SBC-876-101-130

ELECTRICAL PROTECTION GROUNDING

This SBC Practice examines the theoretical and practical considerations underlying effective protection grounding for communication systems. The information presented in this section is of a general and theoretical nature.

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Table of Contents

Figures

Tables

1. GENERAL

1.01 This section examines the theoretical and practical considerations underlying effective protection grounding for communication systems. The information presented in this section is of a general and theoretical nature. Engineering information related to measuring and establishing low impedance grounds is included in BSP layer 876-7XX-XXX. Specific information concerning choice and construction of "made" grounds for various types and arrangements of plant is contained in BSP layers 876-2XX-XXX through 876-6XX-XXX.

1.02 When this practice is reissued, the reason(s) for reissue will be stated in this paragraph.

2. PURPOSES OF GROUNDING AND DEFINITIONS

2.01 The purposes of protective grounding in a communication system are to:

(a) Reduce the hazard of electrical shock from ac and dc voltages and from lightning surges.

(b) Mitigate the destructive effects of lightning and power surge voltages and currents in communication facilities.

(c) Facilitate the rapid deenergization of power lines that contact communication plant, thereby reducing shock hazard and damage to telephone facilities.

(d) Provide paths to ground for longitudinal shield currents in metallic cable shields, thereby reducing the voltages induced in cable conductors.

(e) Reduce noise voltages in sensitive circuitry by providing an effective common reference point for circuit potentials to which extraneously induced currents can flow without disturbing circuit operation.

(f) Minimize damage to structures when they are struck by lightning.

(g) Obtain voltage equalization, thereby minimizing the effects of potential differences.

Definition of Terms Used in Protective Grounding:

2.02 To provide a common language base discussing the theory of grounding, the following definitions are presented. [1]

(a) **Ground (Earth):** 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.

Note: The connection is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential on conductors connected to it, and for conducting ground current to and from the earth (or the conducting body).

(b) **Grounding Conductor:** A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes.

(c) **Grounded Conductor (Electric System):** A conductor that is intentionally grounded, either solidly or through a current limiting device.

(d) **Grounding Connection (Ground Connection):** A connection used in establishing a ground, which consists of a grounding conductor, a grounding electrode, and the earth (soil) that surrounds the electrode.

(e) **Grounded Effectively:** Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current carrying capacity to prevent the building up of voltages that may result in undue hazards to connected equipment or to persons.

(f) **Grounding Electrode:** A conductor (usually a rod, pipe, or plate) or group of such conductors in direct contact with the earth for the purpose of establishing a connection with the earth.

(g) **Ground Grid:** A system of grounding electrodes consisting of interconnected, bare conductors buried in the earth to provide a common ground for electric devices and metallic structures.

Note: The system may be connected to rods or other auxiliary grounding electrodes to lower its resistance.

(h) **Ground Mat:** A system of bare conductors, on or below the surface of the earth, connected to a ground or a ground grid intended to provide protection from dangerous touch voltages.

Note: Grounded plates and gratings of suitable area are common forms of ground mats.

(i) **Ground Rod (Grounding Electrode):** A conducting rod that is driven or placed into the ground to serve as a ground terminal, such as a copper clad rod, stainless steel rod, solid copper rod, galvanized iron rod, or galvanized iron pipe.

(j) **Ground Resistance (Grounding Electrode):** The resistance, in ohms, between the grounding electrode in question and a remote grounding electrode of zero resistance (also called leakage resistance).

Note: "Remote" means at a distance such that the mutual resistance of the two electrodes is essentially zero. (Ground resistance should not be confused with mutual resistance or earth resistivity [ρ].)

(k) **Ground Terminal:** A lug or screw terminal on a piece of equipment intended to be connected to a grounding conductor or grounding electrode by means of a ground connection.

(l) **Ground Bus:** A bus to which the grounding conductors from individual pieces of equipment are connected, and which, in turn, is connected to ground at one or more points.

(m) **Common Bus:** A low impedance conductor that provides a potential reference point or plane within a system or piece of apparatus. A common bus may or may not be connected to remote earth via a grounding connection and a grounding electrode.

(n) **Ground Clamp (Grounding Clamp):** A clamp used in connecting a grounding conductor to a grounding electrode or to a grounded object.

(o) **Surge Impedance:** The impedance of a grounding electrode at the frequency of the current wave applied. At low frequencies, the surge impedance is close to the dc resistance. When a surge is applied, the instantaneous impedance varies with time and is dependent on the waveform of the surge and the physical characteristics of the particular grounding electrode.

(p) **Earth Resistivity (ρ):** The resistance of the soil on a per unit basis. The commonly used unit of measure is the meter-ohm which refers to the resistance measured between opposite faces of a cubic meter of soil.

(q) **Mutual Resistance of Grounding Electrodes:** The voltage change in one electrode produced by one ampere of direct current in a second electrode, expressed in ohms.

2.03 The terminology used to designate the various types of grounds in the office (central office ground, ac service ground, etc.) and the mechanics of establishing them are described in SBC-TP76416. All these grounds are eventually connected by grounding conductors to the same reference point, the grounding electrode system. The power multigrounded neutral should also be connected to the same reference point.

2.04 An effective grounding system must not only limit voltage to ground on the affected circuit, but must also coordinate properly with other protection arrangements intended to equalize potentials on that circuit and associated circuits and equipment. Rarely can a ground be considered as an isolated arrangement apart from the total protection design, which usually requires complementary protection measures (see BSP 876-100-100). These measures must include the employment of (a) every practical means of minimizing the impedance of the grounding connections (b) adequate bonding practices, and (c) mitigative measures to protect communication plant against the excessive rise in potential of a subscriber station ground caused by lightning surge currents or power line faults to ground and associated induction. Examples of proper grounding in different types of plant in a coordinated protection program are also presented in the application sections of this division, BSP layers 876-2XX-XXX through 876-7XX-XXX.

3. EARTH AS A COMMON REFERENCE

3.01 The earth is a conducting mass whose potential is commonly taken as the reference potential for voltage measurements. During cloud to earth lightning discharges the earth is one of the terminal points, and although lightning strokes may initially contact objects protruding above the earth's surface, the stroke current will ultimately flow to earth. Equipment in the path of even a portion of the lightning current will be subjected to an overvoltage with respect to ground.

3.02 Electrical systems and equipment are normally provided with sufficient insulation to withstand operating voltages plus some overvoltage. However, it is generally uneconomical to rely solely on insulation for protection against abnormally high voltages. It is more practical to limit the buildup of such voltages by means of some protection measure. For voltages to earth, grounding either directly when the circumstances permit, or through discharge devices (protectors and arresters) is such a protection measure.

3.03 In summary, grounding provides a means of establishing definite voltage relationships to earth and of providing parallel conductive paths for excessive current to avoid undue electrical stress on lines and equipment. Grounding provides a controlled path to earth for lightning stroke currents and, along with supplementary measures to be discussed in BSP layers 876-5XX XXX and 876-6XX-XXX, is essential in reducing physical damage and shock hazards. Grounding also provides low impedance fault return paths for power circuits to ensure prompt operation of fault current limiting devices.

4. ELECTRICAL CHARACTERISTICS OF SOIL

A. Soil Resistance and the Protection Problem

4.01 Many protection problems involve earth conduction effects. Therefore, some knowledge of the electrical properties of the materials composing the earth's crust is essential. The electrical resistivity of various types and combinations of soils has important effects upon:

(a) Grounding - establishing the resistance of grounding electrodes, determining preferred locations for constructing grounds, and selecting the kind of grounding electrode system most suitable on a given site for a given application.

(b) Earth return circuits, coupling, shielding, etc.

(c) Protection of buried cable plant, specifically, leakage of surge current from the cable’s shield, arcing of lightning strokes directly to a cable, effects of remote strokes, choice of cable design, and anticipated trouble incidence.

4.02 Soils consist of particles that may differ greatly in composition as well as in moisture and chemical content. The surface and subsurface conditions vary to a considerable extent; consequently, the resistivity ρ (rho) may vary widely even among soils that appear to be of the same general type. This wide variation indicates that a non-homogeneous medium is involved, especially with respect to different areas and depths. Earth resistivity is generally expressed in meter-ohms. When the resistivity value is expressed in centimeter-ohms (or ohm-centimeters), the meter-ohm equivalent is obtained by dividing by 100. The resistivity of soil around a grounding electrode is to some extent current dependent; it appears to decrease with increasing lightning impulse current densities because of soil ionization adjacent to grounding electrodes. Ionization can occur on the surface or within the soil, establishing low resistance paths for the current. Soil also behaves like an electrolyte in that within limits, its resistance changes inversely with temperature. If heating should evaporate contained moisture, soil resistivity will assume a high value.

B. Determining Soil Resistivity

4.03 Information on soil resistivity may be obtained in three ways: (a) from geological maps, (b) from inspection of excavations or cuts in the area under consideration, and (c) by direct measurements [2]. These three sources are listed in their order of increasing accuracy, ranging from simple estimates of general resistivity that might be expected in a large area of the nation to the actual resistance at a particular site.

4.04 Special maps, available from the Geological Society of America (P.O. Box 9140, Boulder, Colorado 80301and the US Department of Interior Geological Survey USGS Map Distribution Box 25286, Building 810, Denver Federal Center, Denver, CO 80225 provide the first method of estimating the effective resistivity value for use in engineering formulas. These maps show variations in the general structure of the earth's crust. Such maps are useful for problems involving comparisons of large areas. Field measurements have indicated a reasonably consistent relationship between resistivity and the physical formations of the earth, as summarized in Table A. A map of ground resistivity in the United States is shown in Figure 1. From Figure 1, a cumulative distribution of resistivity in the U.S. may be derived (Figure 2). The average resistivity in the United States is approximately 100 meter-ohms.

4.05 Approximation by inspection (method (b) in 4.03) is a common method used for determining resistivity of a small area or site when the accuracy requirements of the problem will permit the practice. This involves inspection of the general nature of the surface and subsurface soil types exposed by cuts or excavations and then the derivation of an approximation of effective resistivity by reference to Table A, plus the exercise of engineering judgment based upon experience. Such an inspection may, in addition, reveal the presence of rock strata near the surface, which could have an important bearing on the type of grounding electrode system to be used on that site.

4.06 Determining ground resistivity by direct measurement (method (c) in 4.03) provides the most reliable information. Direct measurements are commonly used in connection with protection problems, since they may be obtained with relatively simple portable instruments.

4.07 Portable instruments suitable for measuring ground resistivity are available under trade names such as "Megger"*, "Ground Ohmer"†, "Vibroground"‡, etc. [3]. * Meager is a trade name of the James G. Biddle Co.; † Ground Ohmer is a trade name of the Herman H. Sticht Co.; ‡ Vibroground is a trade name of Associated Research Inc.

