

be denied to the fruits of corporate research? Shall the national fiscal policy favor or inhibit capital risks? Shall we be more intent on policing the capital and price structure than on encouraging technological improvement? Shall free enterprise be fostered in areas where great possibilities of technical advance exist? Shall management be always suspect, and labor

deemed incapable of doing wrong? Shall natural resources be nationalized? Our professional future and its potential fruitfulness to society are inseparable from these and kindred social issues.

There can be no powerful and unified engineering profession tomorrow unless it is created today in the consciousness of engineering students. We educators must

do that job, and you must lend your interest and encouragement. In this hour when the prestige of engineering stands high and when engineering education stands forth, as never before crowned with success, let there be no hypnotic self-satisfaction, no seductive complacency among us. This, gentlemen, is the time to mark up our goals!

Grounding Principles and Practice

II—Establishing Grounds

CLAUDE JENSEN
ASSOCIATE AIEE

GROUNDING has become an everyday electrical term and a very common practice in electrical construction and operation. The primary function of most grounding is to increase safety for life and property. Its secondary function is to improve the operation and continuity of service of electric systems. These two functions are often complementary and compatible.

There are a number of methods for making ground connections. The essential requirements are that they shall be durable, have low resistance, have adequate current-carrying capacity, and be economical to install.

This article is a general treatment of the various types of ground connections, their characteristics, methods for improving ground connections, and methods for measuring ground resistances. It is based on the experiences and developments of the industry.

TYPES OF GROUNDS

In general, ground connections may be divided into two groups or classes. The first comprises water pipes, metal frameworks of buildings, well casings, and other metal structures or materials installed for purposes other than grounding. If located near the equipment or circuit being grounded, they can provide convenient and economical types of grounds.

The other group comprises driven electrodes, buried plates, strips, and conductors, and other kinds of specially designed electrodes. These are intended solely for the purpose of making a ground connection and are installed at, or as near as practicable to, the location where the ground connection is desired.

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WATER PIPES

As a means of grounding electric systems, such as secondary lighting services and telephone services, water pipes probably come first from the standpoint of economy. In urban areas, they usually extend over the same area or territory as that covered by the electric-lighting and telephone systems, and are therefore readily accessible at service pipes and at other places. Consequently, ground connections to them are economical in first cost.

Because of the great extent of water-piping systems, they offer good conduct-

This article is the second of five based on a series of lectures on the subject which was sponsored by the power and industrial group of the AIEE New York Section during the 1943-44 season. Various types of ground connections, together with methods for measuring ground resistance, are discussed.

ance to the flow of current into the earth. In many instances, the resistance of a water-pipe ground connection is of the order of a fraction of an ohm and a value of two to three ohms or more would be considered as excessive. This comparatively low resistance may be attributed mainly to the wide extent of such systems and the tremendous volume of earth affected. In many instances, pipes are many miles in length, and sizes range from the ordinary service pipe to mains a foot or two in diameter or even larger depending

upon the water system of the particular city.

The types of soil in which water pipes are embedded may have a wide range of resistivity values. However, this has relatively little effect on the resistance of the ground connection because of the wide extent of the system. Also, the pipes are usually installed at depths below the frost line where the moisture is relatively permanent and where the resistance is little affected by seasonal variations.

On the other hand, the type of joints used in water-piping systems will affect the resistance. Where lead or screw joints are used for joining together lengths of pipe, these usually provide good metallic connections and the resistance is so low as to be almost negligible. In comparison to this, where joints are made with cement or "leadite," resistances may range from several ohms to several hundred ohms and such systems are consequently not good for electrical grounds. However, water-piping systems are widely used and, in general, are satisfactory for many purposes.

METAL FRAMEWORKS

Structural metal frameworks of buildings which make direct contact with the soil and are dispersed over an extensive area of ground may also be used for ground connections. This type of ground is permitted by various codes as an alternate method of grounding when a water-piping system is not available.

The National Electrical Code states that metal frames of buildings have, in general, a resistance substantially below 25 ohms. This depends on the size of the building, the type of footings, and the soil at the particular location. Tests reported by one investigator gave values of 2.4 and 2.2 ohms for steel frameworks of two relatively large buildings.¹ Resistances of this order

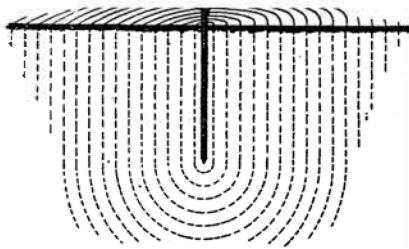


Figure 1. Resistance of earth surrounding an electrode

This may be pictured as successive shells of earth of equal thickness. With increased distance from the electrode, the earth shells have greater area and therefore lower resistance

compare favorably with those of water-pipe grounds and connections to them should provide satisfactory ground connections. However, measurement of resistance is the criterion in determining the suitability of grounds of this type.

