DEEP EARTH GROUNDING VERSUS SHALLOW EARTH GROUNDING

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ABSTRACT
Low resistance earth grounding is essential for safety and protection of sensitive electronic equipment. It is the basis for any facility's power quality assurance program.

This paper presents the advantages of deep driven electrodes over shallow (10 feet or less) electrodes. This paper will demonstrate that deep driven electrodes provide low earth resistance, are economical to install, maintain low resistance over time, are maintenance free, and do not have environmental concerns. This paper utilizes field data taken from over 140 deep driven electrodes installed over a 5-year period in several states. A discussion includes the development of the equipment, materials, and process used to install and test deep driven made electrodes. The process includes a new technique of injecting bentonite into the coupler void to maintain full rod contact of the total length. Several site reports are presented and discussed. This paper would be of value to anyone responsible for specifying, installing or testing low resistance ground systems.

OBJECTIVES
The objectives of this paper are to:

a. Determine the electrode depths required to achieve low resistance values.
b. Determine if standard 8 to 10-foot ground rods meet minimum code requirements
c. Evaluate the stability of shallow electrodes
d. Present a new process for installing deep-driven ground rods

FORWARD
Confusing standards, different philosophies and conflicting opinions have plagued the field of grounding for many years. The majority of these issues deal with the how and why of grounding and bonding in electrical, computer, and communications systems. Little information and discussion has been focused on the earth resistance of the grounding electrode system. Most plans and specifications give little direction for the installation and testing of a grounding electrode system and many merely state "ground per the NEC." One noted publication on grounding[1] stated that engineers who write such specifications are "not assuming their full responsibility for safety" and are leaving the installation of "effective" grounding to chance! Based on power quality site surveys done by the authors, 90-95% of all facilities inspected lack an effective grounding system. In addition, none of the facilities inspected had ever tested the ground resistance of their electrode system.

Effective earth grounding is essential for grounded AC and DC electrical equipment and distribution systems. Effective grounding provides the level of safety required to protect personnel and equipment from shock and fire hazard. The understanding and evaluation of a facility ground system should be part of any power quality assurance program.

In order to understand earth grounding and test procedures, it is necessary to review why grounding is important. The following list gives some of the basic requirements of an effective ground system.

Basic Grounding Requirements

- Limits voltage in an electrical distribution system to definite fixed values
- Limits voltage to within insulation ratings
- Provides a more stable system with a minimum of transient over voltage and electrical noise
- Provides a path to ground in fault conditions for quick isolation of equipment with operation of ground fault protection
- Provides grounding of all conductive enclosures that may be touched by personnel, thereby eliminating shock hazards

- Reduces static electricity that may be generated within facilities
- Provides protection from large electrical disturbances (such as lightning) by creating a low resistive path to earth

A ground system must meet NEC (National Electrical Code) Article 250 requirements. The NEC[2] defines *grounded* as:

"Connected to earth or to some connecting body that serves in place of the earth"

and *effectively grounded* as:

"Intentionally connected to earth through a ground connection or connections of sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazard to connected equipment or to persons."

Grounding an electrical system to earth is done by bonding appropriate components of the distribution system to the grounding electrode system. This system is specified in NEC 250-81 & 83 and includes a combination of available items listed in the following list:

Grounding Electrode System Components

- Metal water pipe
- 10' in-earth metal frame of building
- Concrete-encased electrodes
- Ground ring
- Rod and pipe electrodes
- Plate electrodes

The NEC does not specify a maximum earth resistance for the grounding electrode system required under Article 250-81. The only place that does specify earth resistance is under Article 250-84, for "made" (rod, pipe, and plate) electrodes. Here the NEC specifies a resistance to ground of 25 Ohms or less for a single electrode. If the electrode does not meet 25 Ohms, it must be supplemented by one additional electrode. However the combination of the two electrodes does not have to meet the 25 Ohm requirement! One can only speculate that the writers of the NEC are assuming the combination of items listed in the preceding list will meet the 25 Ohms or less standard. For power quality concerns this assumption leaves the grounding resistance to chance.