4.08 The arrangement for measuring earth resistivity employing the "4 terminal" method is shown in Figure 3. This illustration shows a Megger ground tester, but other four terminal instruments are available for this purpose and are used in a similar manner. Some of these instruments produce a test voltage referred to as interrupted direct current. The polarity is reversed to reduce interference from stray dc potentials. Although these instruments nominally produce a flat top wave, the actual waveshape departs substantially from an idealized square wave, especially under relatively low load resistances. No significant change in performance will result, however, because both the current and potential waves are similarly affected. Another type of ground tester operates on the "null balance principle." The waveshape of the output voltage of this device is approximately sinusoidal, and circuit load resistance has practically no effect on the waveshape of the output current and voltage. With hand cranked instruments such as these, the frequency of the output current and voltage may be varied within modest limits by changing the speed at which they are cranked. The instruments are provided with clutches that limit the maximum operating frequency by slipping when the crank is turned faster than a set speed. Even small changes in the frequency of the output wave are quite effective in reducing interference from stray potentials.

TABLE A
RANGE OF RESISTIVITY VALUES FOR SEVERAL TYPES OF SOILS (SEE NOTE) [2]

PHYSICAL COMPOSITION	**RESISTIVITY (METER-OHMS)**
Sea water (Reference)	1 - 2
Marsh	2 - 3
Clay	3-160
Clay Mixed with Sand and Gravel	10-1350
Chalk	60-400
Shale	100-500
Sand	90-800
Sand and Gravel	300-5000
Rock (Normal Crystalline)	500-10,000

Note: When the moisture content of soil drops below 25 percent by weight, the resistivity increases rapidly with further decreases in moisture content. Resistivity also increases rapidly as the soil temperature drops below the freezing point (32° F) if any moisture is present in the soil (see Part C).

4.09 The procedure for measuring earth resistivity consists of measuring the mutual resistance between two pairs of ground electrodes spaced at regular intervals. If the spacing between the electrodes in feet is **S** (Figure 3) and the mutual resistance between the inner and outer pair of electrodes is **R** ohms (read from meter), the average earth resistivity to a depth of **S** feet is found from the formula:

$$\rho_{meter\text{-}ohms} = 1.92 \bullet S_{feet} \bullet R_{ohms}$$

4.10 An instrument having substantially greater flexibility in earth resistance measuring problems than the instruments previously described is the Gish-Rooney type, "Geohmeter" test set. It is self-powered from a bank of dry cell batteries and is considerably larger and more expensive than devices such as the Megger test set. However, its capability of achieving high sensitivity by the use of battery potentials of about 500 volts provides the flexibility for operation under a much wider range of environmental conditions. Consequently, the Geohmeter test set is the only instrument that will perform satisfactorily in very high resistivity soils and with large electrode spacing. The Geohmeter test set uses essentially the same 4-electrode configuration for measuring soil resistivity as that shown in Figure 3. An additional neutral electrode, "G", is placed midway between the two potential electrodes. Potential measurements are made between "P1" and "P2" and "G" as selected by a switch. In normal operation the instrument sends a measured direct current that is periodically reversed through the outer electrodes. The resulting potential is detected in the intermediate set of electrodes by a potentiometer incorporated in the set. Potential is measured by a "null" method so the resistance between the intermediate electrodes and earth does not enter into the measurement. The commutator and reversing switch may be operated manually or with a motor incorporated in the set.

4.11 Since the earth is not homogeneous, in most cases one must employ a series of tests designed according to the specific requirements of the problem. In setting up the procedure for a series of resistivity tests, consideration must be given to the selection of test locations and the depths to which the investigation should be carried.

4.12 For long cable routes, low-frequency coupling problems and considerations of lightning damage to cable necessitate measurement of resistivity to considerable depths at several points throughout the exposure. In connection with such problems, resistivity measurements are made at 5 and 10 mile intervals with electrode spacing ranging from a few feet through approximately 1000 feet. However, where previous studies of geology indicate low resistivity in underlying strata, measurements to a maximum electrode spacing of 350 feet may be sufficient. If a decided change in resistivity occurs between any two locations, measurements may be desirable at one or more intermediate locations to determine where the abrupt resistivity change occurs. Measurements at short and long electrode spacing are made to secure the required data for computing an effective value of resistivity suitable for use in engineering formulae. Further information for methods of determining effective resistivity from a series of "4-terminal" type measurements is available. [4] [5]

4.13 For the design of “made” grounds at locations such as small power stations, radio stations and central offices (approximately 50 feet by 50 feet maximum), knowing the earth resistivity is unnecessary much below a 30-foot depth unless long driven rods or metal well casings are being considered for use as the station grounding electrode.

C. Practical Aspects of Variations in Soil Resistivity With Changes in Temperature

and Season

4.14 A very rigorous approach to a resistivity survey is not generally justified because other aspects of ground conduction problems frequently resist accurate evaluation. The resistance to ground of an electrode varies directly with soil resistivity; consequently, any changes in the seasonal environmental factors shown in Figures 4 through 7 have a proportional effect on electrode resistance. Since changes in resistivity due to these factors tend to be equal over sizable areas, measurements apply to protection at sites throughout a reasonably large area. [6]

4.15 Resistivity values have an important practical significance in protection engineering for relating lightning trouble rates to cable design factors. Empirical studies of these relationships, which control the design of cable for buried plant application, have suggested a procedural sequence to facilitate proper protection engineering of buried plant. For engineering application of this procedure, refer to the appropriate BSP in layer 876-4XX-XXX of this division.

Figure 1 –Estimated Average Earth Resistivity in the U. S. (Meter-Ohms)

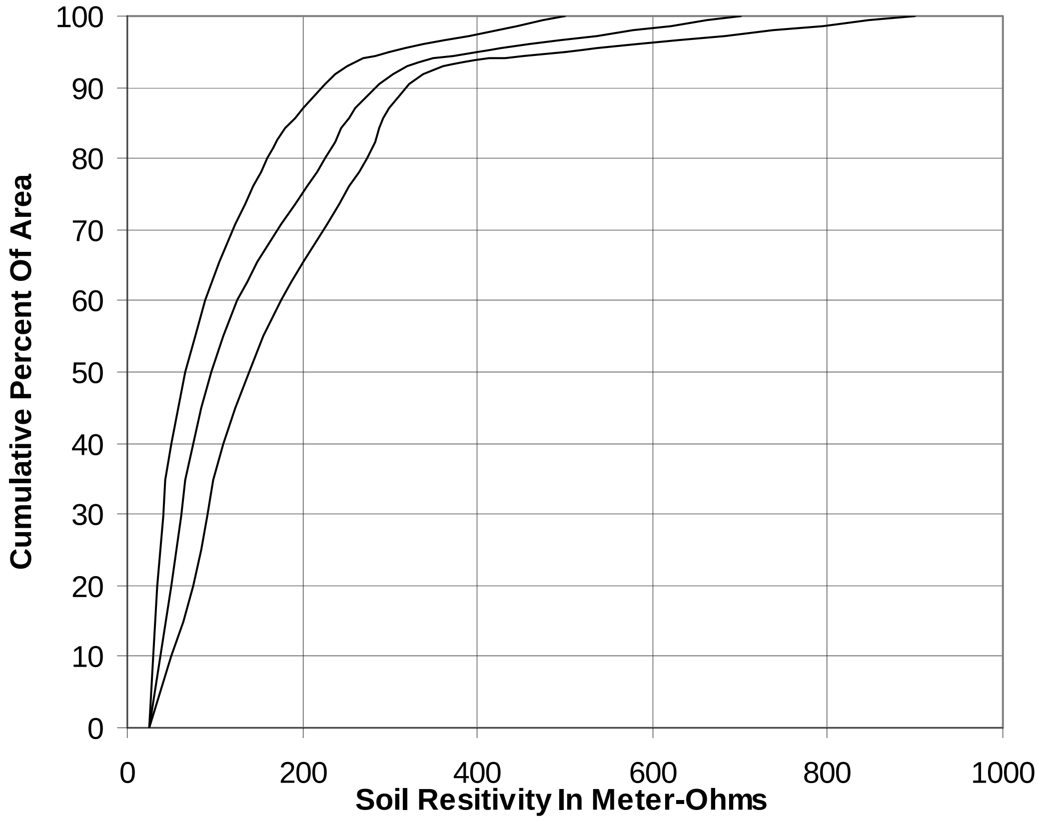
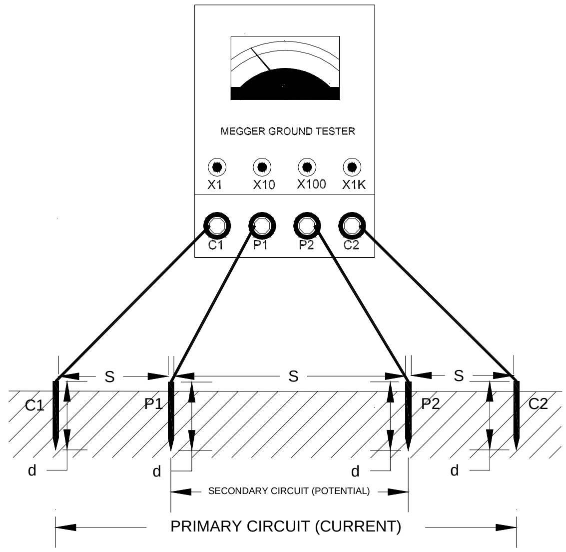


Figure 2 – Distribution of Soil Resistivity for U.S.



NOTES:
1. Electrodes are placed in a straight line at equal intervals.
2. S=Consistant spacing between electrodes (Feet).
d= Depth of test electrodes (in Feet), which should not exceed S/10 FT at short spacings. Electrode depth need not exceed 3 to 4 feet for large values of S

Figure 3 – Megger Ground Tester

5. EFFECTIVE PROTECTION GROUNDING

A. Grounding Electrode Theory

5.01 Grounding electrodes may assume physical forms ranging from existing public or private water pipe systems to "made" grounding arrangements such as driven rods, buried wire grids (mats), horizontal buried wires (counterpoises), and combinations of these arrangements. The effectiveness of grounding electrodes in fulfilling their intended purpose depends upon the judgment used in selecting an arrangement suitable to fulfill the specific requirements of the situation. An extensive public metallic water pipe system, such as found in a metropolitan area, is the closest approach to a universal grounding medium. In rural or urban areas the use of specific auxiliary electrode arrangements, such as the grounding grids constructed at power stations or the ring counterpoise at radio stations, may be required. A grounding electrode system may not necessarily require a low dc resistance to ground to be effective in specific situations (see BSP 876-210-100). Usually, however, a practical effort is made to obtain a reasonably low resistance relative to soil resistivity values and other physical conditions at a specific location. Low surge impedance is the controlling factor where lightning is a consideration. Where minimizing surge impedance is desirable, compact electrode arrangements should be used. Table B shows the relative effectiveness of different types of grounds commonly used in the communications industry. These ground systems are described in Part 6.