WELL CASINGS

Steel pipe used as casings in wells is sometimes used for making ground connections at substations and also in rural areas where a well is located near to the system or equipment being grounded. Usually such pipes extend a considerable distance into the earth and can affect a tremendous volume of earth so that grounds of this type should be comparatively low in resistance. One reference mentions a substation-ground connection to a 14-inch-diameter steel casing 100 feet in length which had a resistance of approximately 1.3 ohms.²

In using any of the foregoing methods for making ground connections, it should be remembered that they serve a twofold purpose. One is the original purpose for which the equipment was installed, and the other is its use as a ground connection.

Any changes or alterations in the equipment or facilities as related to the original purpose may affect its use or functioning as an electrical ground. For example, the removal of a water meter would disconnect the water pipes in a building from the service pipe and street mains.

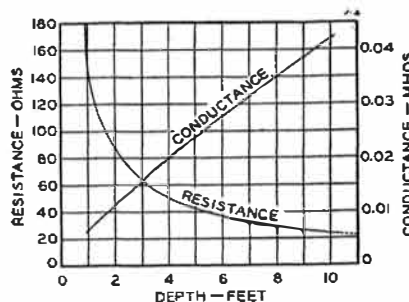


Figure 2. Effect of depth on resistance and conductance of a driven ground for uniform soil resistivity

From Bureau of Standards Technologic Paper 108

Grounds Tested	Soil	Resistance in Ohms		
		Average	Minimum	Maximum
24....	Fills and ground containing more or less refuse such as ashes, cinders, and brine waste	14....	3.5....	41
205....	Clay, shale, adobe, gumbo, loam, and slightly sandy loam with no stones or gravel	24....	2.0....	98
237....	Clay, adobe, gumbo, and loam mixed with varying proportions of sand, gravel, and stones	93....	6.0....	800
72....	Gravel, sand, or stones with little or no clay or loam	554....	35....	2,700

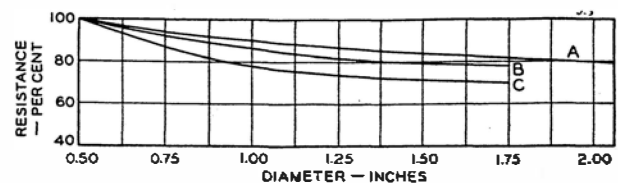
Certain precautions are therefore necessary to prevent any break in the path to earth. In the case just mentioned, the National Electrical Code requires that if the ground connection cannot be made on the street side of the meter, the water-piping system shall be made electrically continuous by bonding together all parts which are liable to become disconnected.

DRIVEN ELECTRODES

Considering the group or class of grounding electrodes which are installed solely for the purpose of making a ground connection, the driven electrode is used far more than the other types. This results from its numerous mechanical and electrical advantages as compared to other types of installed grounds such as buried plates, buried strips or cables, grids, and so forth. The outstanding advantage is the low cost of driven grounds compared to the other forms of grounds, also the simplicity of driving a rod compared to the task of excavating for and installing buried electrodes. In addition to this, the ground area required for a driven electrode is small, which is a decided advantage in locations where excavation is difficult or where space is limited.³

Another important advantage is that the connection between the ground wire and the driven electrode can be made above the surface of the ground, which makes it convenient and easy to inspect

Figure 3. Effect of electrode diameter on resistance of a driven ground



A—From Bureau of Standards technologic paper 108
B—Average of Underwriters Laboratories tests at Chicago
C—Average of Underwriters Laboratories tests at Pittsburgh

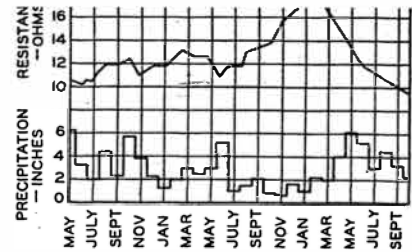


Figure 4. Seasonal variation in resistance with rainfall

the connection or to disconnect the ground lead if it is desired to test the resistance of the ground.

The conductance of a driven electrode compares very favorably with that of other types of installed grounds. It has the advantage that two or more electrodes may be driven and connected in parallel and, for a given cost, it is possible to obtain a much lower resistance with driven electrodes than with other types of installed grounds.

Where the permanent moisture level or a layer of better conducting soil is at a considerable depth below the surface, rods can be driven to a depth far beyond that which would be practical or economical for buried grounds. Furthermore, the use of artificial treatment as a means of reducing the resistance of a ground lends itself more readily to driven electrodes than to the other types.

These advantages of the driven electrode account for its widespread use. However, to secure the best results in practice, an understanding of the general principles and characteristics of driven grounds is necessary.

CHARACTERISTICS OF DRIVEN GROUNDS

Although the earth may be considered as a conductor which has practically unlimited conductance capacity and, on account of its size, negligible resistance, it cannot be assumed that all connections to the earth will have the same characteristics. The electrical conductance of soil is determined largely by its chemical ingredients and the amount of moisture in the soil.