According to the IEEE Green Book[3], the grounding electrode resistance of large electrical substations should be 1 Ohm or less. For commercial and industrial substations the recommended ground resistance is 2-5 Ohms or less. This low resistance is required due to the high potential to earth of the electrical system. Many equipment vendors and communication companies require ground systems of less than 3 Ohms resistance.

With modern construction methods and materials, it is becoming more difficult to achieve a low resistive ground system. Many municipalities are insulating metallic water mains for corrosion protection, or are switching to non-metallic water pipes. Building steel can only be used when effectively grounded.[4] At most facilities, it is not. Concrete encased electrodes (Ufer grounds) are not common in many regions. Ring grounds and plate electrodes are rarely used due to their high installation cost. An untested 8 to 10-foot ground rod is the typical "made" electrode for most facilities.

For many sites that have minimal or missing grounding systems, installing a new grounding electrode system is cost prohibitive or impractical. It was for this reason that a process was developed to install deep driven ground rods as a low-cost, effective solution.

INTRODUCTION

Starting in 1986 a study was done to determine the most effective method of installing low resistive earth grounding. Various grounding methods and materials were evaluated. The majority of the standard methods were rejected for practicality or cost reasons. New methods of using chemical rods and soil enhancement materials looked promising but left unanswered questions as to environmental impact and liabilities. When questioned about the "secret" chemical composition of one vendor's product, a response was given that the item was EPA approved to be placed in a landfill. The problem is landfills do not require low resistive grounding! One state environmental engineer cautioned against using chemical soil enhancements near municipal water supplies. He was concerned about ground water contamination from the chemicals.

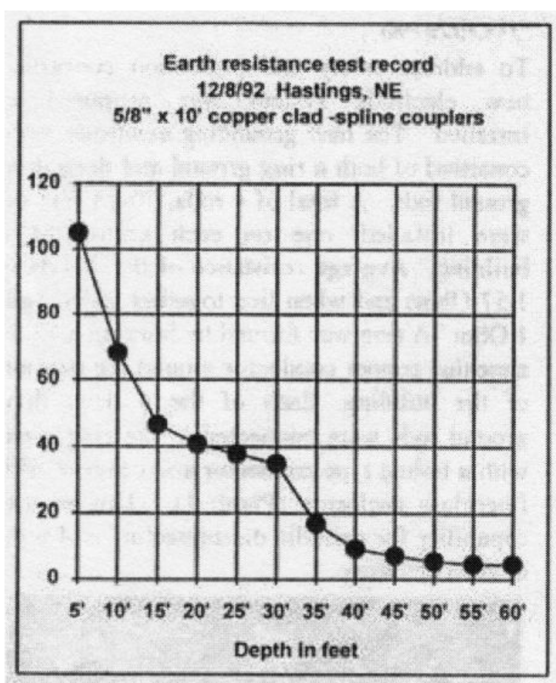
Based on the study it was determined that deep-driven ground rods would offer the best solution for low resistive earth grounding, if full rod contact could be maintained. In 1988, a new process overcame the problems associated with installing deep ground rods.

This paper evaluates the field data taken from 140 deep-driven ground rods installed between May 1988 and July 1993. The ground rods were installed in 6 states with the majority in Nebraska. Ground rod depths ranged from 15 to 90 feet. All resistance measurements were done with the three point fall-of-potential method using a Biddle Megger, Model No. 250220-1, Null-Balance Earth Tester.