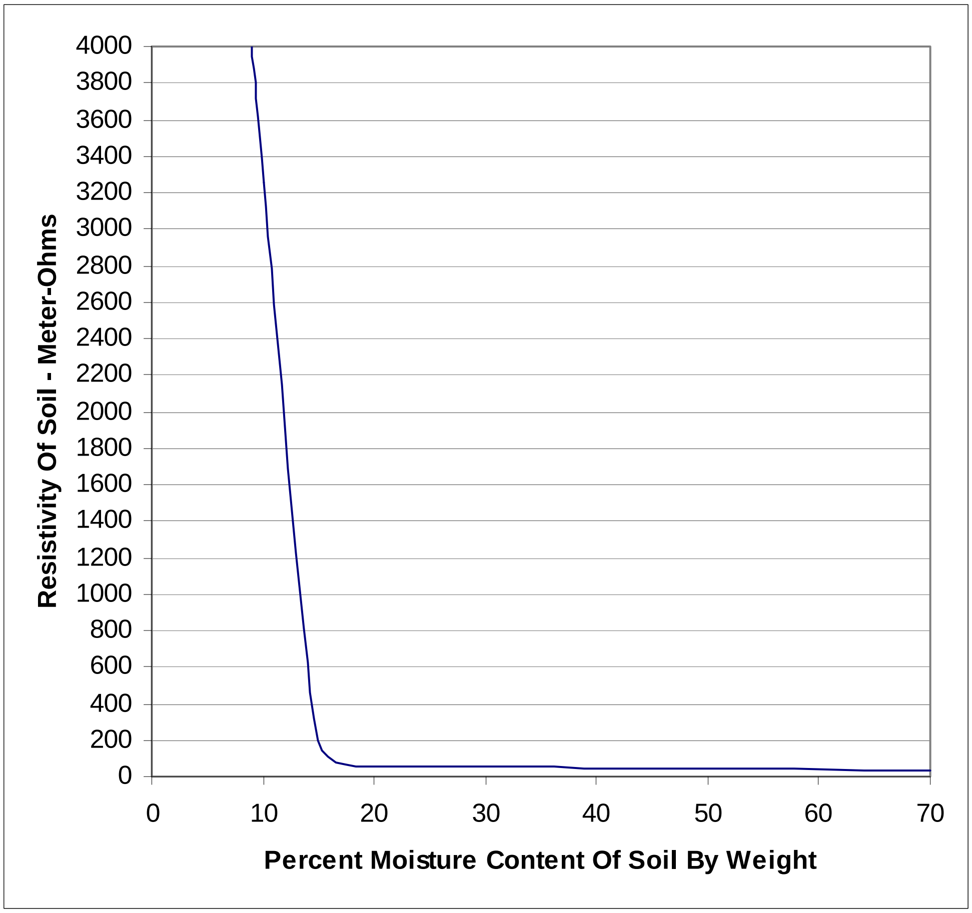
5.02 Article 800 of the National Electrical Code (NEC) [7] covers the general grounding requirements for communication circuits. The reference in Article 250 to a 25 ohm ground should not be construed as a mandatory value, and in no way applies to communication grounds.

5.03 Grounding is not a panacea for all electrical protection problems, nor is a perfect ground obtainable. All grounding connections possess resistance and inductance to varying degrees, and when current is flowing through them to ground, voltage will appear between the connected equipment and other objects associated with remote ground. Such voltages may be limited to acceptable values by good wiring practices and by the use of supplemental measures such as bonding.

5.04 There are many ramifications to the subject of grounding, but two rather basic situations are shown in Figure 8. In the first case (Figure 8A), the resistance of the grounding connection at point B has a direct bearing on protection effectiveness. Current flowing through the impedance of the ground conductor and ground electrode will produce a voltage that may be large enough to cause failure of the equipment. This figure illustrates two errors in grounding: (a) failure to have the protector close to the equipment to be protected, and (b) failure to place a bond between the two separate grounds, thereby losing the benefits of common grounding. In the second case, however (Figure 8B), the resistance of the ground electrode is not critical since the voltage V_{AB} between the two pieces of equipment depends entirely on the voltage drop in the grounding conductor impedance between points A and B. Although the extraneous voltage in the second case will be substantially lower because of common grounding, bonding at the equipment (dashed line in Figure 8B) is desirable to further reduce the potential differences.

Behavior of Ground Rods

5.05 Driving metallic rods vertically into the earth is a relatively simple and common means of constructing a "made" ground. A study of the behavior of a single rod and of simple combinations of rods driven in homogeneous earth provides good approach to the understanding of the performances of more complex arrangements. Figures 9 and 10 present data on behavior of driven rods. The general relationships of parameters are summarized in Table C. Analytical consideration of more complicated grounding structures, such as the mats constructed at power stations, is much more complex; however, references given in this document and in BSP layer 876-7XX-XXX can be of assistance in such problems. When electrodes penetrate soil strata that vary appreciably, an effective resistivity value must be developed, as discussed in 5.09.



Note: Resistivity of red clay soil drops rapidly as its moisture content increases to about 15% by weight

Figure 4 – Variation of Soil Resistivity With Moisture Content – Red Clay Soil

5.06 The general formula for computing the resistance of a vertically driven ground rod is [8]:

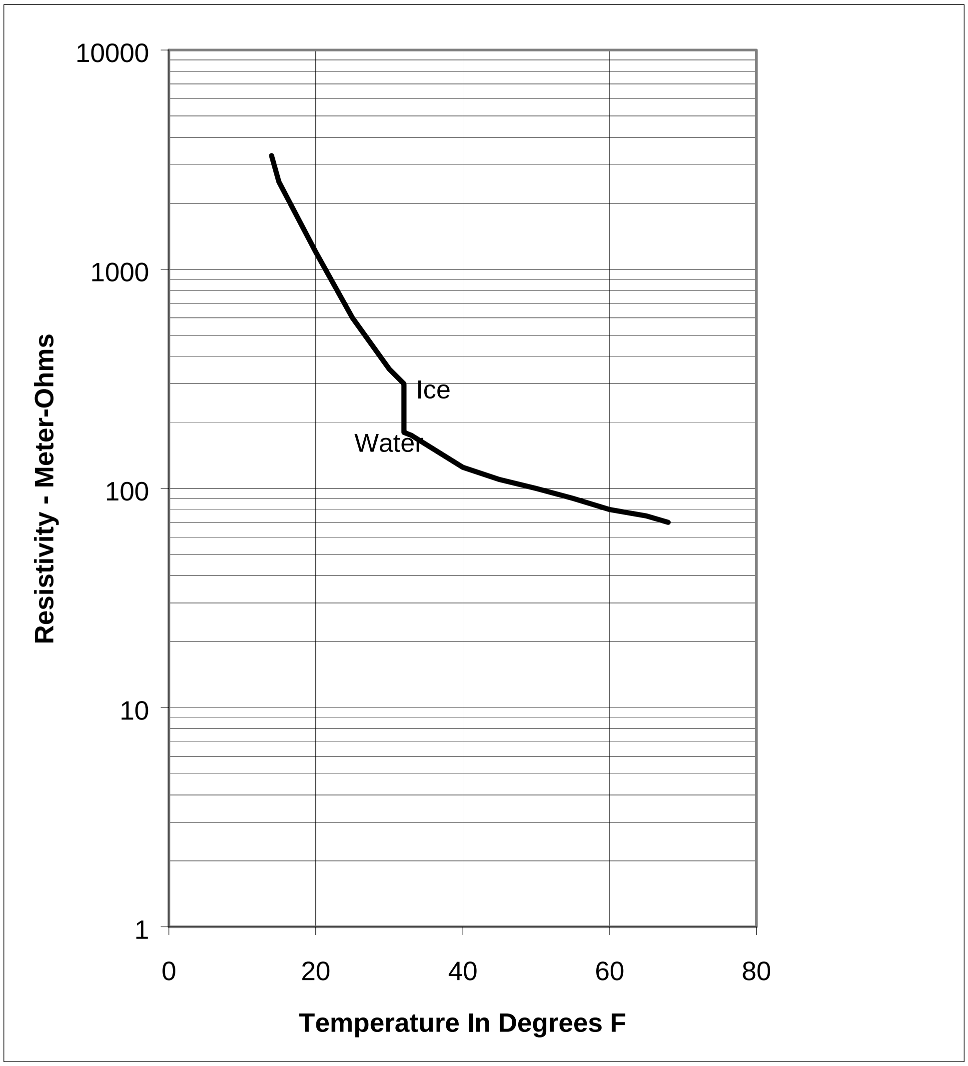
$$R_{dc} = \frac{\rho}{1.92\ell}\left(\left[\ln\frac{48\ell}{a}\right]-1\right)$$

where:

ρ = soil resistivity in meter-ohms

ℓ = length of rod in feet

a = radius of rod in inches.

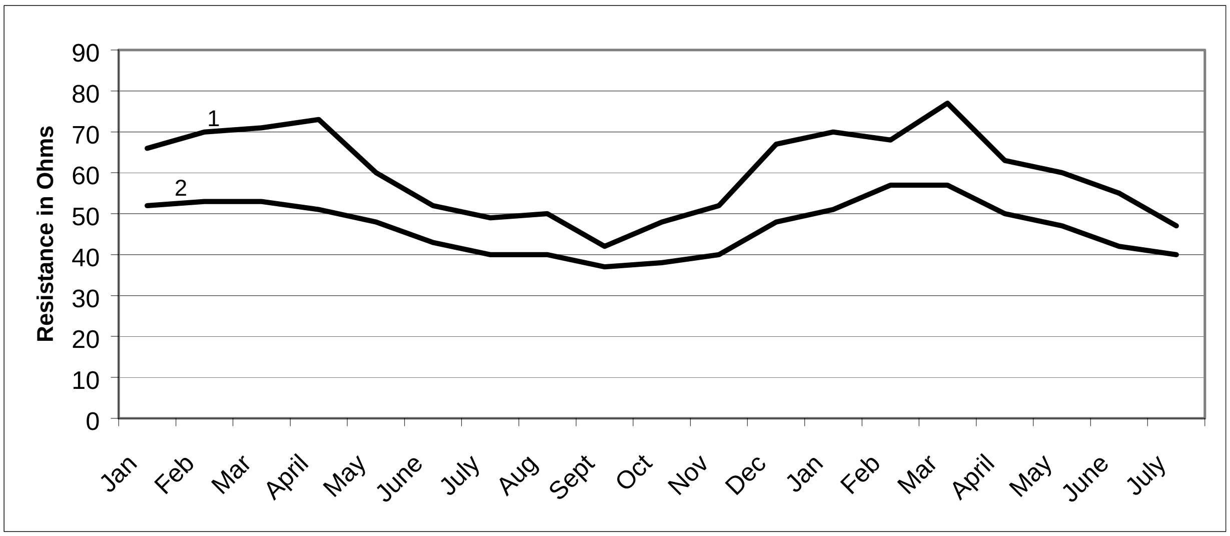


Note: Soil Contained 15.2 Percent moisture.

