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Examination of Distribution Grounding Electrode Configurations for Optimal Lightning Performance

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PRODUCT DESCRIPTION

Ground rods are the most common grounding electrode found on distribution circuits. Driving ground rods often requires a mark-out survey to ensure that the driven rods will not contact existing underground infrastructure such as gas, sewer, or electric lines. Waiting for a mark-out survey can delay work progress, sometimes by days. It also can be difficult to find suitable placement options for ground rods due to existing underground utilities. Maintaining adequate minimum rod spacing can be challenging when installing multiple ground rods at a single pole location. This is especially true when adding additional ground rods for new electronic equipment on existing poles in urban locations.

To simplify ground rod installation, many utilities would prefer to install a single long ground rod rather than multiple shorter rods. This brings up the question of how effectively one long ground rod discharges lightning surge current compared to a multiple ground rod array. The answer is complicated by several aspects such as local soil characteristics and the exact ground rod configurations in question.

Results & Findings

This work focuses specifically on ground rod electrodes. Different ground rod configurations exhibit different dynamic ground resistances while discharging lightning surge current. While it is desirable to use the configuration that offers the lowest dynamic resistance, it is not simply a matter of picking one configuration and using it in every situation. While one configuration may offer the lowest stabilized dynamic resistance, another configuration may show a quicker drop in dynamic resistance even though its stabilized dynamic resistance is somewhat higher. Furthermore, local conditions (for example, soil layers and lack of space for electrodes) often mean that some electrode configurations are not suitable for use. This report facilitates good grounding engineering practice and shows utility engineers how to make effective choices in grounding design. In particular, information in this report can help utilities decide whether to “go deep” or “go wide” based on site characteristics for any specific grounding location on their distribution system.

Challenges & Objective(s)

Most discussions of distribution system grounding deal with ground electrode performance at 60-Hz and ignore the dynamic ground resistance of different electrodes when discharging high-frequency lightning surge currents. However, there are often significant differences in ground resistance when considering the 60-Hz case versus the high-frequency and high-current case. Furthermore, there are several numerical models available to describe and predict ground electrode performance during lightning events, many of which make use of rather complex mathematics. What this means is that even though there has been much written on distribution system grounding, much of what has been written is rather confusing and often is not applicable to lightning surge events.

This report remedies the situation by providing a clear-cut discussion of ground rod electrode performance, including soil and installation factors with the greatest influence on performance. Furthermore, EPRI’s Grounding Guide Software (EGGS) is used to examine lightning current dissipation characteristics of several common ground rod configurations over a range of soil resistivities.

Applications, Values & Use

This report facilitates good grounding engineering practice and shows utility engineers how to make effective choices in grounding design.

EPRI Perspective

EPRI has been involved in improving analysis and design of grounding systems for more than 20 years. EPRI grounding research spans many areas of the power system including substations, transmission lines, and distribution systems. This project takes advantage of continuous improvements in modeling and experimental data of grounding systems and maintains a focus on making these technologies easier to understand and implement.

Approach

At the core of this work is an attempt to answer the question of what practical configurations of ground rods are best suited for discharging lightning current on electric distribution circuits. EGGS is used to investigate the dynamic ground resistance of several common ground rod configurations when discharging lightning current. Other aspects related to good grounding techniques also are examined such as ground rod installation considerations and soil parameters affecting grounding performance.

Keywords

Grounding
Distribution lines
Dynamic ground resistance
Surge impedance
Ground rod

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1

INTRODUCTION

Since the earliest days of electric distribution systems, one of the major concerns for electric utility engineers has been how to properly and safely ground equipment. This problem exists in all fields of electrical engineering from low current grounding of solid state equipment to high current grounding of large power systems. The proliferation of sensitive electronic loads on power distribution circuits serves to reinforce the need for good grounding.

Ground rods are the most common grounding electrode found on distribution circuits. Driving ground rods often requires a mark-out survey to be performed to ensure that the driven rods will not contact existing underground infrastructure such as gas, sewer, or electric lines. Waiting for a mark-out survey can delay work progress, sometimes by days. It can also be difficult to find suitable placement options for ground rods due to existing underground utilities. Maintaining adequate minimum rod spacing can be challenging when installing multiple ground rods at a single pole location. This is especially true when adding additional ground rods for new electronic equipment placed on existing poles in urban locations.

To simplify ground rod installation, many utilities would prefer to install a single long ground rod rather than multiple shorter rods. This brings up the question of how effectively one long ground rod discharges lightning surge current compared to a multiple ground rod array. The answer is complicated by several factors such as local soil characteristics and the exact ground rod configurations in question. This report provides the background information necessary to assess grounding installations based on their individual characteristics. Additional information is provided by modeling analysis of several common ground rod configurations. The goal of this work is to help utility engineers choose the most effective grounding configuration for discharging lightning current for each unique grounding situation on their distribution system.

2
SOIL RESISTIVITY

Soil resistivity is an expression of electrical conduction in the soil with units given in ohm-meters. Soil resistivity has a significant impact on grounding system performance since the resistance to earth of a ground electrode is directly proportional to the resistivity of the soil that surrounds the electrode. Higher soil resistivity results in higher grounding resistance both at the power frequency and during high frequency transient events.

Resistivity of Common Soils

Soil resistivity varies considerably by soil type. Typical resistivity ranges are shown for several common soil types in Table 2-1.

Table 2-1
Typical Values of Low-Frequency Resistivity for Common Soils

Type of Soil	Resistivity Range (-m)	Average Resistivity (-m)
Loams, Garden Soils, etc.	5-50	30
Clays	2-200	40
Sands and Gravel	60-100	80
Clay, Sand, Gravel Mixture	40-250	100
Slate, Shale, Sandstone, etc.	10-500	250
Crystalline Rocks	200-10,000	2,000

Sources: (Tagg 1964; Gustafson, Pursley et al. 1990; EPRI 1013594 2006)

Soil can rarely be considered homogenous in practical distribution grounding applications. Local geology dictates the variability of soil resistivity along a distribution right-of-way. Depending on the location, soil characteristics can remain consistent for 20+ miles or can exhibit significant variations in less than 1 mile. Geological features cause soil to vary from location to location. Variations in the height of the local water table can create significant changes in soil resistivity as a function of depth.

Parameters Affecting Soil Resistivity

Soil conduction is chiefly electrolytic in nature in the upper layers in which ground rods are driven. All soils contain some level of moisture and this moisture combines with salts in the soil to form an electrolyte that is the basis the electrolytic conduction. There are a number of soil parameters that effect electrolytic conduction within soil and thus impact soil resistivity. Some of these parameters are relatively constant while others fluctuate seasonally or with precipitation.

Moisture Content

Moisture content is one of the most significant factors impacting soil resistivity since the amount of moisture influences the amount of electrolyte in the soil. Increases in soil moisture, and hence increases in the quantity of electrolyte, correlate to decreases in soil resistivity. Soil moisture levels are often expressed in percent weight of the soil and typically range from a low of 5% in desert regions to a high of roughly 80% in swampy regions. As indicated in Figure 2-1, soil resistivity tends to increase rapidly as moisture levels fall below approximately 15% (EPRI TR-106661 1996). Conversely, increasing moisture beyond 22% results in only small decreases in resistivity as the soil reaches saturation.

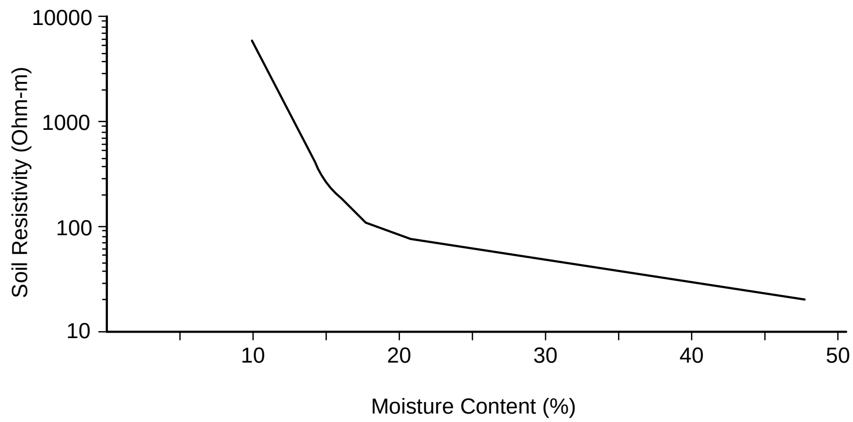

Figure 2-1
Variation of Soil Resistivity with Moisture Content (EPRI TR-106661 1996)

Figure 2-1 is a general description of the relationship between soil moisture and resistivity. In reality, each soil type will exhibit different moisture-resistivity relationships.

Average soil moisture data is often available on a state or regional basis from state agricultural agencies. Short-term and long-term soil moisture data is also available from the National Oceanic and Atmospheric Administration[1] (NOAA) and the U.S. Geological Survey[2] (USGS). It is important to remember that soil moisture varies with depth and over-ground distance and can be different from one pole location to the next. Soil moisture also varies seasonally and with precipitation, especially in the uppermost soil layer.

Dissolved Salts

Dissolved salts play a significant role in determining soil resistivity since they are a primary component in the electrolyte solution formed in the soil. Both the type and concentration of dissolved salts impact soil resistivity. Common sea salt (sodium chloride) yields a more

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[1] www.noaa.gov
[2] www.usgs.gov

conductive solution than either sodium sulphate or copper sulphate but yields a less conductive solution than sulphuric acid at the same concentration (EPRI 1013594 2006).

Sodium chloride (NaCl) and calcium chloride ($CaCl_2$) are commonly used for de-icing roadways and can be found in high concentrations in the soil alongside roads. Other chemicals such as calcium magnesium acetate (lime and acetic acid) and potassium formate are also finding more common use for roadway de-icing.

Temperature

Soil temperature has little effect on resistivity at temperatures above 32˚F (0˚C) but can have a pronounced effect on resistivity at soil temperatures below the freezing point. Moisture in the soil begins to freeze once the soil temperature drops to 32˚F. As the water in the soil freezes, it restricts ion mobility and thus rapidly increases soil resistivity. Freezing can increase soil resistivity by one to two orders of magnitude.