DISCUSSION

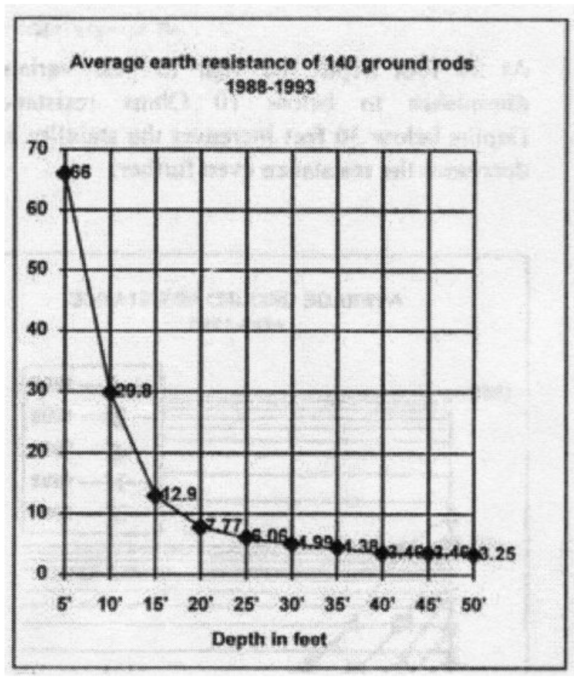
The field data includes earth resistance values for every 5 foot depth of ground rod installation. Ground rod depth was determined by achieving the desired resistance or hitting an obstruction. The resistance of the rod was plotted on a depth vs. resistance graph as shown in Figure 1.

Figure 1. Sample ground rod resistance: ohms versus depth.



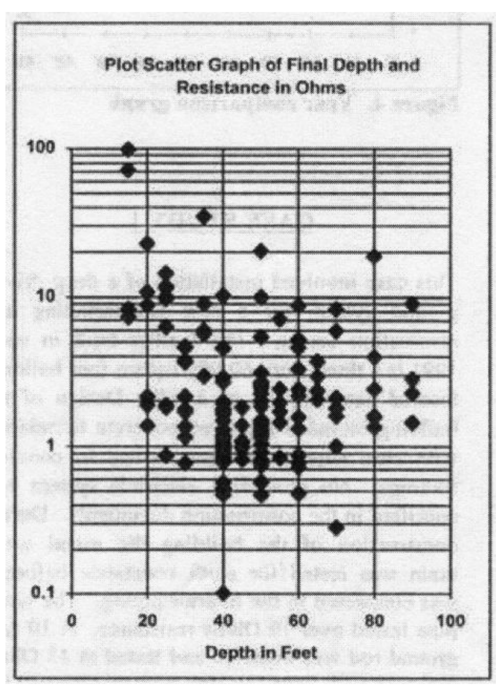
The resistance data from over 140 ground rods is averaged and plotted in Figure 2. Note that the average 5-foot ground rod measured 66 Ohms and at 10 feet is 29.8 Ohms, by interpolation an 8-foot ground rod would average approximately 40 Ohms. The average 8 and 10-foot ground rod failed to meet the NEC minimum of 25 Ohms or less. Depths of 30 feet are required for 5 Ohms or less. The first 20 feet of depth represented the greatest change in earth resistance.

Figure 2. Average resistance graph.



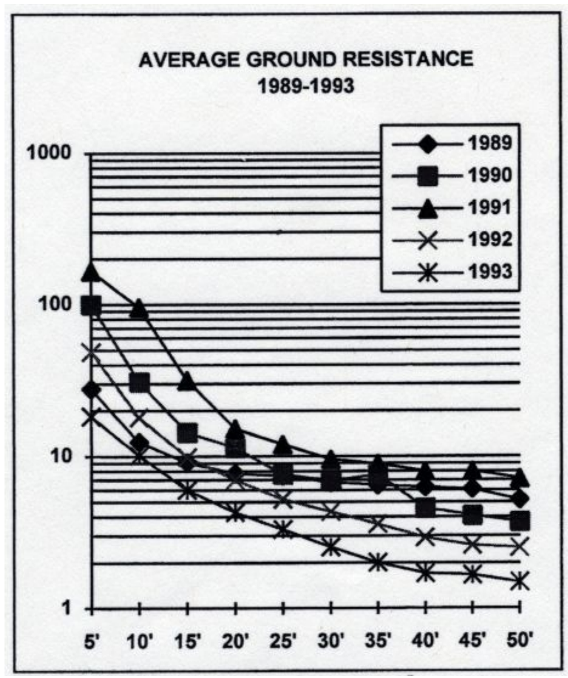
The final depth and resistance of each rod is plotted on Figure 3. The majority of the rods ranged in resistance of 0.9-2.0 Ohms at a depth of 40-60 feet.