Figure 5 – Variation of Soil Resistivity With Temperature

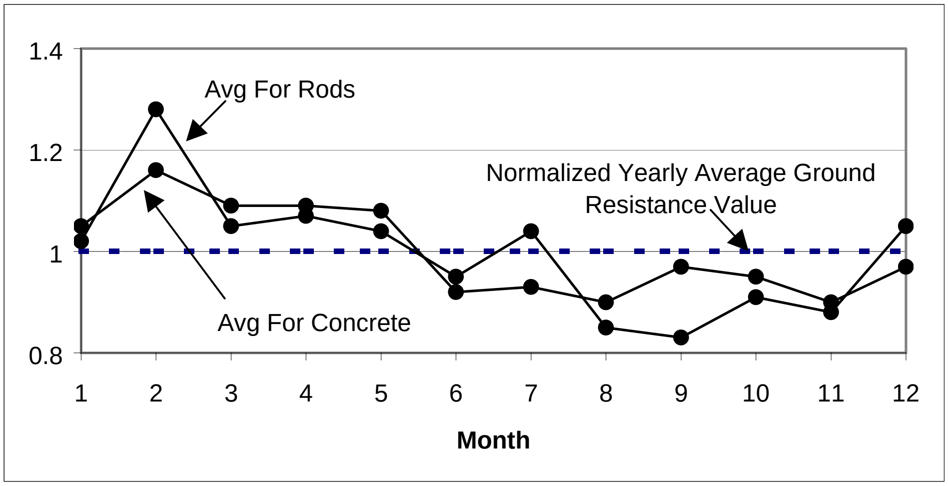
Paralleling Efficiency

5.07 When two or more grounding electrodes are connected, their combined resistance will be higher than the computed parallel resistance of the individual electrodes unless they are widely spaced. If two ground rods are driven a short distance apart and electrical current is sent into the earth through one of them, the potential of the nearby earth, and thus the potential of the remaining rod, will be raised with respect to remote earth. This can be thought of as a mutual resistance existing between the electrodes. The parallel resistance therefore depends upon the relation between the "self" and "mutual" resistance of the electrodes. With rods of the sizes generally used, 90 percent of the total potential drop around a ground rod with respect to an electrode some distance away occurs within six to ten feet of the rod. It may be considered then, that the "effective electrode" consists not only of the rod itself but also of a certain volume of the earth surrounding the rod. Therefore, when two or more rods are paralleled, they should be spaced far enough apart so that the effective electrodes do not overlap to any considerable extent, thus keeping the mutual resistance to a practical minimum. In general, the spacing of the rods should approximate their length, e.g., with 8-foot rods a commonly used spacing is 10 feet. Spacings should be somewhat greater for treated rods. ("Treated" refers to the use of certain chemicals to reduce the resistivity of the neighboring soil.) For practical purposes, the paralleling efficiency of multi-rod arrangements may be taken from the curve in Figure 11. Values thus obtained are sufficiently accurate for rod sizes customarily used in constructing grounds. The values given on this curve were computed on the basis of insulated wire being used to interconnect the ground rods. In practice, the resistance of a multirod arrangement would be somewhat lower than the values obtained with these paralleling figures because of the additional grounding contributed by the bare interconnecting wire [4]. Where practical considerations, such as available space, are not controlling, optimum rod spacing may be determined by balancing the cost of trenching for larger spacings against the cost of driving a larger number or rods.



Notes:
Curve 1 – Average of eight ¾ - inch standard pipes driven to 3 FT depth
Curve 2 - Average of eight ¾ - inch standard pipes driven to 10 FT depth

Figure 6 – Seasonal Variation of Electrical Resistance of Pipe Grounds



Notes:

1. These graphs were derived from data obtained in a 3 year long testing program.
2. These graphs represent $\frac{AVG_M}{AVG_Y}$, Where:

   AVG_M = Average ground resistance value of each type of electrode for a given month.

   AVG_Y = Average ground resistance value for the entire 3 year program.
3. This is a point by point graph, in which the points are connected by straight lines for ease of reading.

Figure 7 – Average Monthly Deviation From Average Ground Resistance Value – Comparison Of Rods And Concrete Encased Electrodes

5.08 The graphs (figures 9 and 10) are useful for determining the length and number of rods of a diameter commonly used when paralleling efficiency data is required at a specific site of known soil resistivity (ρ); a determination that can be made within a practical degree of accuracy. The various parameters can be determined at the site either by measuring the soil resistivity (ρ) or by driving one rod of known diameter and length entirely below the surface, measuring its dc resistance to earth, and applying the result and rod dimensions and numbers to the appropriate graph.

TABLE B

Relative Effectiveness of Commonly Employed Grounding Methods for Communication Systems

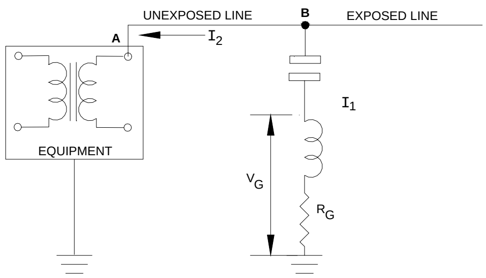
Type of Grounding	Lightning Protection	Power Protection	Comments
Urban Public Metallic Water System	Very Good	Very Good	Supplemental bonding is required to equalize lightning potential
Small Public Metallic Water System (suburban and rural)	Good	Good	Supplemental bonding is required to equalize lightning potential
Private Metallic Water Pipes (minimum of 10 feet in contact with soil)	When a public water pipe system is not available, this usually is the next best choice. When bonded to all other grounds, it is generally satisfactory for protection. If power fault currents must flow through this ground, it may or may not be low enough in resistance for fault current coordination.		
Concrete-Encased Electrode in Contact With Soil	When metallic water pipe grounding means are not available, the next best choice is a concrete-encased electrode of not less than 20 feet of bare #4 AWG or larger copper conductor, encased by at least 2 inches of concrete and located within and near the bottom of a concrete foundation footing that is in direct contact with earth.		
Buried Ground Ring or Counterpoise, As At a Radio Station in a Rural Location	Used where a high probability of lightning and absence of other good grounds are likely to result in high gradients in station area. Thorough bonding of all ground systems and buried conducting objects is mandatory. Also see "Private Metallic Water Pipes" with respect to power fault currents.		
Small "Made" Grounds such as a Driven Rod	Poor (May serve as part of a lightning rod system where bypassing of surge is the only consideration.)	Poor, except as a part of a system of multiple rods (example, a multigrounded neutral power system)	Probably adequate for signaling and transmission purposes, however, it is a last resort as a protection ground. Common bonding with power grounding electrode is required for potential equalization.

<u>General Notes:</u>

1. To equalize or limit possible voltage differences between communication facilities and conducting structures, the communication ground should be bonded to the power service ground and water system. The interconnection of the various metallic systems is referred to as common bonding or grounding in SBC-876-300-100.

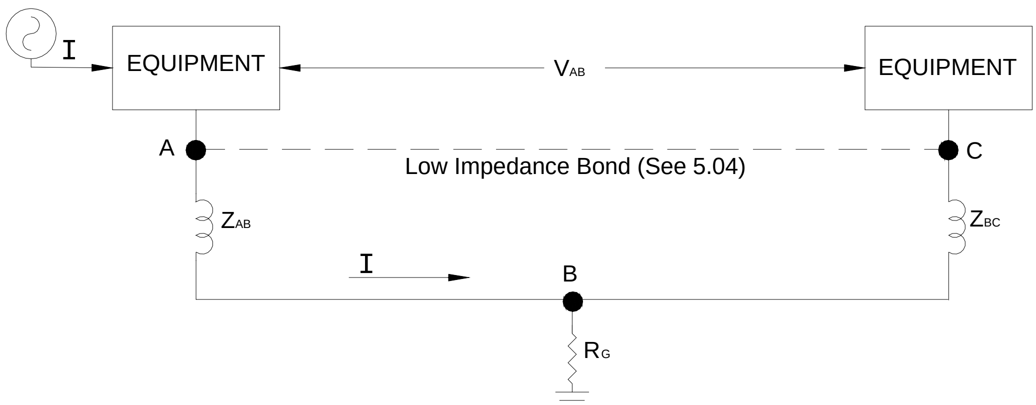
2. Refer to the 2002 National Electrical Code, Article 250, Paragraphs 250-50 and 250-52. Refer also to Article 800, Paragraph 800-40 & 800-41.

3. Metallic water systems may contain plastic fittings that will impair the system's grounding effectiveness. (See Paragraph 6.03)



NOTE:
V_G is a function of both electrode ground resistance and impedance of ground lead and the magnitude and wave shape of current I.

A



NOTE:
V_{AB} is a function of the impedance of the ground lead - A major source of extraneous voltage is eliminated by common grounding.

B

Figure 8 – Basic Protection Grounding Arrangements

Heterogeneous Soil

5.09 In practice, soil tends to be heterogeneous; accordingly, some averaging is generally required to obtain a representative value of ρ for use in the grounding formulas. The most effective means of obtaining knowledge of soil resistivity at a particular location where a ground is to be constructed is by measurements designed according to the requirements of the problem. The procedure for such measurements is described in BSP layer 876-7XX-XXX of this division. For grounding arrangements of moderate size using 8 to 10 foot ground rods, a survey of the soil to a depth of about 30 feet is adequate.