Although pure water freezes at 32˚F, soil moisture often contains a number of other compounds, including salts, which tend to lower the freezing point a few degrees. For this reason, 32˚F should be viewed as a general freezing point at which soil resistivity begins to increase.

Only the upper layer of soil freezes in most areas. The soil deeper down is better insulated from fluctuations in air temperature and tends to stay at a constant yearly temperature. In regions that experience freezing of the upper soil layer it is important to use ground electrodes that extend below the frostline to contact soil that remains unfrozen year round. Gustafson, et al. undertook a 16-month study of seasonal variations in grounding resistance and reported that freezing of the surface soil greatly increased grounding resistance, especially in two-layer soil where the top layer is more conductive than the bottom layer (Gustafson, Pursley et al. 1990).

Physical Soil Characteristics

Grain size, distribution, and packing vary among different types of soil and influence the soil resistivity. Soils with larger, less tightly packed grains, such as sandy soil, tend to exhibit larger variations in resistivity as moisture content changes. Conversely, small grained soils with tight grain packing show much less resistivity variation with changes in soil moisture.

Seasonal Variations

Precipitation, ambient temperature, and humidity often exhibit seasonal changes so it is not surprising that soil resistivity also shows seasonal variations. Soil resistivity is lowest during the wettest parts of the year and highest during the dry parts of the year. Larger variations in seasonal precipitation and ambient temperature lead to larger variations in soil resistivity and resistivity changes by a factor of 10 are not uncommon. The upper layer of soil is most vulnerable to resistivity changes as it experiences the largest swings in temperature cycles (freeze/thaw) and moisture content.

Multi-Layer Soil

Actual soil conditions are often a mix of horizontal and vertical soil layers with each layer having different resistivity characteristics. Horizontal resistivity layers can be the result of differences in moisture levels and soil temperature and are also caused by variations in rock formations. Even relatively uniform soil often exhibits some layering due to surface evaporation and freezing of the uppermost soil layer. The water table can also add a layer of distinctly lower resistivity.

Vertical layers can occur due to changes in the depth of the overburden over a rock layer. Vertical layers are primarily responsible for significant resistivity changes over short distances of a few pole spans.

Soil Resistivity Measurements

In reality, soil resistivity varies both horizontally and vertically. Therefore, apparent resistivity data for a given location or right-of-way is obtained by testing the soil at several locations and, if possible, to a considerable depth.

There are numerous methods of measuring soil resistivity that fall into several technology classifications:

- *Direct galvanic measurements* – measurements made via an electrode array such as the Wenner, Schlumberger, or Lee array.
- *Resistivity measurements of soil core samples* – core samples are often taken for civil engineering and geotechnical work. Resistivity measurements can be made on the core samples, often with time-domain reflectometry (TDR).
- *Passive electromagnetic methods* – these methods use analysis of the attenuation of electromagnetic signals to make high-frequency soil resistivity measurements. Radio wave attenuation and lightning system observations are two more common electromagnetic soil resistivity measurement techniques.
- *Active induction methods* – these methods use low frequency sine wave frequencies to characterize soil resistivity.

The Wenner four-electrode method (direct galvanic measurement) is the most common of these methods and will be examined a bit more closely. The other methods listed above are used to varying degrees dictated by the level of detail required and amount of soil to be surveyed. A detailed discussion of these measurement methods can be found in (EPRI 1013594 2006).

The following sections provide an overview of two of the most common methods for measuring ground resistivity in the field. While these measurements are not difficult to make, they do require some skill in acquiring good data and interpreting the results. Most manufacturers of “ground testers,” as they are common referred to, offer a substantial amount of literature on performing these tests. For both safety and data accuracy reasons, the reader is encouraged to familiarize themselves with the manufacturer’s literature before performing the tests discussed below.

Wenner Four-Electrode Method

The Wenner method, sometimes referred to as the four-pin method, is one of the most widely used method to measure the resistivity of a large volume of undisturbed earth. The methods consists of driving four short pins (P_1, P_2, C_1, C_2) at a shallow depth (D) in a straight line and at equal intervals (A) as shown in Figure 2-2. A test current (I) is passed between the two outer pins and the resulting voltage (V) is measured between the inner two pins. The measurement instrument measures the resistance of the cylindrical soil volume enclosed between the two inner pins and determines the soil resistivity.

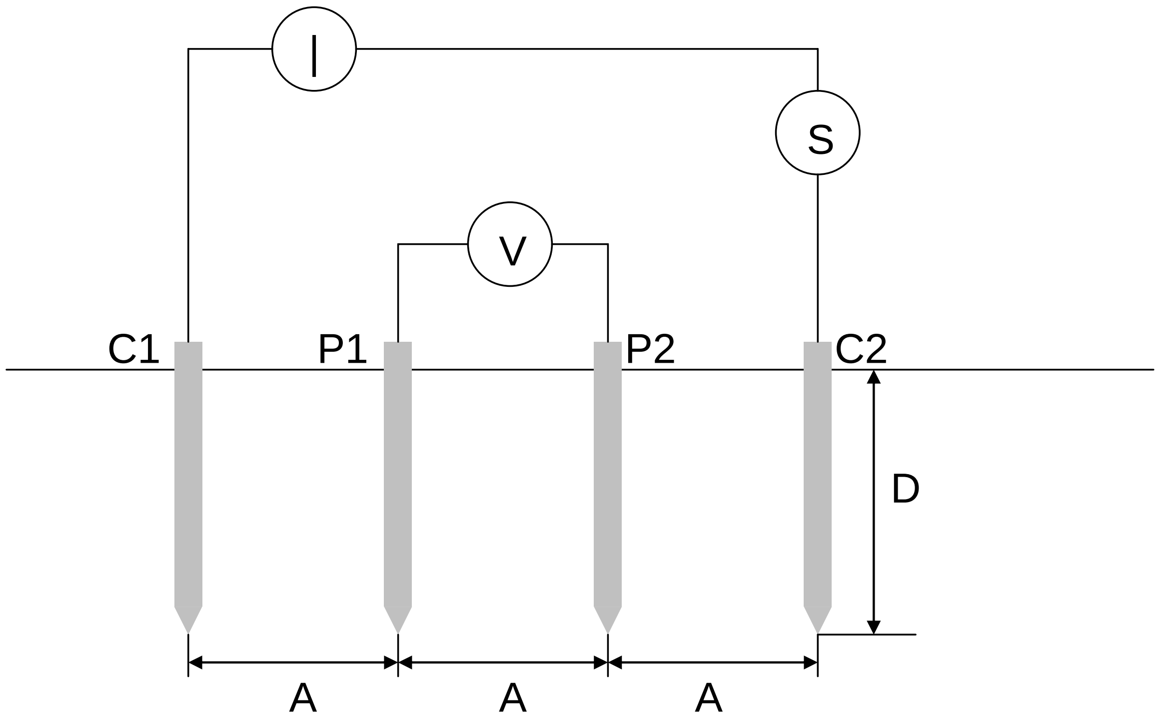


Figure 2-2
Wenner Four-Pin Method for Measuring Soil Resistivity

Three-Electrode Method

The three-electrode method, also called the three-pin method, is another widely used technique for measuring soil resistivity. This method is a special case of the Fall-of-Potential method for measuring ground electrode impedance which is discussed in more detail in Chapter 3.

The three-pin method consists of driving a test rod to a depth (L) and measuring its resistance (R) with respect to a remote ground, with the help of two reference electrodes. The reference electrodes are a current electrode (C2) and a voltage electrode (P2) as shown in Figure 2-3. The reference electrodes are driven to shallow depths and spaced in a straight line. The voltage electrode is placed 62% of the distance from the test rod to the current electrode. It is best to keep distance (D) at least five times the maximum depth of the investigation to minimize inter-electrode interference. Most four-terminal testers can also perform three terminal tests by shorting terminals P_1 and C_1 together at the tester and many testers come with provisions for making both four-electrode and three-electrode measurements.

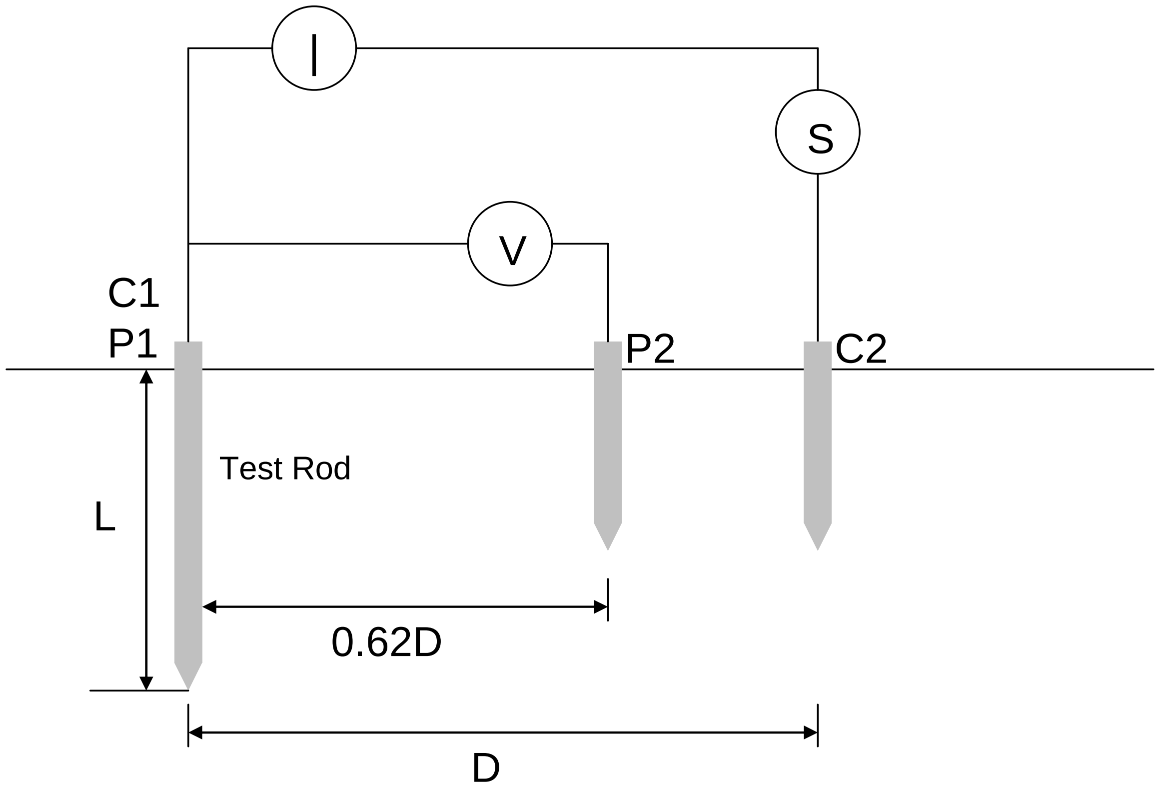


Figure 2-3
Three-Pin Method for Measuring Soil Resistivity

3 GROUND ELECTRODE CHARACTERISTICS

Ground electrodes are buried conductors used to create an efficient conduction pathway between the electrical system and the earth. Ground rods and butt wraps (also called wire wraps) are the two most common grounding electrodes employed in distribution systems. Other grounding devices include plate grounds, concrete-encased electrodes, chemical grounds, and backfills. However, these grounds are much less common and rarely, if ever, used to ground poles carrying sensitive electronic equipment. Therefore, this investigation will focus on the use of ground rods and butt wraps.