That the resistance of a ground connection is dependent mainly upon the type of soil surrounding the electrode is shown in Figure 1. This is pictured as cylindrical

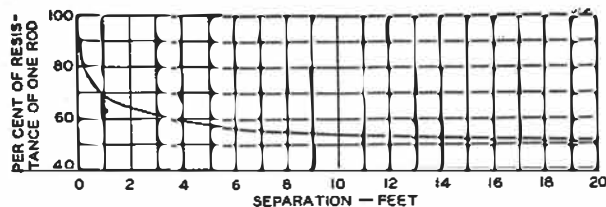


Figure 5. Variation in resistance with distance apart of two electrodes connected in multiple

shells of earth of equal thickness. The greatest resistance is in the shell immediately surrounding the electrode which is the region of smallest cross section at right angles to the flow of current through the soil. Each succeeding shell has an increased cross section. At a distance of eight to ten feet from the rod, the area of the path is so large that the resistance is almost negligible. The resistance varies inversely as the cross section, and therefore, in the area within a few feet from the electrode, where the conducting path is small, the resistivity of the soil is an important factor. Measurements show that 90 per cent of the total electrical resistance surrounding an electrode is generally within a radius of six to ten feet from the electrode.

The wide variation in soil resistance is illustrated in Table I which is based on measurements made by the Bureau of Standards on different types of soil.⁴ As will be seen, values as low as 2.0 ohms were obtained in some soils, whereas for others, the resistance was as high as 2,700 ohms. Even wider variations than these are possible.

CONTACT RESISTANCE BETWEEN METAL AND EARTH

The contact resistance between a ground electrode and the soil can be considered as negligible compared to the resistance of the soil itself, for the metals commonly used for driven electrodes. This assumes that the metal is clean and free from paint or grease and that the soil is firmly packed around the electrode.

The contact resistance between metal and soil has been determined from tests by the Bureau of Standards.⁴ In these

tests, several samples of earth were used, each of which was thoroughly mixed before testing, to insure as uniform resistivity as possible. Tests were made by placing different quantities of soil in a cylindrical glass vessel having an iron bottom, compressing it by forcing an iron piston down upon it and measuring the electrical resistance between the piston and the metallic bottom. These measurements indicated that the effect of contact resistance between clean electrodes and earth, when firmly pressed together, is negligible, since the readings showed the same specific resistance for different depths of soil in the cylinder.

EFFECT OF DEPTH

The depth to which an electrode is driven is probably the most important factor affecting its resistance. There are several reasons for this. First, the volume of soil affected increases directly with the length of electrode below the surface, and second, the soil resistivity usually decreases with depth by virtue of the increased moisture content.

Figure 2 shows the variation of resistance with depth of a driven electrode. This curve was plotted from calculated data assuming soil with uniform resistivity.⁴ Although this is a theoretical curve, it has been checked and verified experimentally by various investigators, with only slight inconsistencies due to nonuniformity of the soil.

In actual practice, soil is seldom of uniform resistivity and so, practically, the curve shows only what minimum depth in conducting soil it is desirable to reach. For example, it will be seen that the decrease in resistance is small for each additional foot greater than about eight feet. Assuming that relatively permanent moisture is reached at this depth, it would appear that eight feet would be an economical depth. However, where the resistivity

decreases with depth, as well as where permanent moisture exists at some distance below the surface, the use of longer electrodes is advantageous.

A useful curve in analyzing the effect of length is the conductance-length curve as shown on Figure 2. In comparison with the resistance curve, which levels off, the conductance curve is practically a continuous upward sloping line indicating that electrodes longer than eight feet are beneficial.

The length of a ground rod is also of importance in localities where winter seasons are very severe and where grounds must function in winter as well as summer. The resistivity of frozen soil is very high compared to that of soil at normal temperatures.⁵ Hence, grounds should extend well below the frost line, otherwise the resistance is apt to vary considerably throughout the year. Even when driven below the frost line, there may be some variation as the upper layers of soil, when frozen, have the effect of shortening the active length of the electrode in contact with soil of normal resistivity.

DIAMETER OF ELECTRODES

The minimum diameter of a driven electrode is determined by mechanical rather than electrical considerations. The usual practice is to select a diameter only large and strong enough to drive it into the soil at a particular location without bending or splitting.

The effect of electrode diameter on the resistance of grounds is shown in Figure 3. Curve A is a calculated curve assuming uniform soil resistivity.⁴ Curves B and C represent the average of hundreds of actual measurements on grounds in two different cities.⁶ Considering the diameters used commercially today, from curve A it will be seen that doubling the diameter from one-half inch to one inch decreases the resistance of a single driven ground by only 9 1/2 per cent.