Figure 3. Scattered plot chart.



A comparison of the resistance at different times is shown in Figure 4. This graph shows the average resistance for rods installed in each year of the survey period. Note how the resistance varies considerably in depths of 10 feet or less. The early part of 1993 was a very wet period and is represented by much lower resistance. At 30-foot depth the year-to-year variance diminishes to below 10 Ohms resistance. Depths below 30 feet increase the stability and decrease the resistance even further.

Figure 4. Year comparison graph.



CASE STUDY 1

This case involved installation of a deep-driven ground system for a new telemarketing and reservation center. The facility built in early 1991 is a three story 60,000 square-foot building located near the top of a hill. Design of the building included a poured concrete foundation with steel support columns bolted to concrete footings. No grounding electrode system was specified in the construction documents. During construction of the building the metal water main was tested for earth resistance before it was connected to the interior piping. The water pipe tested over 10 Ohms resistance. A 10-foot ground rod was installed and tested at 45 Ohms resistance. A lighting risk assessment rated the facility in the moderate to severe category.[5]

To address safety and protection concerns, a new electrode system was proposed and installed. The new grounding electrode system consisted of both a ring ground and deep driven ground rods. A total of 4 rods, 70 - 78 feet deep, were installed, one on each corner of the building. Average resistance of the 4 rods was 1.57 Ohms and when tied together test below 1 Ohm. A ring was formed by burying a #2 bare annealed copper conductor around the perimeter of the building. Each of the 4 deep-driven rods were connected to the ring ground with a bolted type connecter and covered with a fiberglass enclosure (Photo 1). This provided capability for periodic disconnecting and testing of each electrode.

Photo 1. Ground rod enclosure.

The building steel was bonded to each corner column and at alternating columns to the ring ground by an exothermic connection. The ring ground was connected to the main electrical service and water main. Additional systems connected to the ground included the telephone lightning protection, phone system, standby generator, computer room raised floor, and power protection equipment.

It is not possible to compare before and after results since this is a new facility. However some general observations can be made. The facility has shown a history of trouble free operations with no known loss or damage of equipment from power or lightning related disturbances. It is interesting to note that early 1993 had unusual weather with many electrical/lightning storms. Local computer and telecommunication vendors have had record peaks in service calls and equipment failures in the same locale as the facility.

CASE STUDY 2

This case involved an existing facility located in a semiarid mountain region. The 40,000 square foot one story building was originally designed for commercial office use. Approximately 30,000 square foot was leased and remodeled for a telemarketing company. The facility had a history of equipment problems and failures as well as complaints by employees of electrical shock. The company was experiencing a 200% annual failure rate with their 300 computer terminals. Other problems included data communications errors and equipment damage.

A power quality survey and electrical inspection found several power and grounding problems at the facility. Among the most serious problems were violations of the NEC, including improper grounding and a lack of a grounding electrode system. The interior metal water piping was used as the main grounding electrode. However it was found that the metal pipe ran only 5 feet underground where it was converted to plastic. The building steel was not effectively grounded and no other grounding electrode was installed.

A power quality implementation plan was developed to address both safety and functionality of the electrical distribution system. This plan included electrical modifications and upgrading of the grounding electrode system. Local electrical contractors stated the earth grounding was very difficult in the region due to poor resistance of the soil and difficulty of driving ground rods. They suggested a chemical ground rod solution. This type of rod reduces electrode resistance by leaching chemicals (electrolytic salts) into the surrounding soil. The client rejected the chemical rods for both maintenance and environmental concerns.