Ground Rods and Butt Wrap Electrodes

Ground rods are usually copper-clad steel, although bare steel and stainless steel are also sometimes used, and come in standard diameters of 1/2, 5/8, and 3/4 inches and standard lengths of 5, 8, and 10 feet. Longer length rods are available but typically two or more rods will be connected together to form long electrodes as needed rather than using a single long rod. This approach allows for more versatility in the field and easier transportation of ground rods. Ground rods are coupled with threaded or threadless couplers or welded connections.

Butt wrap electrodes are formed by wrapping copper conductor around the bottom of the utility pole before it is placed in the pole hole. The main advantage of the butt wrap electrode is that it is easy to install. However, butt wrap electrodes offer relatively high resistance to remote earth and many utilities are phasing out their usage.

Ground Electrode Behavior during Lightning Events

Ground electrode impedance exhibits a complex relationship with the frequency of the applied voltage. At low frequencies, most grounding electrodes behave as a constant resistance. As the frequency of the applied voltage increases, the resistance of the ground electrode varies. During a lightning discharge event (high-frequency), the resistance of the ground electrode changes as a function of the lightning current waveform flowing through the electrode to ground.

When lightning current flows from the grounding electrode into the soil, the current density on the surface of the grounding electrode may be very large, and the electric field on the surface of the conductor may be large enough to ionize the surrounding soil. Soil ionization decreases the impedance of the electrode by effectively increasing the dimensions of the electrode as illustrated in Figure 3-1. For these reasons, the dynamic resistance of a ground rod during a lightning event is often less than the measured value of ground resistance during steady-state conditions (Chisholm and Janischewskyj 1989). Detailed discussion of ground electrode discharge theory and dynamic resistance calculations are beyond the scope of this work and the reader is encouraged to consult work by Mousa and EPRI listed in the references section of this report for further information (Mousa 1994; EPRI 1001908 2002).

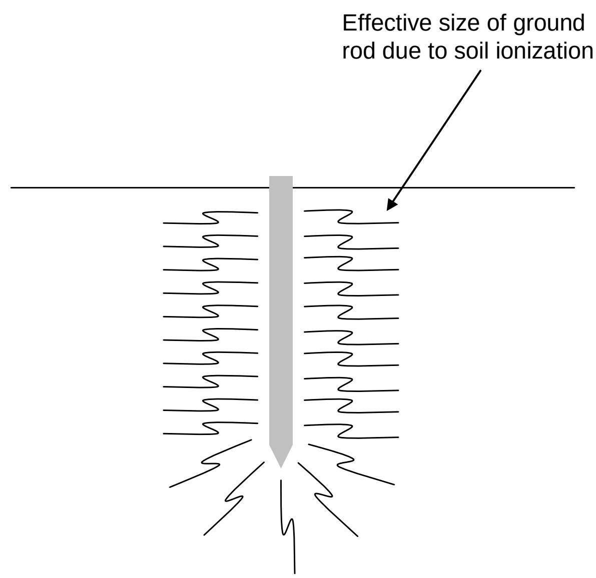


Figure 3-1
Ionization of Soil around a Ground Rod during a Lightning Current Discharge Event

Common Ground Electrode Configurations

There are numerous ground electrode configurations commonly applied in distribution systems that make use of ground rods and butt-wrapped conductors.

- *Single ground rod outside of the pole hole* – this is the most basic ground rod configuration. A single ground rod is driven, usually within three feet of the pole. Ground rod length is often determined by taking steady-state ground resistance measurements with new sections added until the ground rod reaches a desired resistance target. If the resistance target cannot be met with a reasonable length of ground rod then other configurations must be considered such as using multiple ground rods.

- *Multiple ground rods place in a straight line from the pole* – this configuration uses multiple ground rods placed in a straight line extending out from the pole. Two or three rods are common. The electrodes may be a single eight-foot rod or longer coupled rods and all the electrodes are made the same length. Maintaining minimum electrode spacing is critical as discussed below.

- *Single ground rod placed in the pole hole* – driving ground rods is tedious work and it seems logical to simply put the ground rod in the pole hole and then backfill over it. Unfortunately, this is not a viable solution. Placing the ground rod in the pole hole leads to higher ground resistance due to lack of soil compaction and chemical contamination of the surrounding soil as discussed in the next section on ground rod installation considerations.

- *Butt wrap* – butt wrap electrodes are formed by wrapping a conductor (usually copper) around the bottom of the utility pole before it is placed in the pole hole. Although easy to fit during pole installation, butt wraps often do not provide sufficiently low ground resistance and their use is not recommended (NRECA 1993). Although the National Electric Safety Code (NESC) does permit the use of wire wraps (butt wraps), their use is highly discouraged per Rule 94.4A (ANSI C2-2007 2007):

In areas of very low soil resistivity there are two constructions, described in specifications b and c below [pole-butt plates and wire wraps, respectively] *that may provide effective grounding electrode functions although they are inadequate in most other locations*.

If butt-wrap electrodes are used, the NESC dictates that two butt-wrap electrodes count as one ground in the "four grounds-per-mile" rule (Rule 97C) for multi-grounded distribution systems. Additionally, butt-wrap electrodes can not be the sole grounding electrode at transformer locations.

Ground Rod Installation Considerations

Ground rods should be driven in undisturbed soil. Driving ground rods in undisturbed soil provides maximum contact between the rod and the soil and helps achieve lower grounding resistance.

Do Not Place Ground Rods in the Pole Hole

Poor Contact with Soil

Ground rods do not make good contact with earth when placed in the pole hole and surrounded with backfill. The backfill soil around the rod is not sufficiently compacted and this configuration leads to higher grounding resistance. Placing the ground rod in the pole hole can further reduce contact with earth if the ground rod fits tightly to the non-conductive surface of the wood pole thus reducing the amount of ground rod surface making contact with soil.

Pole movement can, over time, also reduce soil compaction around ground rods placed in the pole hole. Pole movements may eventually lead to small voids in the soil surrounding the ground rod and generally decrease the ground rods ability to discharge lightning surge current into the surrounding soil.

Increased Soil Resistivity

Ground rods placed in the pole hole are impacted by preservatives that can leach out of treated wood poles into the surrounding soil. These chemicals increase the resistivity of the surrounding soil and cause a significant increase in grounding resistance. Ground rods placed in the pole hole are further impacted by wood pole preservative treatments performed over the life of the pole. The best way to avoid this issue is to locate ground rods away from the pole. *Ground rods should be placed a minimum of two feet from the pole* to avoid the effects of wood pole preservatives (NRECA 1993).

Preservative contamination may not be the only mechanism by which the soil immediately surrounding wood poles develops higher resistivity than the soil just a few feet away. Wood poles are hygroscopic in nature and absorb water from the surrounding soil. This water absorption can create a drying effect and increase resistivity of the soil in contact with the pole.

Maintain Sufficient Ground Rod Separation

The ability of ground rods to discharge lightning surge current is hampered when rods are driven too close to one another. The effective dimensions of a ground rod increase when discharging lightning surge current due to soil ionization effects as previously discussed in this chapter. If ground rods are placed too close to one another, their ionization areas will overlap (Figure 3-2) and their total effective area will be reduced.

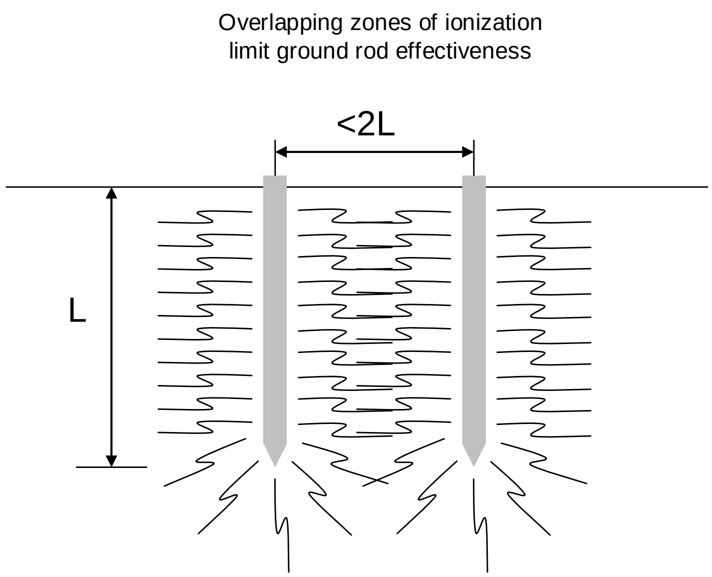


Figure 3-2
Inadequate Ground Rod Spacing for Two or More Rods in Parallel

Maintaining proper ground rod spacing is crucial to avoid overlapping ionization zones and ensuring optimal performance during lightning discharge events. The National Electric Safety Code Rule 94B.2B requires ground rod spacing of at least 6-feet but this is far from optimal for 8 or 10-foot rods. It is better to separate ground rods by a distance equal to twice the ground rod length as shown in Figure 3-3 (NRECA 1993). If separation of twice the length is not possible then maintain as large a separation as possible and at least equal to the ground rod length. Also consider using a single longer ground rod.