SOIL RESISTANCE AFFECTED BY SEASONAL VARIATIONS IN MOISTURE

Seasonal changes in ground resistance vary more or less with the amount of rain throughout the year. Ground resistances are likely to be high following a long dry spell and likewise, lower after heavy rains. Figure 4 shows the variation in ground

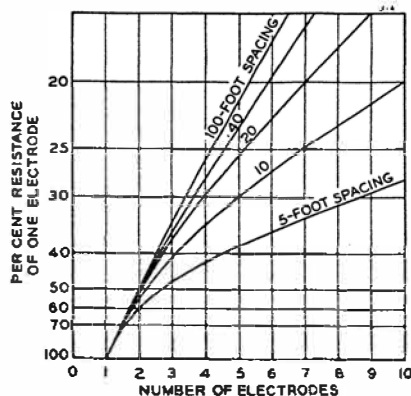


Figure 6. Efficiency of driven electrodes in multiple at various spacings

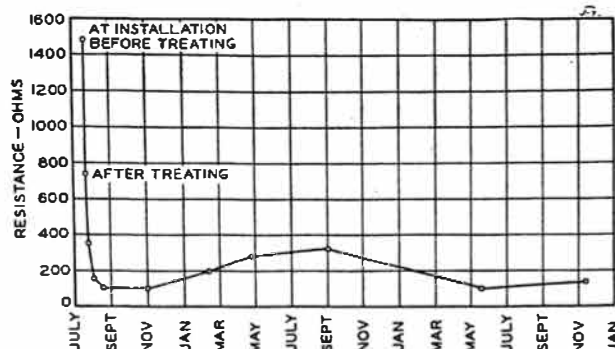


Figure 7. Ground resistance reduced by soil treatment

resistance with precipitation which occurred at one installation.

The normal moisture content of soils ranges from about 10 per cent in dry seasons to around 35 per cent in wet seasons with an approximate average value of about 16 per cent to 18 per cent.³ Tests by the Bureau of Standards showed that when the moisture content is below 22 per cent, the resistivity increases very rapidly.⁵ It may be seen from this that seasonal variation in rainfall can affect the resistance of a ground connection to a considerable extent.

METHODS FOR IMPROVING GROUNDS

Where the resistance of a driven ground connection is very high or in excess of a value considered satisfactory for a particular installation, there are various methods which can be used for improving the resistance of the ground. These are the

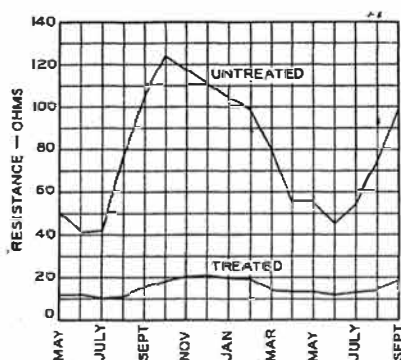


Figure 8. Ground treatment lessens seasonal variation in resistance

use of multiple electrodes, soil treatment, a combination of multiple rods and soil treatment, or deep-driven electrodes.

MULTIPLE ELECTRODES

One of the most convenient and economical methods is by means of multiple electrodes. When two driven electrodes, well spaced from each other, are connected in multiple, they provide two parallel paths to earth. Since 90 per cent of the total resistance is located within six to ten feet of an electrode, these rods should be spaced far enough away from each other to minimize the tendency for overlapping of the current paths away from the electrodes. The effect of spacing on the resistance of two electrodes connected in multiple is shown in Figure 5.⁴

With wide spacings, each additional driven electrode introduces a new cylinder of unused soil and the combined multiple resistance is decreased by an amount approximately inversely proportional to the number of electrodes; that is, two rods in multiple tend to have one-half the resistance of one rod, three rods, one-third the resistance, and so on.

This direct reciprocal relation is not quite reached in practice, however, as the

spacing is necessarily limited and the conducting paths or cylinders surrounding the rods tend to overlap. This point is illustrated in Figure 6. Two rods at 100-foot spacing would have approximately 50 per cent of the resistance of one electrode, but spacings of this order are often impractical. Also, the resistance and reactance of long leads necessary for connecting electrodes at wide spacings would tend to decrease the effectiveness of rods in multiple. However, with spacings of 10 to 20 feet which are generally feasible, the reciprocal relation can be closely approached.

The characteristics of multiple-ground-electrode systems have been discussed in numerous technical articles and papers. In an article by H. B. Dwight,⁷ curves are presented showing the relationship between the number of electrodes, the spacing, ground area, conductance and effectiveness. Similar data are also given in an article by J. R. Eaton.⁸ This information may be useful in designing station grounds where large numbers of electrodes in multiple are used.

SOIL TREATMENT

Artificial treatment of the soil surrounding a driven electrode is often resorted to as a means of lowering the resistance of a ground. Substantial reductions in the resistances of electrodes already installed may be accomplished by dissolving in the moisture normally contained in the soil some substance which is highly conducting in its water solution.

There are a number of chemicals suitable for this purpose, such as sodium chloride, magnesium sulphate, copper sulphate, and calcium chloride. Other chemicals which have been investigated are iron sulphate, sodium nitrate, potassium nitrate, and ammonium sulphate. The selection is largely dependent upon cost, availability, and the corrosive properties of the chemical. Common salt and magnesium sulphate are most generally used.

Chemical treatment can affect reductions in soil resistance anywhere from 15 per cent to 90 per cent. The benefit which can be gained is dependent mainly upon the kind and texture of the soil. Figure 7 illustrates the results obtained for one installation. The percentage reduction in this case is rather high and typical for

grounds having high resistances. Grounds of lower resistance may be improved by treating but not in the same proportion.