A deep-driven electrode system was selected as the best solution for this site. To overcome the difficulty of driving through the hard soil, pilot holes were bored for the rods. Two 60-foot deep by 4-inch diameter test holes were drilled at 70-foot intervals. The first 30 feet consisted of a hard sand and gravel layer, the last 30 feet was shale. According to ANSJ/IEEE standards,[6] the resistance of sand and gravel soil ranges from 15,800 - 135,000 Ohms/cm. The resistance of shale ranges from 4,060 - 16,300 Ohms/cm. The lower shale layer provides approximately a 10 times reduction in resistance as compared to the upper layer.

The test holes were filled with hydrated sodium bentonite into which the ground rod(s) were driven. Both rods consisted of 6 each 3/4 inch by 10 foot copper clad rods with drive on couplers. Final resistance of the two rods was 0.88 and 0.48 Ohms respectively.

As a general statement the facility has experienced a dramatic reduction in equipment failures and communication errors. From the client's perspective the facility has become one of their most trouble free sites.

CASE STUDY 3

This study involves a military computer facility that was located in a converted aircraft plant. A dedicated substation with a 13,800 volt primary and 480/277 volt secondary was provided for the facility. The facility's power protection system included parallel redundant static UPS and backup diesel generators. The specifications called for the grounding electrode system to be 3 Ohms or less ground resistance. The grounding electrode system consisted of a 6 3/4 inch by 10-foot ground rods installed through the basement floor of the building. All 6 ground rods were installed within 6 inches of each other and bolted to a copper ground bar. The electrical substation utilized the same ground system. Design of the facility precluded using building steel, water pipes or ring grounds as grounding electrodes.

The site was plagued with computer hardware problems that the vendor blamed on power and grounding. The ground rod system was tested by facility personnel and measured 0.0 Ohms. A power quality survey revealed that the ground testing had been done incorrectly and that there was a safety hazard. Standard earth resistance testing methods require that the ground rods be disconnected during the test to prevent false readings.

Two 70-foot deep ground rods were installed at 90-foot intervals to augment the existing system. The earth resistance tested at 1.1 and 0.8 Ohms respectively. The new rods were connected to the existing ground bar to provide the facility earth ground. The 6 old rods were then disconnected and tested at 27 - 32 Ohms resistance.

After installation of the deep-driven ground rods the computer service vendor reported fewer problems with the hardware. This case illustrates the problem of relying on improper ground resistance testing. The original design of installing ground rods adjacent to each other violates the NEC requirement of 6-foot minimum spacing.[7] As a general rule ground rods should be spaced an interval that is not less than there depth. The poor resistance of the original ground system created a safety hazard to both personnel and equipment. A ground fault on the primary of the substation could have caused excessive voltage potential in the facility ground system.

INSTALLATION METHOD

The earth resistance of an electrode is dependent on several factors, including soil resistance, contact resistance of the rod(s), couplers, and connections.

An effective, deep-driven grounding installation includes the following considerations:

- Selection of rod material
- Selection of coupler type
- Diameter and length of rod(s)
- Type of driving equipment
- Installation procedures
- Testing procedures
- Wire termination

Installing ground rods beyond 10 feet deep presents several problems. Sectional rods must be used (typically 10 - 12 feet long) and coupled together to achieve the desired depth. The coupler is a larger diameter than the rod and therefor forms a hole bigger than the rod itself (Photo 2). This creates a coupler void limiting soil contact to the rod surface of the additional sections. Only the first section will maintain full rod to soil contact.

Photo 2. Ground rod and coupler.