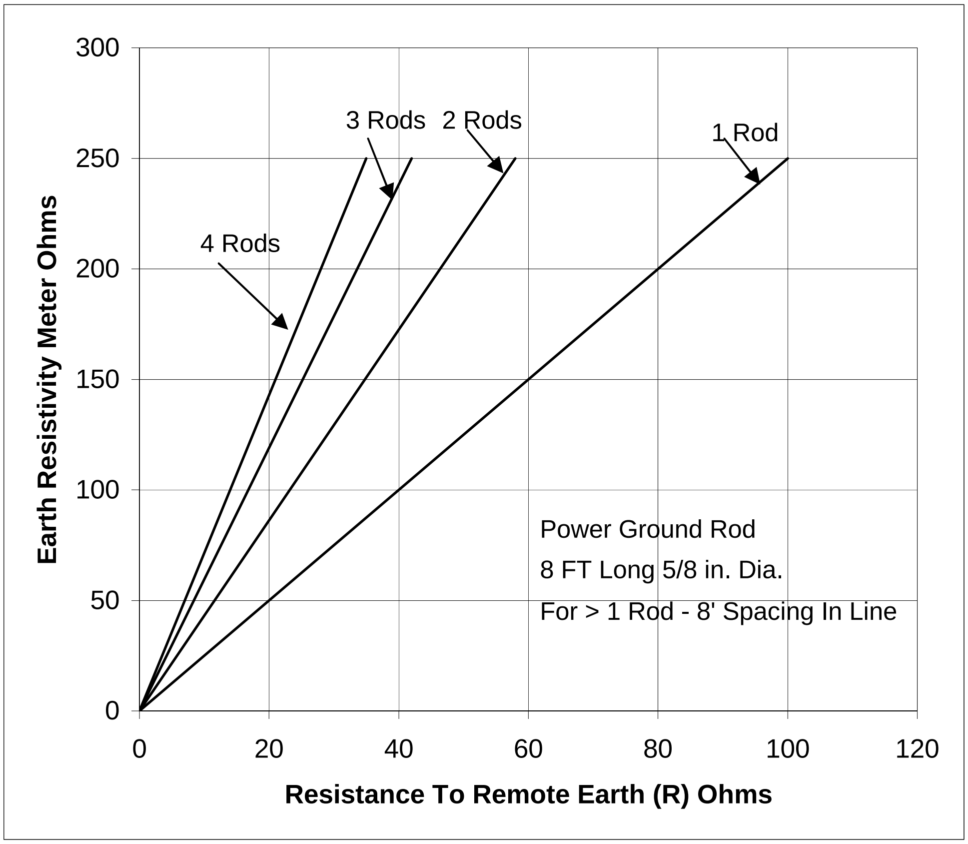


Figure 9 – Grounding Resistance of Driven Rods

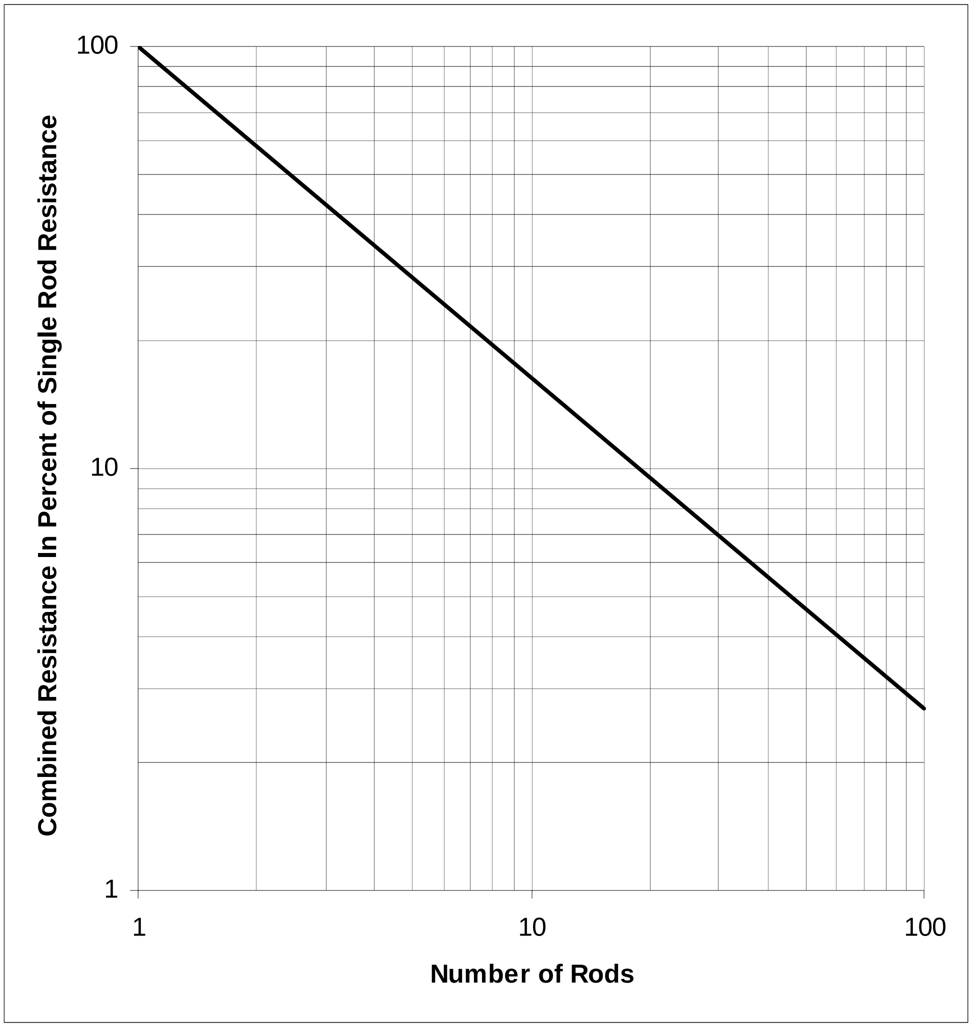


Figure 10 – Effects of Paralleling Rod Electrodes [5]

Thermal Effects

5.10 Steady-state heating of the soil surrounding an electrode may occur when an electrode carries substantial current for long periods of time. If the rise in temperature is sufficient to cause evaporation of contained moisture, an appreciable increase in resistance will occur. This heating effect decreases in importance as the electrode to soil contact area is increased. The steady-state current-carrying capability of a grounding structure is of principal concern in power applications, but may also be a consideration in the case of a "made" ground of restricted dimensions used in applying cathodic protection. Heating effects are not of concern in the case of lightning surges. Further information on this subject is available in published literature [4].

TABLE C
APPROXIMATE BEHAVIOR OF A ROD ELECTRODE

PARAMETER	EFFECT ON RESISTANCE TO EARTH
Diameter of Rod	Practically negligible for diameters commonly used (5/8" to 1")
Soil Resistivity (ρ)	Resistance of rod varies directly with soil resistivity
Length of Rod in Contact With Soil	In homogeneous soil the resistance of the rod varies approximately inversely with the rod length; however, longer rods have a somewhat higher resistance per unit length.
Paralleling Efficiency	Paralleling efficiency is a function of mutual coupling; consequently, as rod spacing is reduced, paralleling efficiency decreases. The reduction is especially large at spacings less than the length of the rods.

Earth Potentials

5.11 Whenever an electrode conducts a current to ground, the potential of the surrounding earth rises relative to the remote earth potential. This earth potential rise can stem from several causes, such as lightning surges, power system faults, etc., and can amount to thousands of volts. This potential will appear as a potential difference on cable sheaths and support strands that are used to bond the affected grounding electrode to remote grounding electrodes. Such large potential differences can present hazards to telephone personnel and equipment, and even extensive ground electrode systems cannot eliminate the problem. Therefore, other protection measures are required.

5.12 In the event of a fault to ground on an electric power transmission or distribution line terminating in a grounded neutral transformer bank at a power station or substation, fault current will flow from ground to the system neutral by way of the station ground mat. Under fault conditions, the resistance of the ground mat to earth connection will result in a rise in potential of the mat with respect to remote ground. The magnitude of the potential rise depends on such factors as the impedance to ground of the station mat, the location of the fault, the kVA capacity of the banks feeding the fault, the presence or absence of ground wires on the line, etc.

5.13 While the impedances of power station grounds are normally quite small (typically from about 0.25 to 5 ohms), the fault currents may be very large. Maximum fault currents estimated analytically are frequently in the range of 10.0 to 20.0 kA. Since the major part of the fault current in many instances flows into the station ground mat, ground potential rises of several thousand volts are not uncommon. The voltage gradient of the ground around the power station with respect to remote ground usually declines rapidly with distance (approximately exponentially) from the edge of the ground mat. Even for a large power station with a mat area of about 900,000 square feet, over 50 percent of the drop in potential occurs within the region of about 500 feet from the edge of the mat. This subject is covered in much greater detail in SBC-876-310-100.

Impulse Characteristics of Grounds

5.14 The resistance values of grounding electrodes obtained with the instruments described in Paragraph 4.07 are valid for low frequency applications but may not indicate surge performance. However, such measurements provide a basis for estimating surge behavior with sufficient accuracy for practical purposes. Grounds subjected to lightning discharges are required to carry much larger currents than those for power or signaling applications. When the grounding connection is of limited dimensions, such as a single rod or even a few rods in parallel, soil ionization is likely to occur adjacent to the electrodes. Under such conditions the surge impedance may be substantially less than the corresponding dc resistance value. Ionization of the soil around a rod occurs when the radial field (E_R) exceeds the breakdown gradient of the soil (E_o) and the ionization extends out to the point where E_R just equals E_o. The decrease in resistance is thought to be caused by arc bridging of high resistance contacts among those particles of soil having the greatest conductance. The decrease occurs at or near the surface of the electrode when sufficient voltage is present. This produces an increase in the effective radius of the conductor. The resistance of a vertical ground rod (r_o) under heavy surge current conditions may be computed using the following expression:

$$r_o = \frac{\rho}{1.92\ell}\left(\left[\ln\frac{48\ell}{a_o}\right]-1\right)$$

and for a horizontal ground rod [4]:

$$r_o = \frac{\rho}{0.96\ell}\left[\ln\frac{24\ell}{\sqrt{24a_o d}}-1\right]$$

where: $a_o = \frac{I\rho}{1.92\ell E_o}$

a_o = The effective radius of the rod in inches, which includes the ionized area around the rod

I = Crest discharge current in amperes

D = Depth of burial of horizontal ground in feet

ρ = Soil resistivity in meter-ohms

ℓ = length of rod in feet

E_o = Breakdown gradient of the soil in volt/meter, which may be secured from Table D [9]

Example: An 8 foot vertical ground rod in soil of ρ = 1000 meter-ohms has a dc resistance of about 400 ohms. If the soil has a breakdown gradient of 1.8 X 10^6 volts, this rod, when subjected to a median surge of 20,000 crest amperes, will have, because of ionization effects, an effective resistance in the order of 160 ohms. The curve in Figure 11, based upon test data secured by P. L. Bellaschi [10], shows the approximate relationship between the impulse and the 60-Hz resistance of a 1 inch diameter steel rod driven about 8 feet into soil with a resistivity of about 100 meter-ohms.