In addition to lowering the resistance of a ground, soil treatment also smooths out seasonal fluctuations, as shown in Figure 8. The curve for the treated ground shows some variation, but it is not nearly so great as for the adjacent untreated ground.

Chemical treatment has one disadvantage in that its effect is not permanent, the solutions being gradually carried away and dissipated by the natural drainage in the soil. The rate of dissipation is dependent upon the porosity and type of soil and the amount of rainfall. Renewal of the treatment may be necessary after a few years or when periodic tests indicate a constant increase in the resistance. This is illustrated in Figure 9 which shows that the effect of soil treatment was completely dissipated after a period of five years and the resistance was then the same as that of an adjacent untreated rod.⁹

METHODS OF APPLYING SOIL TREATMENT

A typical method for installing soil-treating material is to place the chemical in a circular trench around the electrode as shown in Figure 10. This is effective in that it not only prevents direct contact of the chemical with the electrode, but also the materials are advantageously placed so that the solution spreads through and affects a greater volume of soil than when placed directly around the electrode.

Certain chemicals, such as common salt, calcium chloride, copper sulphate, and iron sulphate when placed in direct contact with electrodes and in the presence of moisture, tend to cause corrosion of the electrode. However, by placing them in a trench as shown, they do not come into direct contact with the electrode. As the crystals are gradually dissolved by rainfall, the solution permeates through the soil to the electrode and since the solution is relatively weak compared to the concentrated chemical, the corrosive action is minimized.

Another method of treating which has been used is to place the chemical in a tile pipe 16 to 18 inches long alongside the electrode as shown in Figure 11A. This method is convenient where space is restricted. It is also effective in preventing direct contact of the treating material with the electrode. However, with this method,

Table II. Low Resistances Obtained With Deep-Driven Grounds

Description of Soil	Length of Sectional Rod, Ft	Ground Resistance Measured at Various Depths When Installing Rod									Remarks
		8 Ft	16 Ft	24 Ft	32 Ft	40 Ft	48 Ft	56 Ft	64 Ft		
Clay.....	64	29	14	8	4.5	3	3	3	3		
Clay.....	48	270	230	48	13	10	6				
Clay.....	32	140	45	15	5.5						
Clay.....	40	75	45	21	8	4					
Clay.....	48	50	23	18	8.5	5.5	2.5				
Sand and clay.....	32	200	22	11	9					Struck pard laver, 28 feet	
Clay.....	32	45	30	9	2					Struck stone at 24 feet	
Sand.....	40	200	55	40	33	16				Salted ground	

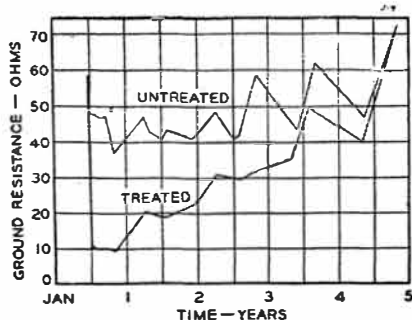


Figure 9. Variation of resistance to ground with time for adjacent electrodes

the chemical is more concentrated and at least, initially, is not so effective as the trench method.

A third method which has been used is to place the chemical in a basin directly around the electrode as shown in Figure 11B. The objection to this method insofar as corrosive chemicals are concerned has been mentioned previously. Where chemicals have relatively little or no corrosive effect on the electrode, such as when magnesium sulphate is used, the basin method is applicable.

In using any of these methods, it is advisable, particularly during dry periods, to flood the ground thoroughly with water after installing the chemical, so that the solution immediately will start penetrating into the soil. Otherwise, some time may elapse before sufficient solution resulting from normal precipitation permeates through the soil to lower the resistance of the ground.

MULTIPLE RODS AND SOIL TREATMENT

In cases where it is necessary to overcome exceedingly high ground resistances, a combination of multiple electrodes and chemical treatment of the soil is often very effective.

DEEP-DRIVEN GROUNDS

Where a single electrode of ordinary length has an extremely high resistance, the use of deep-driven grounds is often helpful in obtaining lower ground resistances. For example, Figure 12 illustrates graphically the relation between the character of the soil and the resistance at one ground installation. In this case, a ten-foot rod driven

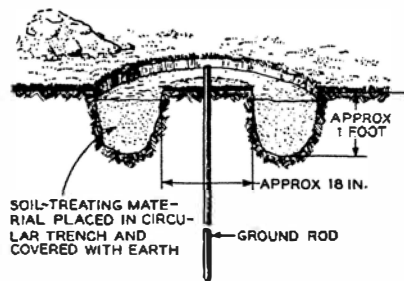
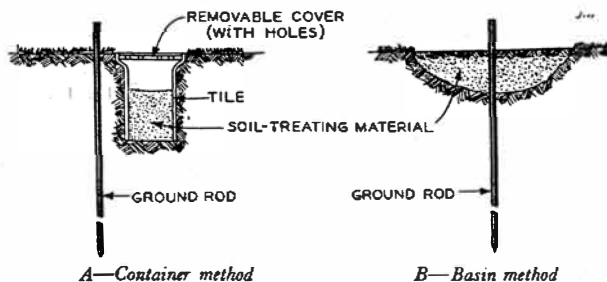


Figure 10. Trench method of soil treatment

Figure 11. Container and basin methods of soil treatment



in sandy soil had a resistance of 250 ohms. It would have taken something over five ten-foot rods in multiple to approach a 50-ohm ground. However, by extending the ground rod through the sand, it was found that the resistance decreased substantially at about 15 feet depth, and a value of 50 ohms was obtained with a single 20-foot rod. This is a typical example of where deep-driven grounds can be helpful and economical.