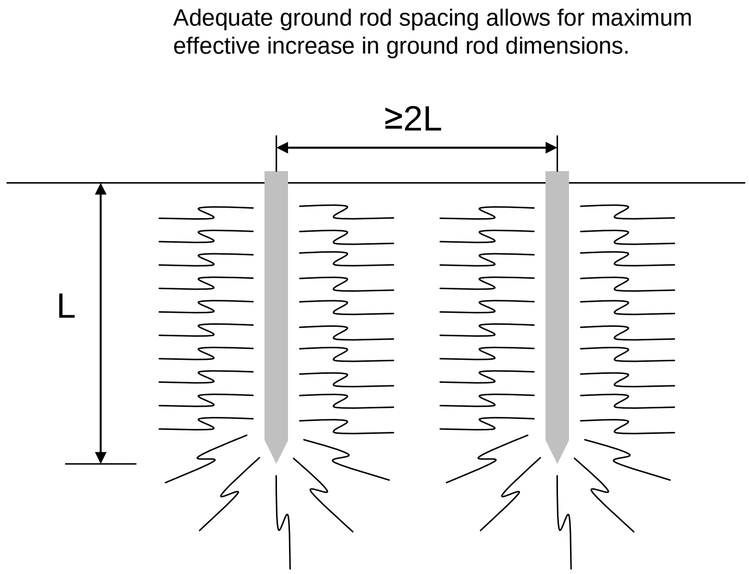


Figure 3-3
Proper Ground Rod Spacing for Two or More Rods in Parallel

Ground Rod Length Considerations

The National Electric Safety Code Rule 94B.2a requires that ground rods be at least 8-feet (2.44 meters) in length (ANSI C2-2007 2007). Many utilities also have specific steady-state ground resistance targets for grounds at different equipment locations. Targets are generally between 10- and 25- depending on the utility and the type of equipment being grounded and it is often necessary to increase ground rod length beyond 8-feet in order to meet the ground resistance target. Another option is to add ground rods in parallel and Chapter 4 contains a detailed discussion of the lightning discharge performance of long grounds rods versus short rods in parallel.

Ground rods longer than 8-feet have several advantages:

- *Lower 60-hertz ground resistance* – as a rule of thumb, doubling the ground rod length lowers the resistance by about 40% (NRECA 1993; EPRI TR-106661 1996).
- *Lower dynamic ground resistance* – increasing ground rod length lowers the dynamic resistance exhibited during lightning current discharge events (EPRI 1006866 2002).
- *Reach the water table* – longer ground rods are more likely to come close to or intercept the water table which can greatly lower steady-state and dynamic ground resistance.
- *Reach below the frost line* – soil resistivity increases dramatically when soil freezes. Longer ground rods are better able to reach beyond the frost line into the temperature stable earth below. Even though 8-foot ground rods may accomplish this task, longer rods place more electrode length below the frost line.
- *Intercept multiple soil layers* – longer ground rods are more likely to intercept multiple soil layers increasing the chances or reaching a lower resistivity layer.

- *Reach more moisture stable layers* – the uppermost soil layer is exposed to the sun and ambient temperature and is therefore more susceptible to swings in moisture content. Reaching the more moisture stable lower soil layers can help reduce seasonal variations in ground resistance.

Grounding Inspections

Proper grounding benefits both the utility and utility customers by helping to reduce lightning-related damage and outages. Maintaining adequate ground connections also helps improve line safety. Grounding resistances are measured during equipment installation to verify that they fall within prescribed limits. It is also necessary to measure grounding resistances later when investigating a variety of issues including lightning outages, poorly performing circuits, and stray voltage complaints.

Be Aware of Underground Lines

Verify that there are not any underground lines at the test location before driving any rods, spikes, electrodes, or other apparatus into the ground. Contacting an underground cable with a ground rod will be problematic at best and could result in serious bodily harm or death. Be aware of any buried infrastructure such as electric, gas, water, or sewer lines. Also be aware of street lighting wires, traffic light cables, cable TV lines, and telephone lines.

Methods for Measuring Ground Resistance

Before measuring the ground resistance, check the following:

- Verify that a ground connection is present at equipment poles such as transformers, capacitors, arresters, etc.
- Verify that any equipment on the pole is bonded appropriately including neutral conductors, guy wires, and line apparatus.

There are several methods for measuring the earthing resistance of utility pole ground systems:

- *Clamp-on Method* – This method uses a clamp-on ground meter to measure electrode resistance to ground and offers the benefit of allowing ground measurements to be made without disconnecting the grounding electrode from the ground system.
- *Fall-of-potential method* – This is a commonly employed method of measuring the earthing resistance of pole grounds. This method is influenced by nearby buried metallic objects so it is not suitable for use near buried utility lines or other buried metallic objects.
- *Two-point method* – The two point method is an alternative to the fall-of-potential method used when there are nearby buried metallic objects or when space limitations or ground cover make the fall-of-potential method unworkable.

Clamp-On Method

Clamp-on ground meters inject a current pulse into the ground conductor and calculate the value of the ground conductor resistance from the current pulse amplitude. Unlike the fall-of-potential and two-point test methods, using a clamp-on ground meter does not require the ground electrode under test to be isolated from the ground system. Another benefit of the clamp-on test method is that it does not require the use of any auxiliary probes or spikes. However, clamp-on ground resistance meters are not suitable for use in single ground systems. The meters function in a manner such that they need a ground connection in front of and behind the meter. For calculation purposes, the meter assumes that the resistance of the multiple adjacent grounds is very small (Parker 2006).

The procedure for making measurements with a clamp-on ground meter is quite simple. Start by inputting the proper meter settings (such as setting the measurement type to ohms). The meter must be placed in the ground path and a few feet up the pole from the ground rod is usually a convenient location. If the ground conductor is inaccessible then the meter can be clamped around the ground rod itself (Dranetz-BMI 2006). Clamp the meter jaws securely around the ground conductor, trigger the unit to take the resistance measurement. The measurement should be recorded in an inspection log along with the inspector's name, location, time, date, and the weather conditions. Since it is much easier than other methods, this method is preferred for regular ground checks.

Fall-of-Potential Method

The fall-of-potential method is sometimes referred to as the two-spike method since it involves driving two auxiliary spikes or probes (A and B) in a straight line with the grounding electrode under test (E); usually the pole ground rod. The test set-up is depicted in Figure 3-4. It is best to place auxiliary probe B as far away from electrode E as possible; usually 60 to 100 feet is sufficient. A four terminal earth tester is used to circulate current in the loop formed by electrode E and auxiliary probe B. The voltage drop between E and probe A is measured. The resistance of the auxiliary probes A and B does not have a direct bearing on the test result (EPRI 1002021 2004).

To accurately measure the resistance, auxiliary probe A is driven in at a number of points roughly on a straight line between the earth electrode and B. Resistance readings are logged for each of the points and a curve of resistance versus distance is drawn. The true earth resistance is read from the curve where it flattens out. Under ideal conditions the generic fall of potential curve will always intersect the "true theoretical resistance" at 61.8% as shown in Figure 3-4 (Megger Limited 2005). This rule is only valid when there is proper spacing between E and B, the probes are laid out in a straight line, and the soil is homogeneous.

Taking numerous readings between points E and B can be time consuming. If time constraints limit the inspection to just a few readings start at 62% of the distance between E and B. Then take two more readings at 52% distance and 72% distance respectively. All three readings should be close to one another indicating that measurements are being made on the flat part of the curve shown in Figure 3-4.