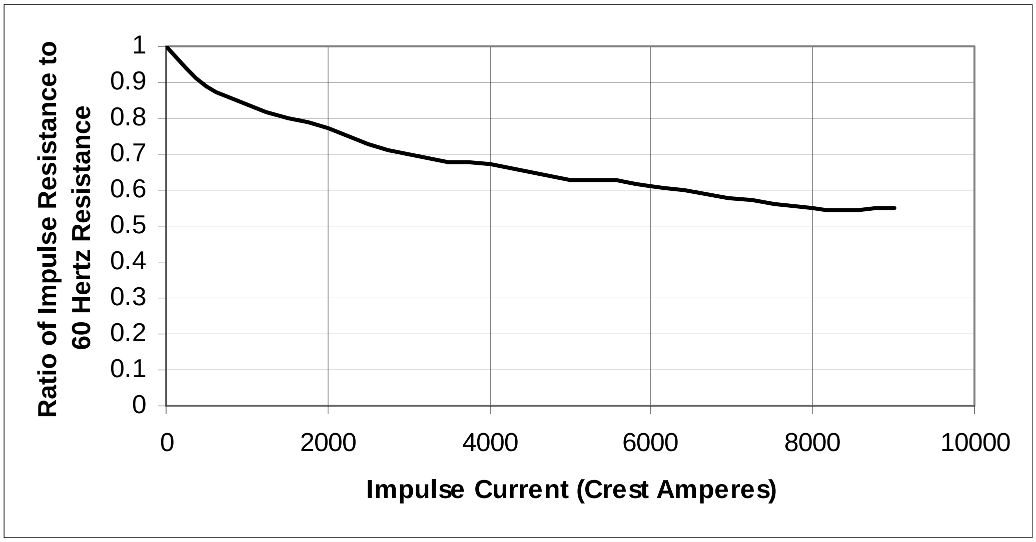


Figure 11 – Impulse Current Versus Ratio of Impulse Resistance to 60 Hertz Resistance of Ground Rod

Counterpoise Grounds

5.15 Situations exist in which a counterpoise (conductor buried in a shallow trench) is a more practical method of securing a ground connection than driving rods. An example would be an area with an extensive outcropping of rocks, making the driving of rods impractical. The counterpoise can be used successfully for the grounding of lightning surges provided that some of the facts concerning their behavior are understood. Studies by Bewley [11] describe this behavior and the optimum configuration and lengths of such counterpoises. His conclusions are summarized in 5.16.

5.16 A single buried conductor energized at one end and open at the other conforms to the behavior of a single wire transmission line that has a surge impedance ranging from about 150 to 200 ohms depending on soil conditions. As a current surge travels along this conductor, or counterpoise, the surge is reflected from the open end, 180 degrees out-of-phase with the incident surge. Consequently, as the reflected surge approaches the incident point, the surge impedance will finally decrease to the dc resistance value (due to the canceling effect) in a time interval depending on the length of the counterpoise and the speed of propagation of the surge. A surge in a buried conductor travels at approximately one third the speed of light. In a 1000-foot counterpoise the surge will propagate to the end of the conductor and return by reflection from the open end in 6 microseconds. In this time the surge impedance of the counterpoise will have dropped from its initial value of about 150 ohms to a value approaching its direct current resistance. The initial surge impedance and the time required to achieve a reduction in the impedance are important from a protection standpoint. A single 250 foot conductor will also have an initial surge impedance of 150 ohms; therefore, if the original 1000 feet of conductor are utilized as four 250 foot runs radiating from a common point, the initial surge impedance will then be only 37.5 ohms (four 150-ohm impedances in parallel). This indicates the desirability of using several short runs in constructing a counterpoise ground rather than one long run, since the direct current resistance is largely a function of conductor length in contact with the soil and will be approximately the same for four commonly connected 250 foot counterpoises as for one 1000 foot counterpoise. The curves in Figure 12 illustrate the relative performance of counterpoises employing one to four conductor runs that use the same linear length of conductor in each case. The curves show that there is little advantage in using more than four counterpoise wires.

TABLE D
BREAKDOWN GRADIENT OF SOIL [9|
(1.5x40 Wave)

TYPE OF SOIL	FRONT	BREAKDOWN GRADIENT (VOLT/METER)
Gravel, Moist	Breakdown on front of wave Breakdown on tail of wave	1.85×10^6 1.19×10^6
Gravel, Dry	Breakdown on crest of wave or not at all	2.18×10^6
Sand, Moist	Breakdown on front of wave Breakdown on tail of wave	2.02×10^6 1.45×10^6
Sand, Dry	Breakdown on crest of wave or not at all	1.8×10^6
Clay, Plastic	Breakdown on front of wave	2.89×10^6

5.17 The approximate ground resistance of a horizontal, buried conductor in homogeneous soil may be computed with the following expression [8]:

$$R = \frac{\rho}{4\pi\ell}\left(\ln\frac{4\ell}{a} + \ln\frac{4\ell}{S} - 2 + \frac{S}{2\ell} - \frac{S^2}{16\ell^2} + \frac{S^4}{512\ell^4} \bullet\bullet\bullet\right)$$

For small values of S/ℓ and with S, ℓ and a in meters, this equation can be modified and simplified for convenience:

$$R \cong \frac{\rho}{3.84\ell}\left(\ln\frac{48\ell}{a} + \ln\frac{4\ell}{S} - 2\right)$$

Where:

ρ = Soil resistivity in meter-ohms

2ℓ = Length of buried conductors in feet (or ℓ is equal to ½ the length in feet)

a = Radius in inches

S/2 = Depth of buried conductor in feet (or, S is equal to twice the depth in feet).

In homogeneous soil, the depth at which a wire is buried does not have a critical effect on its leakage resistance, e.g., there will only be about 10 percent decrease in leakage resistance between a depth of one foot and a depth of three feet.

B. Effective Grounding Systems

5.18 Voltage equalization between conducting surfaces is basic in achieving effective grounding. Equalization is accomplished via low impedance connections or bonds connecting such surfaces and other grounded equipment. With voltages on the affected surfaces or equipment thus equalized, extraneous currents find their way to ground via many parallel paths afforded by such interconnection arrangements. Figure 13(a) is a simple demonstration of equalization.

5.19 The effectiveness of any ground system in limiting lightning surge voltages to earth, in providing adequate voltage equalization, and in coordinating with the dielectric strength of associated equipment, depends upon the surge impedance (rather than the resistance) of the entire grounding system. The surge impedance includes not only the impedance of the ground electrode but also the impedance of the connections between the equipment and the buried ground electrode. The entire front of wave voltage drop to earth (IZ) is expressed as V_F and defined in the expression [12], [13]:

$$V_F = L_G \, \ell \, (di/dt)$$

Where:

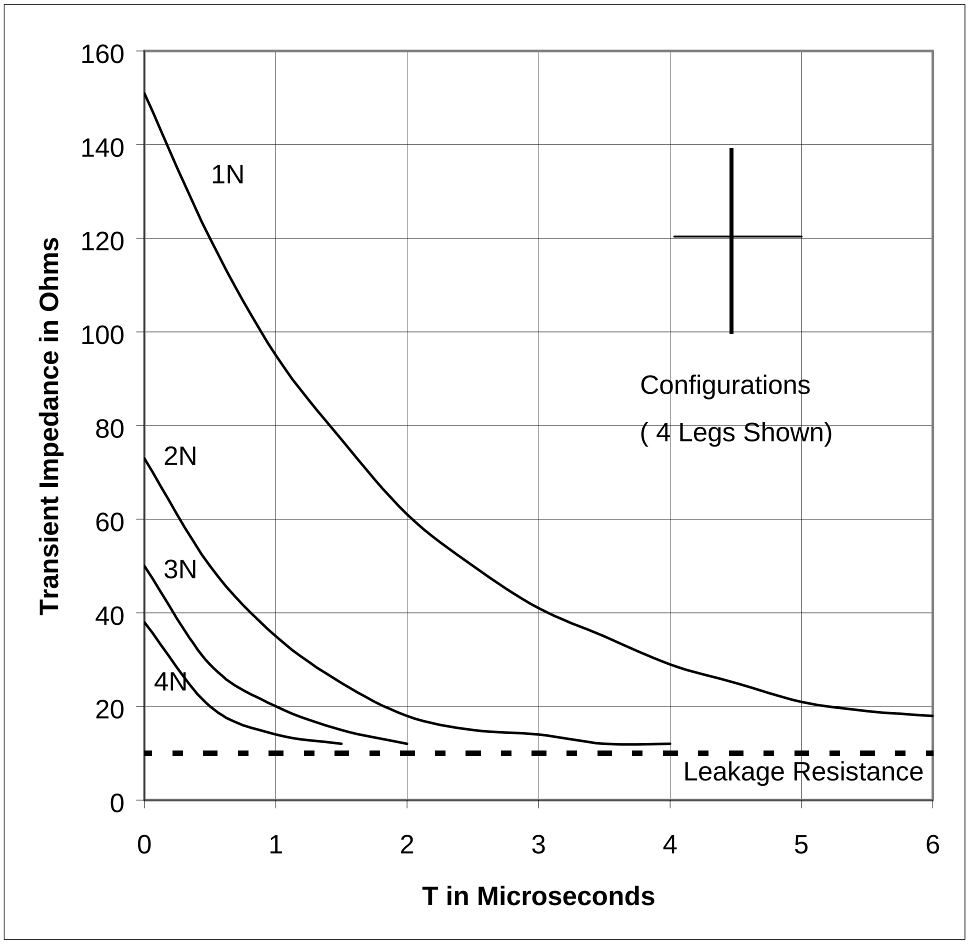
L_G = self inductance of the ground connection in Henrys per foot

di/dt = rate of change in current in amperes per unit of time in seconds

ℓ = distance from end to end of grounding conductor in feet.

The self inductance of a ground path (points A to B) or L_{AB} may be obtained from the following expressions, the second form being a conversion of the first for convenience:

$$L_{AB} = 0.002\ell\left[\left(\ln\frac{2\ell}{a}\right) - 0.75\right]10^{-6}$$



Conditions:

1. Initial surge impedance occurs at T=0

2. N = Number of legs

3. Total length of wire in all cases = 1000 feet
   Depth of wire = 1 foot
   Soil resistivity = 1000 Meter-Ohms.

Figure 12 – Effective Resistance of Counterpoise Configurations

Where length and radius of nonferrous conductor are in centimeters, or

$$L_{AB} = 0.00508\ell\left[2.303\left(\log_{10}\frac{4\ell}{d}\right) - 0.75\right]10^{-6}$$

Where:

ℓ = Length in inches

d – diameter of a nonferrous conductor in inches.

However, for practical purposes it is unnecessary to calculate L_{AB} for each case since the results for various sizes of conductors with which we are concerned (2 to 18 AWG) average about the same per unit length, or approximately 0.4 X 10^{-6} Henrys per foot [14]. This value is satisfactory for engineering estimation purposes and for substitution for L_G in the expression for calculating V_F. This value yields realistic results when substituted in the V_F expression, since it assumes average spacing and influence of other conducting surfaces within several feet as well as a straight run of the affected conductor. By contrast, the expression for L_{AB} assumes an essentially isolated conductor. Representative values for di/dt are 10 kA/microsecond for rate of rise in a lightning channel such as experienced at a radio tower, and 5 kA/microsecond for rate of rise at a subscriber station.