Manual driving of the rods with sledge hammers, pipe drivers and other means cannot provide adequate force to penetrate hard soils. Mechanical or powered drivers are necessary for deep driven rods. The rod material and coupler design must be able to withstand the force necessary to drive through hard subsoil.
The first rods installed in 1988 were done by climbing a ladder and holding an electric hammer on top of the rod. This procedure was both awkward and dangerous to the installer. A driving machine was then constructed to better facilitate this part of the process. Photo 3 shows a picture of the machine. This machine consists of a support frame with leveling jacks and wheels. A vertical assembly holds an electric impact hammer and can be manually cranked up and down by the operator. The electric hammer is equipped with a special driving tool that prevents "mushrooming" of the rod and actually reforms the rod end.

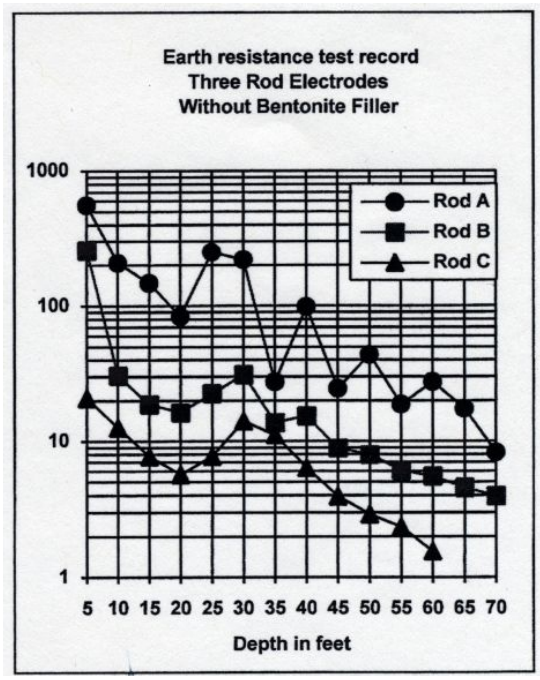
Photo 3. Ground rod driving machine.

Due to extreme forces required to penetrate hard soils, it was found that screw type couplers were mechanically failing. The threads were being stripped causing poor rod-to-rod contact. A new type of tapered spline coupler was found to be the most reliable coupler used. A test rod was driven and then pulled to check the mechanical durability of the coupler. Photo 4 shows a cut open section of the test rod. This driven-on coupler design simplified the process by making it possible to use smooth rods of any length. This allowed deep-driven systems to be installed inside buildings with minimal ceiling heights (as in Case Study 3).

Photo 4. Drive-on spline rod coupler.

To maintain full rod-to-soil contact, a slurry mix of sodium bentonite (a naturally occurring clay) is injected in the coupler voids as the rods are installed. This provides a conductive material between the rod surface and soil over the depth of the rod. A typical 60-foot ground rod requires 2 to 5 gallons of bentonite in the coupler void. Figure 5 shows a comparison graph of three ground rod installations without the bentonite. Note how the dry rods showed a fluctuating resistance as compared to the graph in Figure 1.

Figure 5. Dry rod resistance graph.



CONCLUSIONS

As shown by the data presented, the average 8 to 10-foot ground rod will not meet minimum NEC code requirements for earth resistance. The resistance of a shallow (10 feet or less) electrode will vary greatly as seasonal conditions change. Due to high earth resistance, the typical shallow electrode is unable to maintain an electrical system at earth potential during transient voltage conditions and lightning surges. Where stable resistance values of less than 5 Ohms are required, electrode depths of 30 - 60 feet are necessary.

The case studies have shown that installing deep driven electrodes is effective and practical for both new and existing facilities. The new method of installing deep-driven ground rods provides a universal means of effective earth grounding.

REFERENCES

1. The IAEI Soares Book on Grounding. 4th Edition, page 128.
2. ANSI/NFPA 70-1991, National Electric Code, Article 250.
3. ANSI/IEEE Green Book, Std 142-1982.
4. NEC Article 250-81, (b), (FPN).
5. NFPA 78, Appendix 1.
6. ANSI/IEEE Std. 142-9182, Green Book, Section 4.1 Table 5.
7. NEC Article 250-84