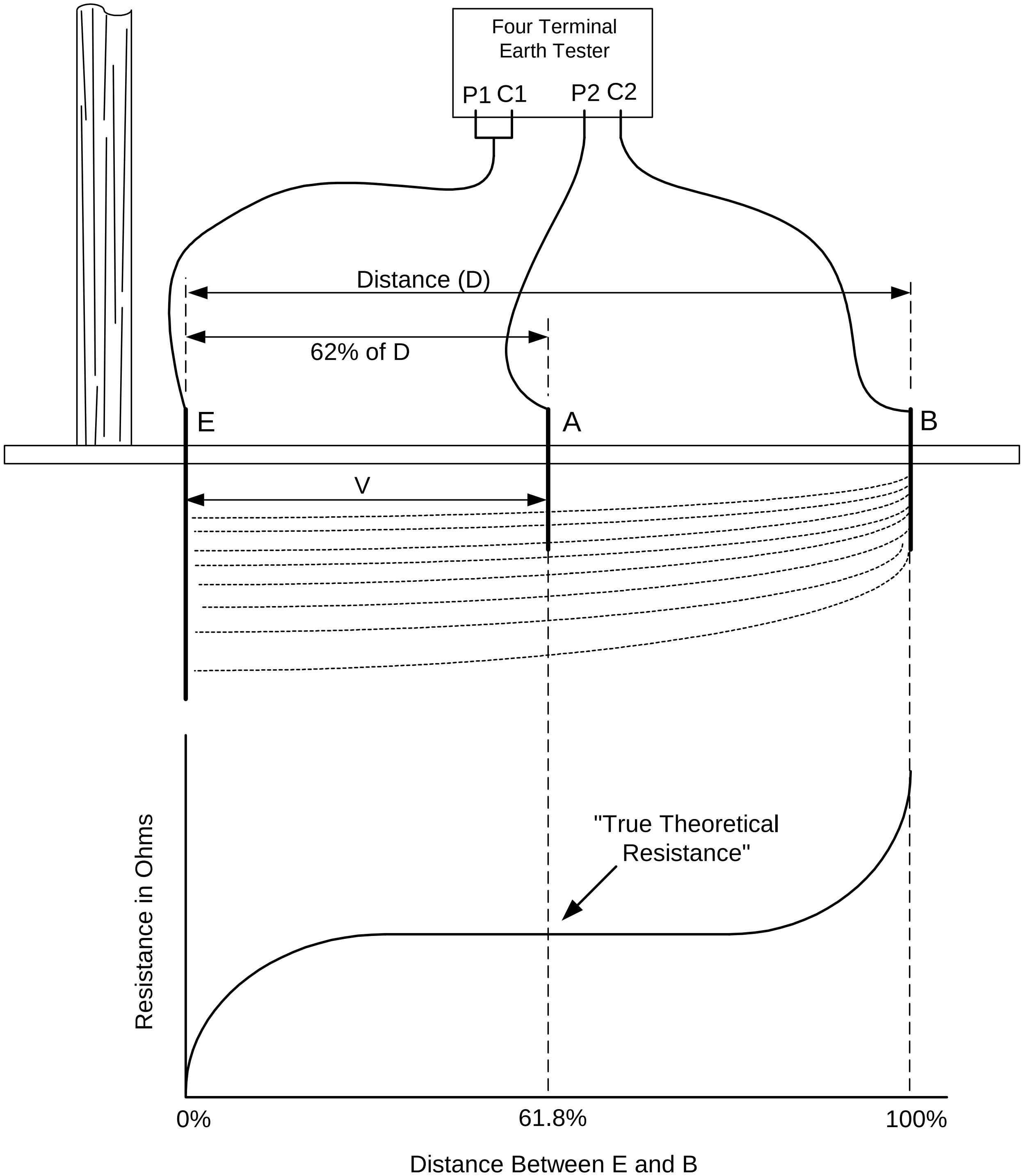


Figure 3-4
Fall-of-Potential Test Method

The test probes should be closer to the grounding electrode than any other external buried structures. If a buried metallic conductor is suspected to be nearby (but not so close as to pose a safety hazard for driving the probes) then moving B farther from E might help reduce errors. A local buried metal conductor could effectively nullify probe A thus making voltage V measured between E and B. If this occurs, the resulting measurement will be falsely elevated and appear to indicate a higher ground resistance than actually exists. Because of this possibility, the two-spike method is often used to verify unexplained high pole ground readings.

Also note that the pole groundwire (and ground electrode) cannot be connected to the ground electrode of adjacent poles; this usually occurs through a connection to the system neutral near the pole top. If electrode E is electrically connected to adjacent pole ground systems then this test will actually be measuring the resistance to earth of not just the local ground electrode but of all the adjacent pole ground electrodes connected by the neutral as well.

Two Point Method

The two point method is used to verify fall-of-potential measurements that may have been corrupted by nearby buried metal objects. With the two point method, a four-terminal earth tester is used in a similar manner to the fall-of-potential method except that now only two separate points are used. Terminals C1 and P1 are jumpered together and connected to the electrode under test (E). Terminals C2 and P2 are also jumpered together, and they are connected to a nearby buried metallic object (O) protruding from the ground as shown in Figure 3-5. Current is passed through the loop formed between the electrode E and the buried metal object O, and the voltage between E and O is measured.

The two point method measures both the resistance of the electrode under test (E) and that of the buried metallic object (O). However, the resistance of O is assumed to be small enough that it does not appreciably affect the measurement and the result is presumed to be the resistance of E (Energy Australia 2005).

As with the fall-of-potential method, the electrode under test (E) cannot be connected to the ground electrode of adjacent poles; this usually occurs through a connection to the system neutral near the pole top. If the electrode E is electrically connected to adjacent pole ground systems then this test will actually be measuring the resistance to earth of not just the local ground electrode but of all the adjacent pole ground electrodes connected by the neutral as well.

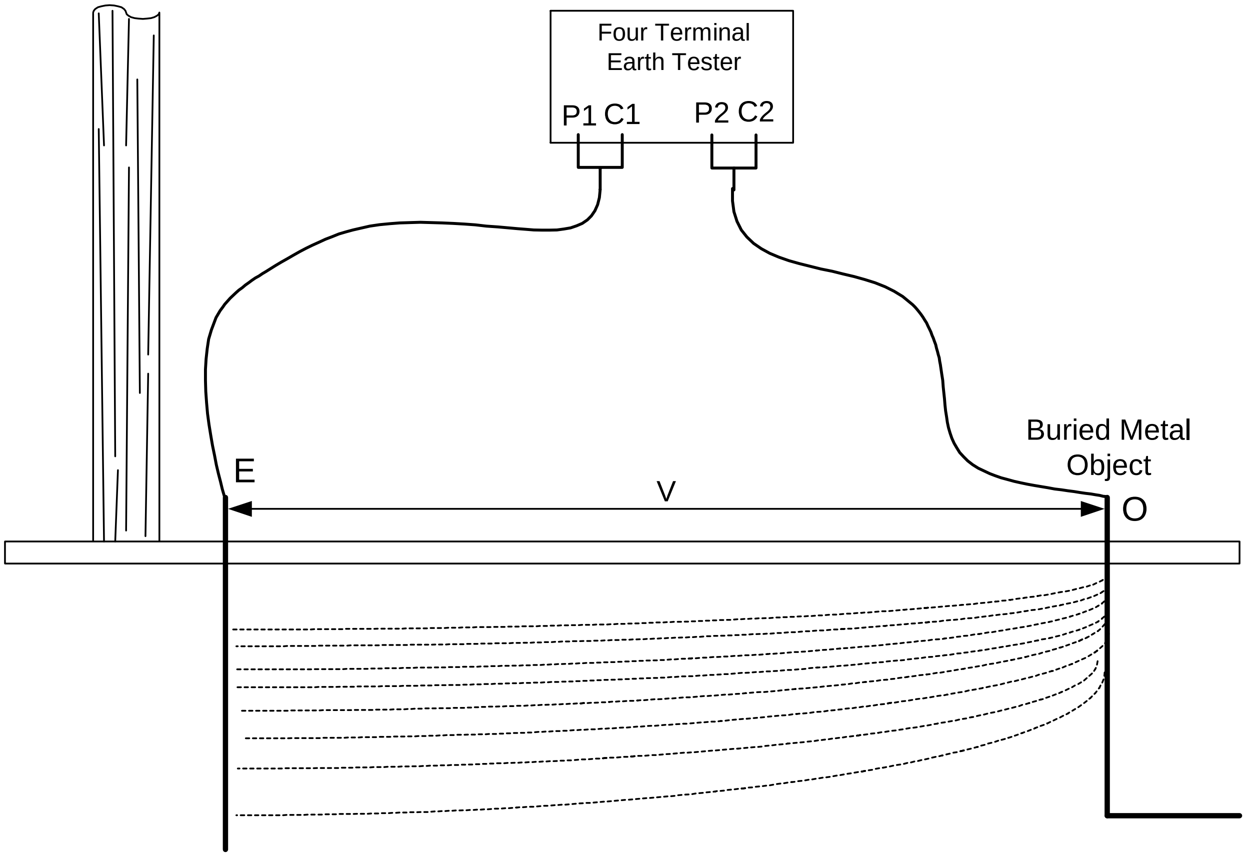


Figure 3-5
Two Point Test Method

Ground Inspection Forms

Figure 3-6 provides an example pole ground resistance inspection report. This report form is suitable for use with both fall-of-potential and two point ground resistance measurements. The report form provides space for resistance measurements at thirteen different locations between electrode E and probe B although they don't all have to be used. Additionally, there is a blank graph section for plotting electrode ground resistance versus probe distance for use during detailed inspections. If the fall-of-potential method yields questionable results or is not suitable due to the presence of a buried metallic conductor then this can be indicated on the report along with the details of a two point method ground resistance test.

Pole Ground Resistance Inspection Report

Date & Time: ____________________ Circuit #: ____________________
Technician: ____________________ Pole ID #: ____________________
Location: ____________________

Meter Mfr.: ____________________
Model: ____________________ Ground System Type: ☐ Single Rod Rod Depth:_______ ft
Serial #: ____________________ ☐ Multiple Rod / Grid Longest Diagonal Dimension:_______ ft

Test Conditions
Weather: ____________________
Temp: ____________________

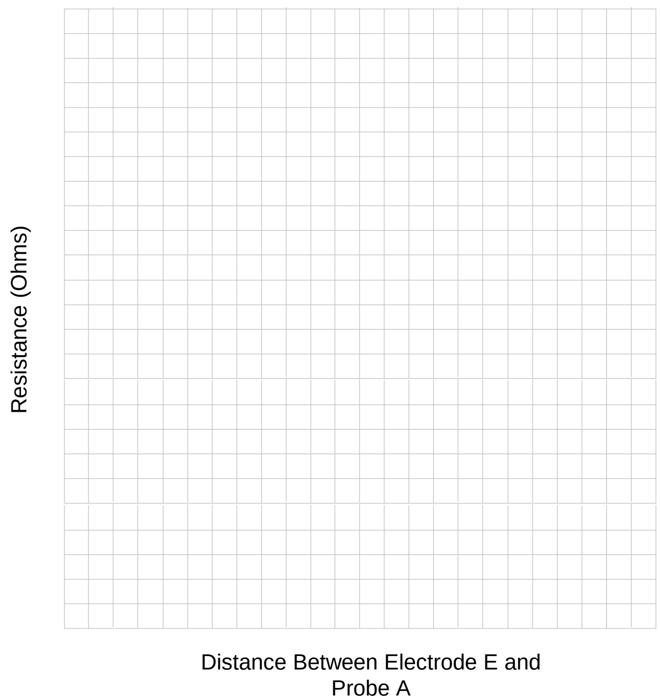
Soil Conditions
☐ Dry ☐ Moist
☐ Loam ☐ Sand / Gravel ☐ Shale ☐ Clay ☐ Limestone ☐ Other:_________

Comments

Fall-of-Potential Measurements

Distance between electrode under test (E) and probe B:_________ft

% of Distance Between E and B	Distance Between E and A (ft)	Measured Resistance (Ohms)



Resistance Scale: ☐ 50 ☐ 100
Multiplier: ☐ x1 ☐ x10

Fall-of-potential method unsuitable ☐
Reason: ☐ Possible buried metallic conductor
☐ Known buried metallic conductor
Distance from Electrode (E):_________ ft

☐ Two point measurement taken, data shown below

Two Point Method
Measurement: [ ] Ohms

Distance between electrode E and buried object O:________ ft
Describe buried metallic object:

Comments

Figure 3-6
Example Pole Ground Inspection Report

4
EPRI GROUNDING GUIDE SOFTWARE (EGGS) MODELING

EPRI's Grounding Guide Software (EGGS) was used to calculate the steady-state ground resistance and dynamic ground resistance for several configurations of ground rod electrodes.