5.20 The voltage drop V_F determines the instantaneous voltage that any object struck by lightning will assume with respect to remote or true earth during the period while stroke current is flowing. To avoid the obvious hazards of high voltage differences (equipment to ground) and possible side flashing, telephone lines should, for example, be brought in as near as possible to the power service entrance. Proximity of these two entry points facilitates the establishment of a short, straight, low impedance common connection of the power and telephone grounds. Bends or loops in the ground connections should be avoided wherever possible because they are inductive and can raise surge impedance significantly. Practical examples of good voltage equalization in ground systems for different types of plant are described where applicable in BSP layers 876-2XX-XXX through 876-6XX XXX. Refer to ANSI/NFPA 780, Lightning Protection Systems for protection of persons, buildings, and miscellaneous property. [15]

5.21 For prompt operation of circuit fuses or breakers, the electrical continuity of conduits and raceways from the utilization equipment back to the neutral bus is of primary importance. Grounding is required to limit voltages with respect to earth but is incidental in providing a fault-current path. The recognized practice of providing additional conductivity back to the neutral bus with a third conductor (green wire) gives greater assurance of prompt and reliable operation of current interrupting devices.

5.22 Figure 13(B) shows an unacceptable arrangement that will not operate the overcurrent protection on a power circuit even though the conductors are enclosed in a grounded metallic conduit. The separate grounding of a power conduit as shown in Figure 13(B) is not permitted by the National Electrical Code. In this illustration, no direct metallic path exists from the fault back to the neutral. Consequently, the fault current passes through a 20 ohm ground connection, which limits fault current to 6 amperes less than the operating value of the fuse. This condition allows the conduit to remain at a potential of 120 volts, which constitutes a very serious shock hazard. The correct arrangement is shown in Figure 13(C) where, in the event of a fault, the interconnection of the conduit with the neutral conductor will reduce the fault voltage on the conduit to a negligible value and facilitate prompt operation of the fuse [16], [17]. This type of problem is described in more detail in the application engineering sections, layers 2 through 6 in this division.

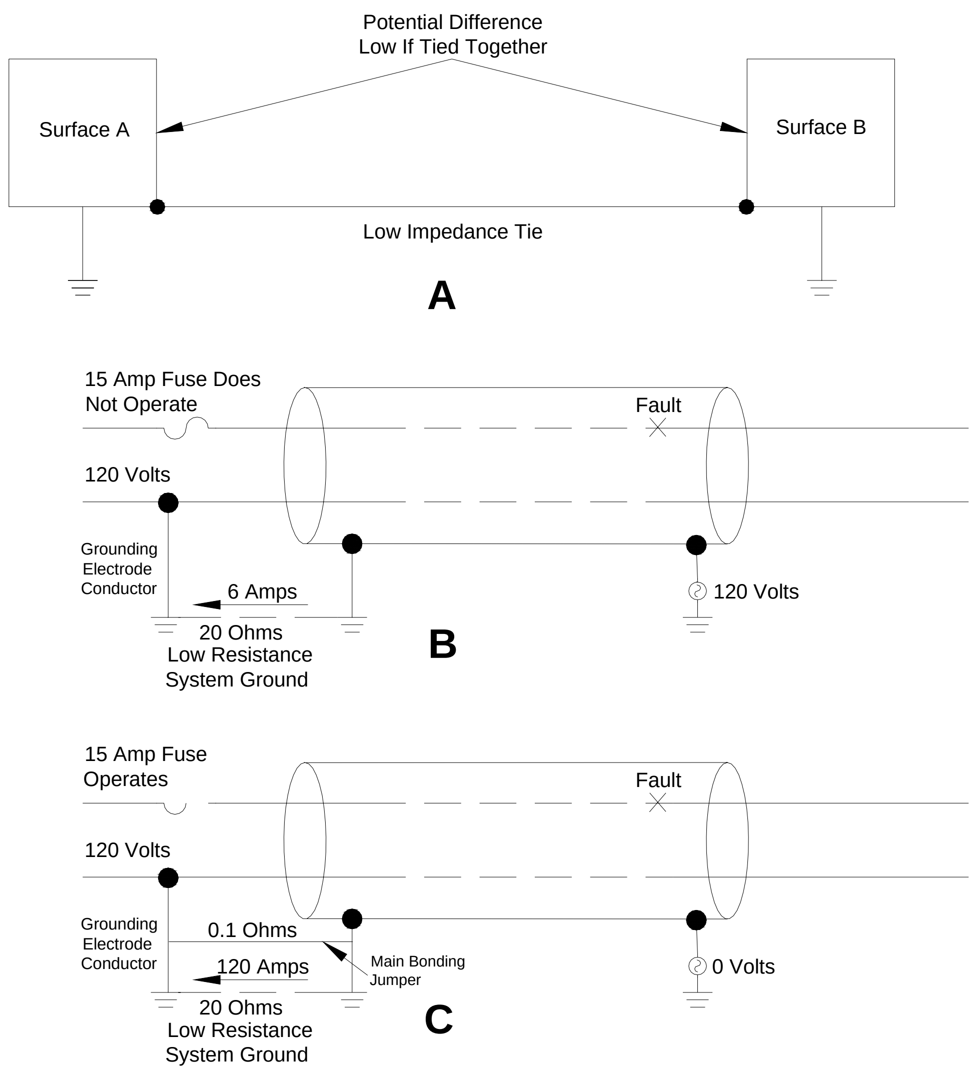


Figure 13 – Typical Voltage Equalization And Ground Problems

6. TYPES OF GROUNDING ELECTRODE SYSTEMS

6.01 The relative effectiveness of common types of grounding electrode systems is compared in Table B. A ground connection of any configuration is, in fact, an impedance element connected between the electrical circuit and remote earth, although that impedance may in some cases be very low. As long as no current flows through the grounding connections and electrode systems, they will all be at earth potential; however, when current flows in such a system, the system ceases to remain at earth potential (see Part 5). If current flowing in the grounding system is dc or low frequency ac, the potential that develops will be chiefly an IR drop with most of the voltage due to the contact resistance between the electrodes and the soil. Under lightning surge conditions and especially on the front of such surges, voltage appearing in the grounding system is largely inductive and usually will be substantially larger than that experienced with steady state dc or low frequency act. When such voltage drops do not exceed the dielectric strength limits of the plant involved and do not present a shock hazard, the plant is considered to be effectively grounded. Additional factors that influence the choice of a grounding electrode system are site peculiarities, nature of the substrata, type of plant installation, and availability of "ready-made" grounding electrodes. Generally speaking, the effectiveness of any grounding electrode system improves with electrode area and/or dispersal of the system.

A. Urban Public Water Systems

6.02 The metropolitan or urban public water system (metallic piping) is a ready made ground electrode system unmatched in extent and availability. The resistance of such systems is very low (approximately 1 ohm), but its effectiveness depends upon the use of low resistance grounding conductors employing direct routes from equipment locations to the point of connection to the pipe.

6.03 To prevent corrosion of their metal pipes, water companies sometimes insert insulating couplings to break the metallic continuity between the piping in a building and the buried external piping system. A typical example is the use of an insulated coupling, or bushing, at a water meter. The NEC requires the installation of bonds bypassing insulating couplings where necessary to ensure metallic continuity in piping systems that are used as grounding electrodes (250-68). In addition, the use of nonmetallic pipe in the repair of existing systems and in the construction of new water systems is increasing. If a metallic water pipe system is the only means of grounding at a building, and if it is modified at some later date so that it no longer provides adequate grounding, the construction of a substitute ground could be relatively expensive. Because of such possibilities, the practice is increasing of establishing a supplementary "made" ground during the construction phase of new buildings, especially in those of large size.

6.04 SBC-TP76416 discusses the factors affecting electrical continuity and use of water piping for grounding with respect to communication equipment buildings.

6.05 Customer station grounding is subject to specific codes and regulations. Approved grounding methods for station protectors and cable shields are described in SBC-876-300-100.

B. Small Public Water Systems

6.06 All grounding considerations applicable to metropolitan or urban water systems are applicable to small public water systems. Usually, however, such systems are found in suburban or rural environments, where lightning surge protection becomes increasingly critical as the environment becomes more rural. Accordingly, the following factors require careful attention:

(a) Electrical continuity of the metallic piping system.

(b) Short, low impedance paths to ground for all ground connections to dissipate lightning surges to earth.

(c) Close proximity of power and telephone service entrances into the subscriber premises. Common grounding of the power neutral and telephone ground by the shortest, most direct route is necessary for low surge impedance and voltage equalization (see 5.20).

C. Grid or Mat of Wires

6.07 Electric power stations and substations are equipped with a grounding electrode system called a "mat" or "grid" buried in the earth under the station. The ground mat serves as the common grounding electrode for both power and communication equipment. The power station neutral is connected to this mat. The impedance of such a mat is typically 0.25 to 0.5 ohms. Ground mats are designed to handle very large fault currents, as would be encountered in the case of a fault to ground of a power transmission or distribution line.