For grounds requiring electrodes from 15 to 20 feet in length, it is possible to use rods of a single continuous length. However, the handling and driving of long rods is somewhat of a problem and sectional rods provide a convenient and practical method for installing deep grounds.

One type of sectional rod is made in sections eight or ten feet long of various diameters and with threads at both ends. In practice, the first section is driven using a coupling and a driving bolt at the top end. When this is driven to the ground line, a second section is coupled to the first and the driving continued. In this way, long rods are handled nearly as easily as ordinary-length rods.

Table II shows some typical resistance readings obtained with sectional rods and illustrates good applications for deep-driven grounds. In the second example, for instance, a 16-foot rod had a resistance of 230 ohms. By extending the depth to 24 feet, the resistance dropped to 48 ohms, indicating that the rod had penetrated into the lower resistivity soil. With a 48 foot-rod the resistance of the ground was reduced to six ohms.

A typical example of the use of deep grounds is cited by one power company which uses sectional rods in lengths up to 100 feet for improving the resistances of transmission-tower grounds. These have

been effective in reducing the resistance to the order of five to seven ohms per structure.¹⁰

BURIED PLATES

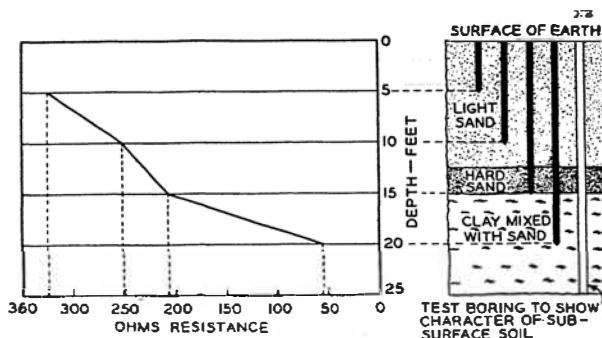
The use of buried metal plates as a means of grounding electric systems has been confined largely to station grounds. However, the use of this type of ground connection appears to be decreasing which is probably due to the fact that the desired results can be obtained with other methods and with much less expense. As there are cases where plates are used, a brief discussion of their electrical characteristics may be of interest.

The same general principles as already discussed for driven grounds apply to plate grounds. Apparently the preferred practice is to bury plates on edge, since less excavation is required than when buried horizontally. Also when backfilling, it is possible to obtain more satisfactory contact with the soil as the earth can be packed firmly on both sides of the plate. Insofar as electrical performance is concerned there appears to be little difference between the resistance of a plate when buried on edge or when laid horizontally.

VARIATION OF RESISTANCE WITH DEPTH

The curve showing variation of resistance with depth of a plate electrode is similar to the curve for the resistance of two driven electrodes in multiple. (See Figure 5.) Assuming uniform soil resistivity, the resistance decreases rapidly with the first few feet increase in depth and then more slowly, approaching a relatively constant value. Consequently, for plates of ordinary size—that is, of areas say from 10 to 20 square feet—the depth in conducting soil should be from five to eight feet since greater depths would

Figure 12. Deep grounds effective in lowering resistance



normally not show any appreciable decrease in resistance.

VARIATION OF RESISTANCE WITH AREA OF PLATE

The resistance of a plate ground is dependent upon the area of the plate, or more correctly stated, on the extent or over-all dimensions of the plate, since the volume of affected soil is the actual determining factor. The variation of resistance with the size of plate is illustrated in Figure 13. This curve is calculated for a circular plate assuming uniform soil resistivity.⁴ It will be noted that quadrupling the area of such a plate approximately halves the resistance. This same relation holds approximately true for rectangular shape plates, although because of the nonhomogeneity of the soil, this should be taken only as an indication of the relationship mentioned and not as a check upon it. This curve also shows that increasing the area of a plate beyond 25 to 30 square feet does not result in an appreciable decrease in resistance. Consequently, where plate electrodes must be used, it would require much less labor and material to install two small plates at a distance from each other and connect them in multiple than to install one equivalent large plate.

BURIED STRIPS

Where bedrock is near the surface of the ground, it is frequently out of the question to drive electrodes or to dig deep enough to make an effective ground connection with plates. In such places, the ground is apt to be very dry, particularly during periods of drought, as the soil is not deep enough to permit the storage of moisture during wet seasons. The best procedure under such circumstances is to make a ground connection by burying narrow strips of metal, solid wire, or cable in trenches dug as deep as the rock layer will permit. Because of the high resistivity of the soil which is encountered in dry seasons, it is necessary to have a ground connection of considerable extent, and metal in the form of strips, wires or cables, offers the most efficient method.