EPRI Grounding Guide Software

The EPRI Transmission Line Grounding Guide Software (EGGS) is a set of tutorial and engineering applications to aid utility engineers in designing transmission line grounding electrodes. The software consists of 10 applets run from a web-page platform to illustrate complex ground electrode behavior and perform the necessary engineering calculations for the design of ground electrodes:

- Estimate of Soil Parameters from Sets of Resistance Measurements
- Ionization Model for Rod Electrodes
- Calculation of Ground Electrode Resistance
- Ionization and Propagation Model for Counterpoise
- Propagation Model for Tower and Ground Plane
- Voltage on Tower Ancillary Circuits during Phase to Ground Faults
- Influence of Ground Electrode on Lightning Performance
- Potential and Step Potential Near a Ground Electrode
- Calculations of Ground Electrode Dimensions to obtain a desired value of Resistance
- World Map of Ground Flash Density and North America Map of Earth Resistivity

Although the software was developed with the transmission engineer in mind, it is also well suited for examining distribution system grounding configurations. The ground electrode modeling performed for this work focused specifically on *Ionization Model for Rod Electrodes* and *Calculation of Ground Electrode Resistance*.

Ionization Model for Rod Electrodes - Applet

This applet calculates the dynamic resistance of ground electrodes when conducting lightning surge currents to earth. When ionization occurs, the resistivity of earth in the region where ionization occurs changes with time and with current. This applet accounts for earth resistivity and ionization and calculates the dynamic resistance, so called because it changes with time as the current varies and may exceed values that cause earth ionization. The effect of earth ionization is very complex and is treated differently by different investigators. This applet compares the results obtained by applying the method developed by Liew-Darveniza with that developed by Korsuncev.

Calculation of Ground Electrode Resistance - Applet

This applet is an engineering tool to calculate the ground resistance of electrodes of any shape in either a homogeneous one-layer or in a two-layer soil. The calculated value is the low-frequency no-ionization resistance.

The geometry of the electrodes and the parameters of the soil must be provided. In the case of a homogeneous soil the soil is characterized by its resistivity. In the case of two layers the soil is characterized by upper layer resistivity, lower layer resistivity, and upper layer depth. For a few typical electrodes, algorithms were derived from the technical literature. The applet also provides the tools for entering the relevant data and calculating the ground resistance of complex electrodes using the *method of images*.

Grounding Configurations under Investigation

The modeling investigation focused on two common electrode configurations – a single long ground rod and an array of multiple ground rods placed in a straight line as illustrated in Figure 4-1. The modeling work included several variations in the number of ground rods used and their spacing for the case of a multiple ground rod array. The following ground rod configurations were investigated:

- A single 24-foot (7.32-meter) ground rod. In practice, the ground rod would likely be constructed of three 8-foot (2.44-meter) ground rods coupled together to obtain a total length of 24-ft.
- Three 8-foot (2.44-meter) ground rods spaced 16 feet (4.88 meters) between each rod
- Three 8-foot (2.44-meter) ground rods spaced 8 feet (2.44 meters) between each rod
- Two 8-foot (2.44-meter) ground rods spaced 16 feet (4.88 meters) between each rod
- Two 8-foot (2.44-meter) ground rods spaced 8 feet (2.44 meters) between each rod
- One 8-foot (2.44-meter) ground rod

All ground rods are modeled as 5/8 inch (1.59 cm) in diameter.

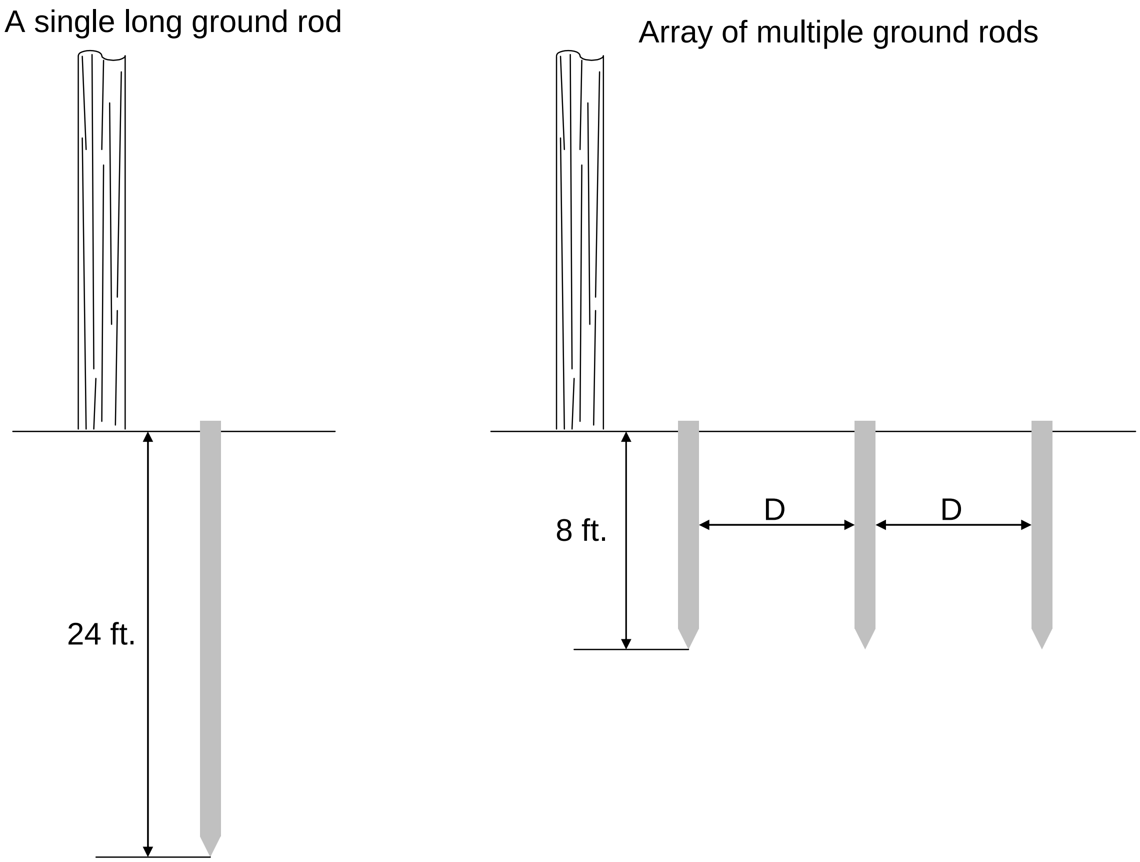


Figure 4-1
Ground Electrode Configurations Examined with EPRI Grounding Guide Software (EGGS)

Modeling Results

Low-Frequency Non-Ionization Resistance

Low-frequency ground electrode resistance is included in this work since lightning surge performance is not the only criteria, nor even the primary criteria, against which ground electrode performance is often judged. Therefore, low-frequency non-ionization ground resistance in single layer soil was calculated for each ground electrode configuration over a range of soil resistivities. As Figure 4-2 indicates, the electrode configurations fell into three distinct groups related to the length of conductor in the ground. Configurations with 24-feet of ground rod, either in a single rod or three separate 8-foot rods, offered the lowest ground resistance and their calculated resistances are quite close to one another. Not surprisingly, the single 8-foot ground rod showed the highest ground resistance. This information can be used in conjunction with the dynamic ground rod resistance data to determine which ground electrode configurations to apply to meet specific grounding needs (for example, equipment pole vs. non-equipment pole, high-lightning area vs. low-lightning area, etc.).

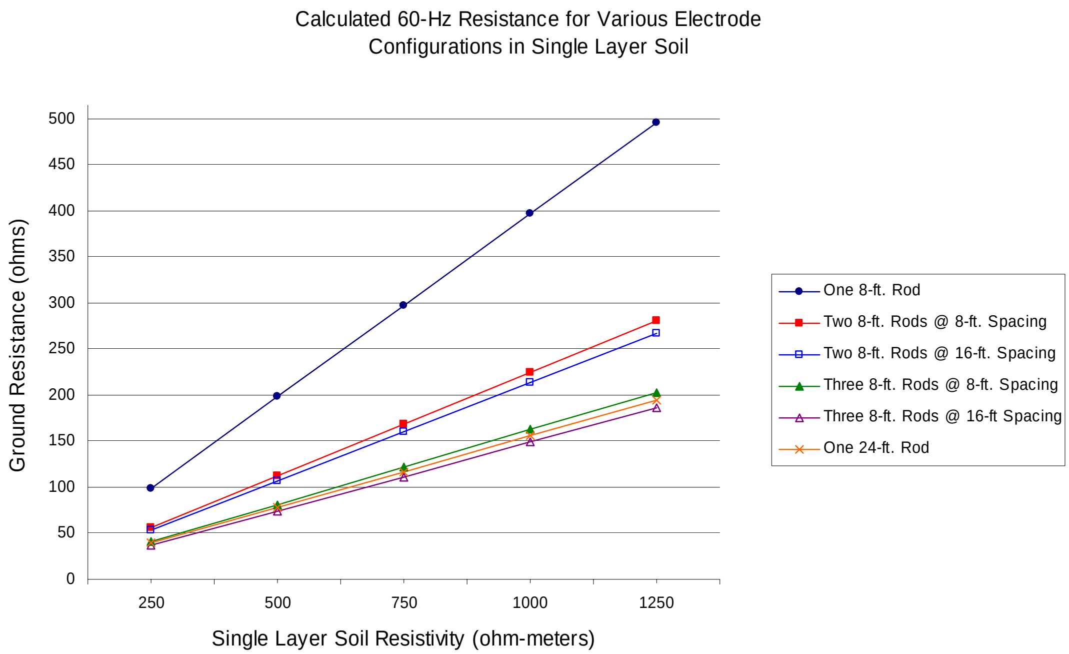


Figure 4-2
Calculated 60-Hz Resistance Values for Various Electrode Configurations in a Single-Layer Soil over a Range of Soil Resistivities

Dynamic Ground Resistance

The ground resistance of a ground electrode changes during a lightning discharge event as a function of the lightning current being discharged due to the ionization of the soil surrounding the electrode. At the onset of the discharge, the soil is not yet ionized and it takes a few microseconds for current density on the electrode to increase and soil ionization to fully develop. Dynamic resistance usually stabilizes by about 6 microseconds, as shown in Figure 4-3, but much of the damage from ground potential rise can occur within the first 2 microseconds of the event.