D. Concrete Encased Electrodes

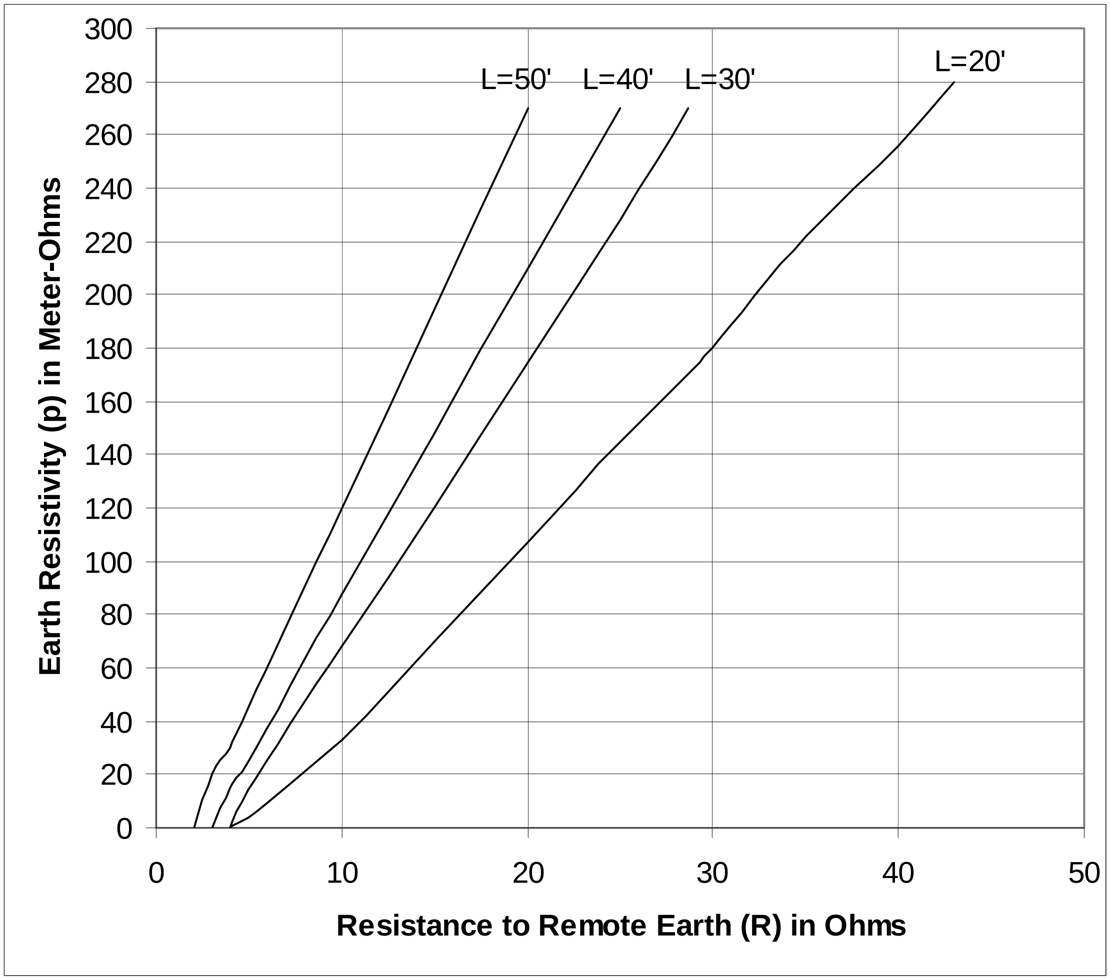
6.08 The 2002 edition of the National Electrical Code (NFPA, No. 70), Article 800-40, permits the use of concrete-encased copper conductors as an alternate grounding electrode for station protectors. [7]

6.09 The behavior of concrete encased electrodes is described by H. G. Ufer, based on tests conducted for many years in California and in the southwestern part of the United States [19]. The electrode arrangements used varied in size and type of materials, among which were steel conduit, iron reinforcing bars, and No. 4 AWG copper conductors, all of which ranged in lengths from about 20 to 100 feet. Two of the conclusions presented were that a 20 year history indicates that grounding electrodes in concrete footings are a reasonably adequate substitute for a buried metallic water system and that the ground conductor should be placed about 2 inches above the base of a concrete foundation footing.

6.10 Ufer's studies were all conducted in low resistivity areas where the soil ranged from 35 to 150 meter ohms. Subsequent studies (see 6.14) of other factors related to the effectiveness of concrete encased electrodes appear to have incidentally discounted the significance of soil resistivity.

6.11 In all test areas except one, average annual rainfall was very low, ranging from 0.5 inch to 14 inches (see Figure 6.). Thus, the amount of precipitation does not appear to be a major factor in accounting for the effectiveness of concrete encased electrodes.

6.12 The resistivity of concrete is roughly 80 to 100 meter-ohms. It would seem, therefore, that conductors in concrete would have somewhat higher resistance to remote ground than a similar conductor buried directly in 38 meter ohm soil such as Ufer encountered. However, Ufer's data indicates that concrete-encased electrodes tend to have a lower resistance than metallic buried electrodes. This paradox may be explained by the effective increase in the area of the concrete electrode (see 6.17). Thus, Ufer's data suggests that encasing electrodes in concrete should be a particularly effective way of obtaining lower electrode resistance in high soil resistivity areas.



Conditions:

1. #4 AWG copper wire encased in concrete
2. Height = 1 foot
3. Width = 1.5 feet
4. Depth = 3 feet below grade
5. Resistivity of concrete = 50 Meter-Ohms.

Figure 14 – Ground Resistance of Concrete Electrodes

6.13 A low resistance to ground is not the only characteristic of an effective grounding electrode. Ability to handle surge and steady state currents of substantial magnitude is of major importance. The Los Angeles Department of Water and Power tested the ability of concrete footing type grounds to carry 60 Hz current. Studies were conducted on footing grounds about 20 feet in length; the footing grounds had resistances ranging from 6 to 13 ohms. Test voltages of 60 Hz up to 20 kV were applied to these specimens for periods of 10 cycles (0.16 sec.). Discussion of these tests and some of the test data are given in the March 1967 IAEI News (International Association of Electrical Inspectors). It was concluded that an electrode encased in a 20 foot long concrete footing generally provides a better electrical ground than one driven ground rod.

6.14 Other studies have shown that column footings in both reinforced concrete buildings and steel frame buildings provide a relatively low resistance connection to ground [20,21]. Direct efforts are rarely made to interconnect reinforcing bars and structural steel members with such conventional grounding electrodes as water pipes. However, supplemental grounding of substantial proportions is obtained via footing grounds because of the multiplicity of contacts that undoubtedly occur by chance within any sizable structure. It should be mentioned at this point that while concrete encased electrodes are entirely adequate for subscriber grounds, they have not yet been evaluated with regard to corrosion resulting from continuous direct current flow. For this reason they should not be used for central office building grounding. Figure 14 shows the ground resistance of various concrete encased electrodes for a wide range of earth resistivities.

E. Grounding of Concrete Manholes

6.15 In 1971, Bell Laboratories conducted studies of the effectiveness of grounding of 38Y type manholes. The 38Y type manhole is made of concrete reinforced with welded steel bars. Before casting, copper ribbon grounding connections are made to the bars; the ribbons are left protruding from the roof and floor after casting. After installation of the manhole, the equipment and cable shields are bonded to the ribbons. Thus, the entire manhole serves as a concrete encased ground electrode, where it is in direct contact with the soil (not waterproofed).

6.16 A formula for the manhole's expected resistance to ground was derived. It was found that that formula could be adequately approximated by the formula for the resistance of a conducting hemisphere whose area equals the wall and floor area of the manhole:

$$R = \rho/2\pi r$$

Where:

ρ = earth resistivity in meter-ohms

r = radius in meters (= 2.165 meters for the 38Y manhole) and

R = resistance to ground in ohms.

The resistance to ground was calculated for four values of ρ, using both the exact formula and the approximation given above. The results are listed below:

Meter Ohms	R_{exact} (Ohms)	R_{approx} (Ohms)
35	2.6	2.5
67	4.8	4.9
122	8.5	9
435	30.1	32

Since the resistivity of concrete is about 50 meter ohms, it can be seen that the effect of the concrete (which is ignored in the approximation) is

- to increase the resistance over the approximate value in soils where $\rho < 50\Omega$, or
- to decrease the resistance from the approximate value in soils where $\rho > 50\Omega$.

In other words, in high resistivity soil, the concrete acts as an extension of the ground electrode, effectively enlarging it. In low resistivity soil, however, the concrete acts as an imperfect insulator.

6.17 As can be seen from the sample resistance figures given in 6.17, the grounding provided by the 38Y manhole is quite effective in terms of resistance. Because of the large contact area involved, the surge resistance should also be reasonably small. In any case, substantial cost would be involved in constructing a ground of driven rods that would be equally effective.

F. Private Water Pipe Systems

6.18 When public water pipe systems are not available, the private system is usually the next best grounding electrode available. All comments associated with small public water systems (6.06) apply to the private systems. These systems are often found in predominantly rural environments and may offer the advantage of a deep well metal casing pipe as a part of the grounding electrode.

G. Buried Power Systems

6.19 In areas having extensive installations of buried power cable with a bare concentric neutral, this neutral conductor will provide a low resistance ground. Most of the considerations mentioned in regard to water systems also apply to buried power neutral grounds.

H. Buried Ring or Star Counterpoise

6.20 Effective grounding for telephone offices and microwave radio stations is provided by the buried ring or star counterpoise. The ring counterpoise is a common configuration, since it not only grounds but also reduces earth potential gradient within the ring. It consists of a network of ground rods and a ring of wire buried around the exterior of the building and/or the antenna support structure. Because the rods penetrate below the frost line, they are much less exposed to the large increase in electrode contact resistance that occurs when moisture in the surrounding soil freezes. When soil or exposure conditions suggest enlargement of the electrode system, radiating wire extensions or "star" counterpoise electrodes supplement the ring electrode.

6.21 The ring and star counterpoises have analogous electrical characteristics (see 5.16); however, the ring with driven rods is preferable because of its compactness and its ability to maintain voltage equalization within the ring. Limitations in size of property and convenience of installation at time of building construction are additional factors that favor use of the ring counterpoise over the star counterpoise. In addition to the voltage equalization capabilities of the ring itself, the driven rods provide considerable electrode area in contact with the earth, which tend to provide a low impedance to steep wavefront lightning strokes.

6.22 In most installations it is unnecessary to supplement the ground ring with the star extensions; however, if the soil is very dry or if the subsurface consists of bedrock that precludes use of driven rods, the star counterpoise may be used to supplement the ring counterpoise. The wire extensions are buried in shallow trenches at a minimum depth of 1-1/2 feet and radiate from the corners of the ground ring for a minimum of 25 feet. If no property restrictions exist, the wires should be longer, particularly at stations with tall towers and vulnerable connecting facilities. Extending the wires beyond a length ranging from 200 to 300 feet offers very little advantage. [9]

6.23 It is desirable to have a low resistance ground to dissipate lightning current. However, experience has indicated that constructing a buried counterpoise of a given resistance value may be unduly expensive because of the electrical behavior of counterpoise electrodes and variations of soil resistivity. [9] Specification of only the dimensions of the buried network and its general configuration is therefore preferable. The electrode effectiveness usually increases in proportion to the amount of metal in contact with the earth. Rather than go to extremes with the enlargement approach, however, the engineer can obtain satisfactory results more economically by employing supplementary protection on the power and communication facilities. Refer to BSP layer 876-2XX-XXX of this division for specific recommendations related to radio station and office grounding, aerial shielding of structures, and tower footing protection.

I. Small "Made" Grounds—Driven Rods

6.24 When no other more effective grounding electrode is available, a driven ground rod may be used. A rod is generally adequate for signaling and transmission purposes, but its effectiveness as a lightning and power ground is minimal. A single driven rod is the last resort as a protection ground.

6.25 Driven rods are often used as part of a lightning rod system where bypassing the surge to ground is the major consideration but the rods are always interconnected with other conducting and grounded objects in the vicinity. Common bonding of the rod, particularly to the power service ground, is required for potential equalization.

J. Metallic Gas Pipe Systems

6.26 The NEC refers to the use of metallic gas pipe systems for grounding purposes.
However, any such use of gas pipes must first be cleared with the gas company, and permission is usually not given. Therefore, gas pipe systems shall not be considered for telephone grounding.

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