VARIATION OF RESISTANCE WITH LENGTH

That an extensive length of metal is required for obtaining a ground connection with low resistance may be seen from the curve shown in Figure 14. This is a theoretical curve based on uniform soil resistivity.⁴ Actual measurements which have been made are substantially in agreement with this curve allowing for inconsistencies in the resistivity of the soil existing at the particular location.

It appears from this curve that if the length of the strip is doubled, the resistance is approximately halved. This ratio assumes strips buried in a straight line. If the strips are curved or coiled, the resistance would tend to be higher as the affected soil would be less. With long leads, reactance is also a particularly im-

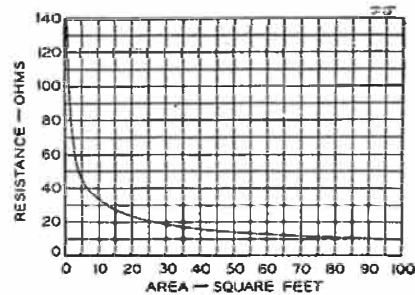


Figure 13. Variation of resistance of a circular plate with area, assuming uniform soil resistivity

portant factor when dealing with lightning. Consequently, the use of a number of strips in parallel, but well spaced from each other, is usually preferable to one extra-long strip.

VARIATION OF RESISTANCE WITH DEPTH

Where bedrock exists near the surface of the ground, the depth at which the strip of metal can be buried is necessarily limited. However, where this is not the case and this type of ground is indicated, the relation between depth and resistance may be of interest. Tests by the Bureau of Standards show that the decrease in resistance for a variation in depth between the minimum permissible on account of cultivation—about 18 inches—and the maximum to which it would be practicable to bury an electrode—say three feet—is only about five per cent assuming uniform soil resistivity. Also, the effect of conductor size is extremely small within the range normally used for this purpose.⁴

GRIDS

Grid systems consisting of copper cables buried about six inches in the ground and forming a network of squares are sometimes used at generating plants or substations. The purpose of this grid is to provide equipotential areas throughout the entire station plot, thus avoiding any gaps where differences in potential would be hazardous to life and property.

Such a system usually extends over the entire station yard as well as some distance beyond the fence which surrounds the buildings and equipment. The spacings of the conductors, and therefore the size of the squares, will vary with the different installations. However, cable spacings of 10 to 12 feet have been used at some locations. All crossing points of the cables should be securely bonded together and the entire grid system tied in with the station ground. Also, all structural steel work and equipment are tied in with this network to prevent any differences in potential between these and the ground.

Protective systems of this type, as well as low-resistance grounds, are effective at stations because of the potential gradient which might otherwise result from high fault currents. The cost of installing such

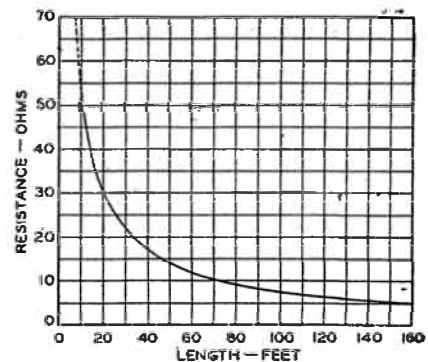


Figure 14. Variation in resistance of a strip electrode with length, assuming uniform soil resistivity

a grid system may be rather high because of the amount of labor involved, but the hazards to life and value of the property involved may justify such installations.

COUNTERPOISE

The counterpoise is used extensively in the United States for improving the lightning protection afforded by overhead ground wires on high-voltage transmission lines. This is an application of the buried-strip type of electrode, although round solid wires or stranded cables are generally used rather than strips.

Its usual application is in districts having high-resistance soils, such as sand or rock formation where a supplementary grounding system may be required. It is beneficial in reducing the impedance of the ground connection and in increasing the capacitance coupling with the conductors. It makes use of the widely distributed contact to the soil similar to a number of ground rods in parallel.

Two different arrangements of counterpoise wires have been employed, the continuous type and the radial type. The continuous counterpoise consists of a conductor or conductors buried under the transmission line from end to end of the line or at certain sections of the line and interconnected with the ground wire at all supporting structures. A method commonly used for installing such a counterpoise is by means of a cable-laying plow which places the wire in the ground at various depths down to as low as three feet beneath the surface.

The radial type of counterpoise consists of a number of wires extending radially from the grounding point. The number and length of the radial counterpoise wires will depend on the requirements at the particular location. Soil conditions, the importance of the line, and installation costs must all be considered in determining the extent of counterpoise installations.