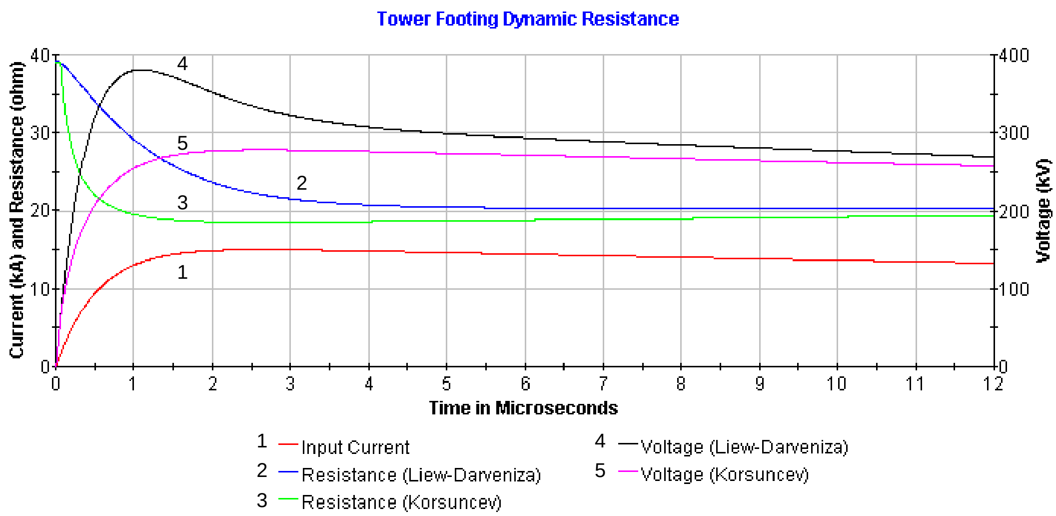


Figure 4-3
Dynamic Resistance Calculation for a Single 24-foot Ground Rod Discharging 15 kiloAmps into Soil with a Resistivity of 250 ohm-meters

Dynamic Ground Resistance during the First Two-Microseconds of Discharge

It is evident from Figure 4-3 that the Korsuncev and Liew-Darveniza algorithms vary slightly in their prediction of dynamic ground resistance, especially in the first few microseconds of the event. Testing carried-out by EPRI found that the Liew-Darveniza algorithm appears to better predict how the dynamic resistance changes in the first few microseconds of discharge (EPRI 1001908 2002). Therefore, the Liew-Darveniza algorithm was used to examine the dynamic ground resistance of the different electrode configurations during the early stages of the discharge event.

Figure 4-4 shows the ground resistances calculated at 2-microseconds into the discharge event for each electrode configuration. The ground resistance calculation is based on the electrode discharging 15-kA in single layer soil with a resistivity of 250 -meters. In the early stages of discharge, when the soil has not yet fully ionized, having more conductor in the ground makes the difference. As Figure 4-4 shows, a single 24-foot ground rod offers the best performance followed closely by three 8-foot rods spaced 16 feet apart. Ground resistances get higher as length of conductor in the ground and spacing are decreased with a single 8-foot ground rod showing the highest ground resistance.

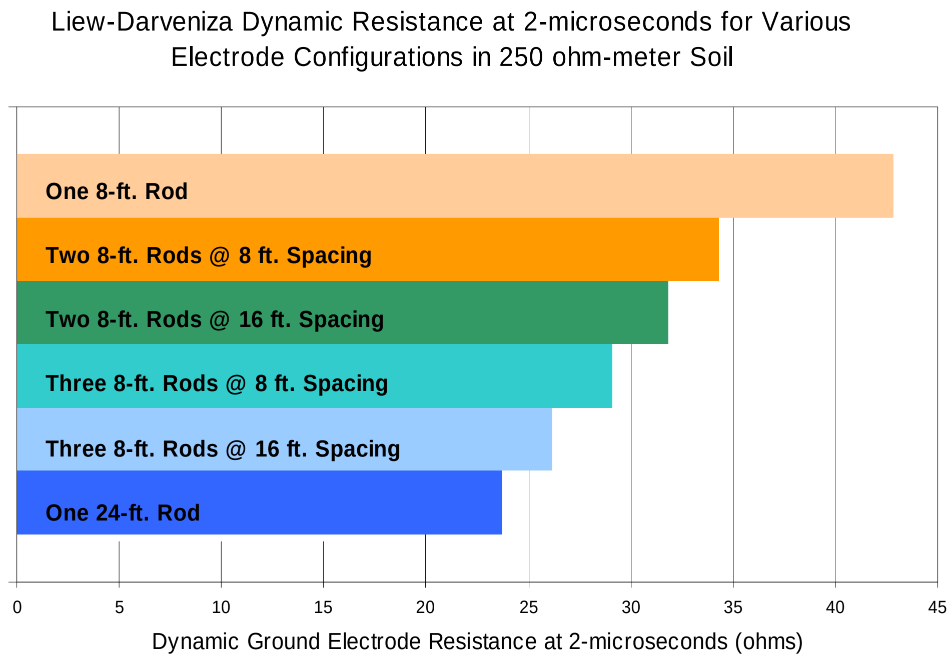


Figure 4-4
Comparison of Ground Resistance at 2 microseconds into the Discharge Event as Calculated with the Liew-Darveniza Algorithm for Electrodes in Single Layer Soil with a Resistivity of 250-ohm-meters

Dynamic Ground Resistance after the First Two-Microseconds of Discharge

Dynamic resistance usually stabilizes by about 6 microseconds. At that point, the soil has fully ionized and electrode dimensions have reached their maximum effective expansion. Proper electrode spacing is important during this stage of the discharge as soil ionization will be limited around electrodes that are located too close together. This outcome is reflected in Figure 4-5 which shows the stabilized ground resistance values for each electrode configuration at 6 microseconds into the discharge event. Three 8-foot ground rods spaced 16 feet apart show lower calculated ground resistance than the other electrode configurations. The next lowest ground resistance is exhibited by three different configurations: three 8-foot ground rods spaced 8 feet apart, two 8-foot ground rods spaced 16 feet apart, and one 24-foot ground rod. The calculated resistances for these configurations are all very close and can be viewed as essentially the same.

Beyond this point, the lightning current will begin to subside, current densities in the soil will begin to decrease, and the soil will start to de-ionize. The timing of these events is dependent upon the lightning strike characteristics.

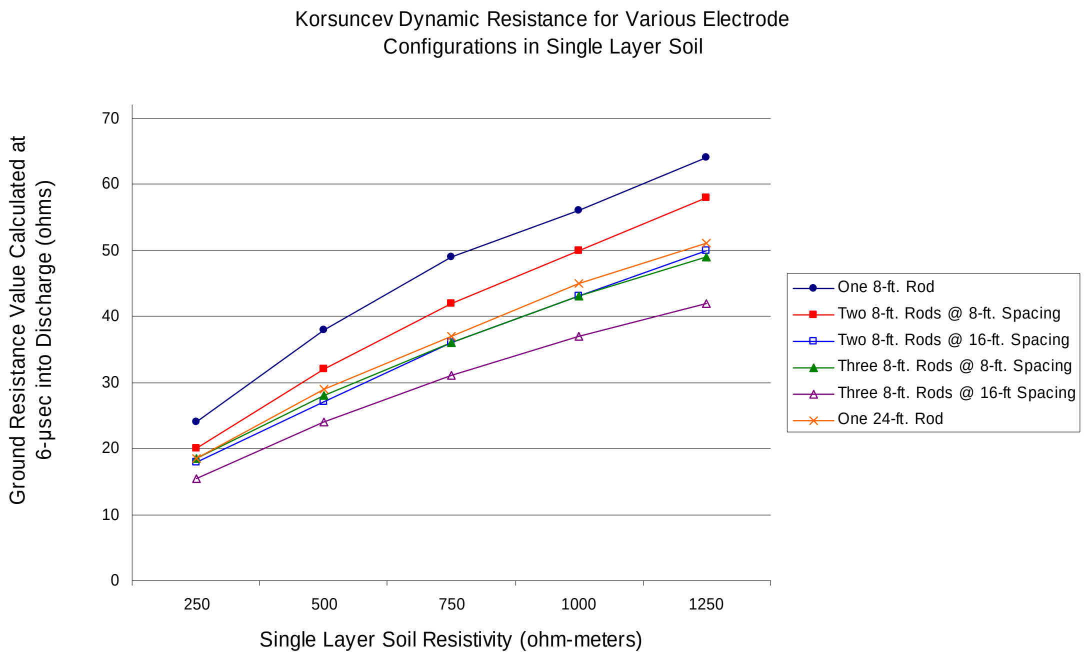


Figure 4-5
Dynamic Ground Resistance Calculated by the Korsuncev Method for Various Electrode Configurations in a Single-Layer Soil over a Range of Soil Resistivities

5
WIRING CONSIDERATIONS AFFECTING LIGHTNING PERFORMANCE

There are several key issues to consider when evaluating electronic equipment installations with regards to surge exposure and protection. Some considerations, such as pole grounding resistance, may not be completely within the utility's control. However, the equipment mounting location and grounding configuration play a significant role in surge exposure and both are very much within the utility's control.

Avoiding On-Pole Ground Loops

For devices that get control power from an auxiliary control power transformer, such as a capacitor controller, ground loops can be created by grounding both the secondary-side of the control power transformer and at the power input terminal to the controller as illustrated in Figure 5-1. The ground loop can cause the controller to be subjected to higher magnitude transients when compared to configurations without a ground loop in the circuit (EPRI 1008573 2005).

