistance tests since each test must take into account on-site conditions, and it is very easy to get erroneous data. Testing can be accomplished using clamp-on resistance testers, Fall-of-Potential methods, or by simply calculating the probable resistance. Detailed procedures for accurate testing can be found in ANSI IEEE Standard 81.

The use of a good test set is the best way to not only design and test a new grounding system, but also to test existing systems for degradation and ensure they will perform properly in the event of a nearby lightning strike. Although the cost for these sets can range upwards of $3,000 (rentals are sometimes available for a fraction of the cost), the cost of a replacement scale system due to a noncompliant grounding system can be much more expensive, not to mention the priceless protection it provides to individuals. ■

electro><magnetic TAG TEAM

Electric current flow and magnetism interact and either one can induce the presence of the other.

If you take a simple bar magnet, place a piece of paper over it, and sprinkle some iron filings on the paper, it looks like the magnet above.

The lines of filings represent the magnetic field that is present.

Whenever there is a flow of electricity, there is also a magnetic field that is produced.

When an electric field is generated from any AC current flow (at any frequency), the field produced will induce a magnetic field in any magnetic (ferrous) metal that is in the field.

On the other hand, whenever a magnet is moved through a set of electrical conductors, an electric current is generated in the conductors. The larger the field, or movement, or number and size of conductors, the larger the induced magnetism or electric current.

An electromagnet can be easily made with a nail with a number of turns of wire wrapped around it. Connect the ends of the wire to a battery, and you have an electromagnet.

Take a coil of wire and move a magnet in and out of the coil, and you will generate an electrical voltage at the ends of the wire.

All of this becomes vital when dealing with a shielded cable such as a load cell cable or a "home run" cable. The shield must have a low resistance to ground connection on one end only, to act as a shield to any induced electrical current.

> Rice Lake offers cable with both foil and more than 90 percent braided shielding.

Grounding at both ends of the shield provides a resistance between two ground potentials, resulting in a ground loop that can carry enough current to actually damage the equipment to which it is connected.

Shield types are foil, wrapped, braided, or any combination thereof. There are advantages and disadvantages to each, although aside from the cost and flexibility issues, a combination foil and good coverage (over 90 percent) braided shield provides the best protection. All of our SURVIVOR® load cell cable offerings have both foil and more than 90 percent braided shielding.

In addition, the actual ground connection needs to be of very low resistance or the advantages are voided. Good quality connectors and grounding methods (360 degree clamp or solder) are essential.