Soil conditions along a transmission right of way may vary widely and one particular method of grounding may not be suitable for the entire line. A practical procedure is to make tests at each location

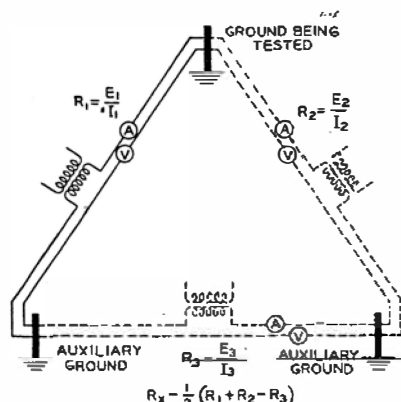


Figure 15. Connections for three-point method of measuring ground resistance, using a-c ammeter and voltmeter

along the line and with the aid of the resistance data obtained, grounding methods can be selected which best suit the requirements. With this plan, low resistances can be obtained at the least cost.

METHODS OF MEASURING RESISTANCE OF GROUND CONNECTIONS

The proper operation of ground connections, like other electric equipment, is dependent largely on well planned testing and maintenance. The resistance of a ground connection should be measured at the time of installation and this should be followed by check tests at regular intervals. Usually precision in such measurement is not required, as it is necessary to know only whether the resistance is of the order of 1 ohm, 10 ohms, 100 ohms, or 1,000 ohms. These values are indicative of whether the ground is satisfactory for the particular installation or whether improvement is necessary.

There are various methods for testing the resistance to earth of installed ground connections. They are similar in that two independent auxiliary electrodes are used in addition to the one under test. These auxiliary electrodes should be placed at a distance remote enough from the ground under observation and from each other so that each ground is independent of any proximity effect of the other two grounds.¹¹

The principles used in the measurement of ground resistances are essentially the same as those used for measuring other types of electrical resistances. However, for purposes of discussion, the various methods for measuring ground resistance have been grouped into three general classes which are described herewith.

THREE-POINT METHOD

With the commonly known three-point method, the resistances of the electrode under test and the auxiliary electrodes are measured two at a time in series. A voltmeter and an ammeter are used for making the measurements. Either alternating current of commercial frequency or direct current supplied from an available circuit

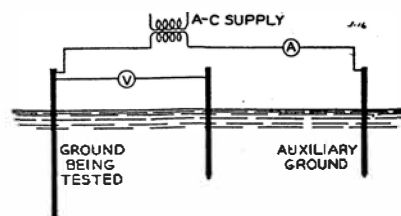


Figure 16. Connections for fall-of-potential method of measuring ground resistance

or from a storage battery may be used. The diagram of connections shown in Figure 15 is applicable when using alternating current. The connections for direct current are similar, but certain precautions as explained later are required. After the three series measurements are made, the unknown resistance is solved by means of the formula

$$R_x = \frac{1}{2}(R_1 + R_2 - R_3)$$

A Wheatstone bridge operating on alternating current at 1,000 cycles per second and with a headphone as a detector to determine the point of balance is also applicable with the three-point method. Another method would be to use a direct-reading self-contained ohmmeter.

To obtain a fair degree of accuracy with the three-point method, the resistances of the auxiliary electrodes should be of the same order of magnitude as that of the unknown, otherwise small errors in the individual measurements may result in a large error in the computed resistance.

Stray direct currents have little or no effect on the readings when using alternating current. However, if stray alternating current of the same frequency as the test current is present, this may introduce an error.

When direct current is used for measurement purposes, the effect of stray alternating currents is eliminated and the effect of stray direct currents can be minimized by reversing the test current. Polarization is also a factor when direct current is used and the formation of gas at the electrodes may give a false indication. Taking two readings by reversing the current polarity helps to correct this condition. The current should be applied for short periods only, or just long enough to obtain the readings.

FALL-OF-POTENTIAL METHOD

Another method for measuring ground resistance is based on the fall-of-potential principle. This involves the passing of a known current through the electrode under observation and one of the auxiliary electrodes. The drop in potential between the former and the second auxiliary electrode is then measured and the ratio of this voltage drop to the known current will indicate the resistance to ground. The diagram of connections for this method using alternating current for test is shown in Figure 16. By using a voltage measuring

device which has a high impedance, the resistance of the potential electrode will have no appreciable effect on the accuracy of the measurements. The determination of ground resistance by this method may be made with an ammeter and voltmeter or with self-contained instruments which are based on this principle and furnish direct readings of resistance.

RATIO METHOD

In a third method for measuring ground resistances, known as the ratio method, the series resistance of the electrode being tested and an auxiliary electrode is determined by means of a Wheatstone bridge. A slide-wire potentiometer is shunted across these two ground connections and the detector is connected between the sliding contact and the second auxiliary electrode. In this way, the ratio of the unknown resistance to the total resistance of the two electrodes in series is obtained, and the required value is determined by multiplying this ratio by the series resistance obtained in the first measurement.

Measurements by this method may be made by using a bridge and a calibrated slide-wire potentiometer for obtaining the ratio, or by self-contained instruments which give direct readings.

PORTABLE GROUND-TESTING INSTRUMENTS

A portable ground-testing instrument provides the most convenient and satisfactory means for measuring the resistances of grounds. It is self-contained, easy to operate, and the resistance is indicated directly on a dial located on the panel of the instrument. The measurement is made with one setup and when desired the whole operation can be handled by one man. When any program of ground testing is planned, the use of one or more of these instruments is recommended, as the convenience and saving in labor will more than justify their cost.

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