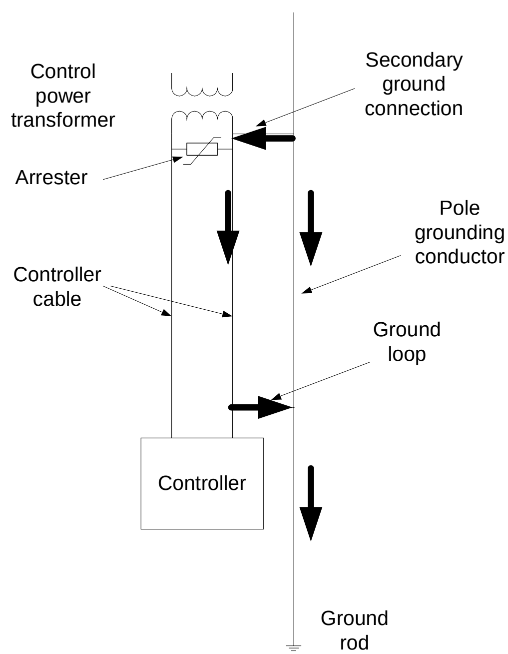


Figure 5-1
Ground Loop Created by Grounding the Control Power Transformer Output and the Capacitor Controller Neutral Terminal

In order to break a ground loop, the circuit should be grounded in only one place. Some equipment comes outfitted with separate secondary neutral and case ground lugs to allow for not grounding the power input. That is not to say that the equipment case should be left ungrounded! When recommended by the manufacturer, equipment case ground connections should always be maintained as not grounding the case could present a life safety issue.

The main criteria for avoiding a ground loop is to only make one connection to ground in the circuit – be it at the control power transformer secondary, the equipment power input, or somewhere else. When possible, provide the ground connection at the control power input while not grounding the neutral at the control power transformer secondary or pole top junction box. However, this configuration is not always feasible. Not all equipment is powered from a dedicated transformer thus there may be other customers sharing the secondary wires. If this is the case, there will be ground connections at each customer's service entrance. The use of a common conductor for both the system neutral and the secondary neutral also makes it difficult to avoid including a ground loop in the system wiring, especially when the controller is not on the same pole as the transformer. Furthermore, when the controller and transformer are not on the same pole, each pole will require a down ground and thus a common neutral will be grounded in at least two places.

Location of Power Supply Transformers

The placement of the sensitive electronic equipment in relation to the control power transformer from which it is supplied plays a prominent role in the magnitude of transients reaching the equipment. Locating the control power transformer on the same pole as the electronic equipment provides the best surge performance. Therefore, if possible, the two units should be located on the same pole for optimum surge performance (EPRI 1010655 2005).

Any control cables that run between electronic equipment and a pole-top junction box should be located as far as possible from the pole down ground lead. In most cases this means that the down ground lead and control cable should be located on opposite sides of the pole. Maintaining the greatest possible separation of the down ground and control cable minimizes the chances of flashover from the down ground to the control cable and should allow for the least surge induction in the control cable from surge current flowing in the ground lead.

Minimizing Arrester Lead Length

Arrester lead length includes both the primary lead and the ground lead length. The total lead length is measured from the point at which the arrester line connection is made to the point where interconnection is made between the arrester ground lead and the protected equipment ground lead, excluding the arrester length as shown in Figure 5-2.

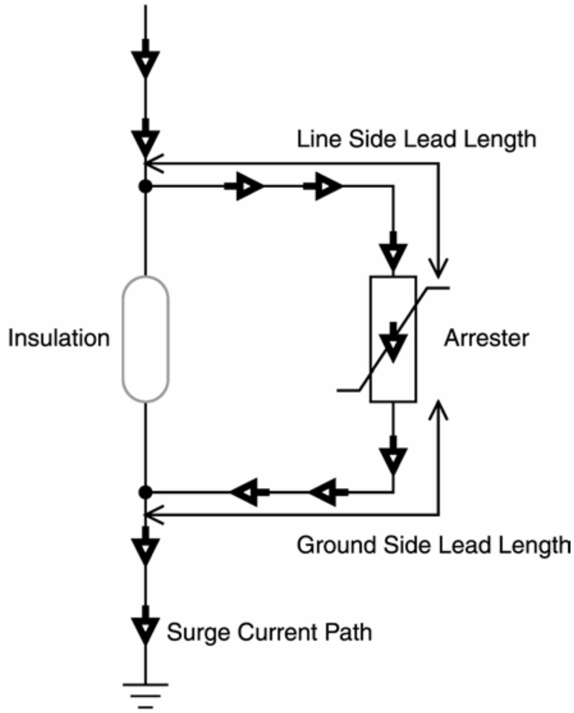


Figure 5-2
Arrester Lead Length

The lead length component is very important; the lead voltage can contribute as much as the arrester protective level for long lengths. The arrester lead inductance is approximately 0.4 µH/foot (1.3 µH/m). Commonly, a rate of current change is assumed to be 20 kA/µs. Together, this is 8 kV per foot of lead length (26 kV/m). This is not an unreasonable rate of rise to use in the calculation, as 20 kA/µs is about the median value for subsequent strokes during the rise from 30% to 90% of lightning surge magnitude (Short 2004).

Lead lengths less than three feet (one meter) are often necessary to achieve a 50% margin for protecting overhead equipment on 13.8-kV distribution circuits. The easiest approach is to tank-mount arresters. Pole or crossarm mounting makes it harder to keep reasonable lead lengths. It is important to remember that lead length includes the ground lead as well as the phase wire lead. Figure 5-3 shows an arrester application with a excessive ground lead length.

It should also be noted that to ensure that equipment is protected properly, arresters must be located at the same pole as the equipment. Moving arresters to adjacent poles will leave the equipment totally unprotected.

Some obvious but important directions for arrester application are:

- *Don't Coil Leads* - While this may look tidy, the inductance is very high.
- *Tie Ground Lead to the Tank* - The NESC (IEEE C2-1997) requires arrester ground leads to be tied to an appropriate ground. To achieve any protection, the ground lead must be tied to the tank of the equipment being protected. Without attaching the ground lead to the tank, the apparatus is left completely unprotected.

Figure 5-3
Arrester Application with Unreasonably Long Ground Lead Length

Secondary Surge Arresters

Depending on installation considerations (mounting location, ground loops, and so on.), it may be desirable to add auxiliary surge suppression to protect pole-mounted electronic equipment. Most likely, the secondary-side surge suppression will be provided by an MOV-technology-based unit. There are also other surge suppression products available the make use of several technologies incorporated into two or more "stages" of surge suppression. Secondary-side surge suppressors often cost less than $100, although two or more protection units may be required if numerous equipment ports are to be protected.

All surge modes for all equipment ports should be covered for optimal surge protection. This means that the incoming lines need to be protected for line-to-line and line-to-neutral surge modes. Furthermore, the surge protection is best added directly across the equipment ports rather than at points further away.

It is not uncommon for utilities to also use arrester protection at the pole top junction box. When used at the junction box, arresters are often connected between the phase conductor and ground and as well as between the neutral conductor and ground. However, using a neutral-to-ground arrester can create a ground loop if another neutral-to-ground arrester is used at the electronic equipment lower on the pole. Therefore, the neutral and ground conductors are better left isolated at the pole-top junction box and connected through a surge arrester at the electronic equipment input.

At this point is should be mentioned that even the best possible surge protection can not eliminate 100% of electronic equipment failures caused by lightning strikes. Some lightning-caused surges are simply too damaging to be protected against. Furthermore, there are many factors that may lead to less-than-optimal surge protection in certain circumstances. Depending on the protective margins and the configuration of built-in (from the manufacturer) surge protection, it may not be possible to coordinate the built-in surge protection with auxiliary surge protection. Surge current will follow the least resistant path to ground. If the built-in surge protection is tightly applied (meaning it begins to conduct near the rated line voltage), it may not be possible to add additional protection that conducts at a lower voltage. Therefore, surge currents will flow though the built-in protection, even if additional surge protection is added. In general, the electronic equipment manufacturer should be consulted before adding additional surge protection.

6
SUMMARY

Modeling Results

Low-Frequency Non-Ionization Grounding Resistance

The low-frequency non-ionization ground resistance in single layer soil was calculated for each ground electrode configuration over a range of soil resistivities. The electrode configurations fell into three distinct groups related to the length of conductor in the ground. Configurations with 24-feet of ground rod, either in a single rod or three separate 8-foot rods, offered the lowest ground resistance. Not surprisingly, the single 8-foot ground rod showed the highest ground resistance.

Dynamic Ground Resistance during the First 2-microseconds of Discharge

Dynamic ground resistance was calculated based on the electrode(s) discharging 15-kA in single layer soil with a resistivity of 250 -meters. In the early stages of discharge, when the soil has not yet fully ionized, having more conductor in the ground makes the difference. A single 24-foot ground rod offers the best performance followed closely by three 8-foot rods spaced 16 feet apart. Ground resistances get higher as length of conductor in the ground and spacing are decreased with a single 8-foot ground rod showing the highest ground resistance.

Stabilized Dynamic Ground Resistance after the First 2-microseconds of Discharge

Dynamic resistance usually stabilizes by about 6 microseconds. At that point, the soil has fully ionized and electrode dimensions have reached their maximum effective expansion. Proper electrode spacing is especially important during this stage of the discharge as soil ionization will be limited around electrodes that are located too close together. Dynamic ground resistance was calculated over a range of soil resistivities based on the ground electrode discharging 15-kA into single layer soil. The configuration of three 8-foot ground rods spaced 16 feet apart showed lower calculated ground resistance than the other electrode configurations. The next lowest ground resistance is exhibited by three different configurations: three 8-foot ground rods spaced 8 feet apart, two 8-foot ground rods spaced 16 feet apart, and one 24-foot ground rod. The calculated resistances for these configurations are all very close and can be viewed as essentially the same.

Grounding Recommendations

Go Wide or Go Deep

The fundamental question relating to lightning performance of distribution ground electrodes is whether to use fewer long ground rods (go deep) or more short ground rods (go wide). In practice, the answer is usually determined by the local soil conditions. Use long ground rods when there is an upper layer of high resistivity soil on top of a layer of lower resistivity soil. The long ground rods will reach down to the lower resistivity soil and possibly the water table as illustrated in Figure 6-1. Conversely, use an array of short ground rods when there is an upper layer of low resistivity soil over top of higher resistivity soil or rock.

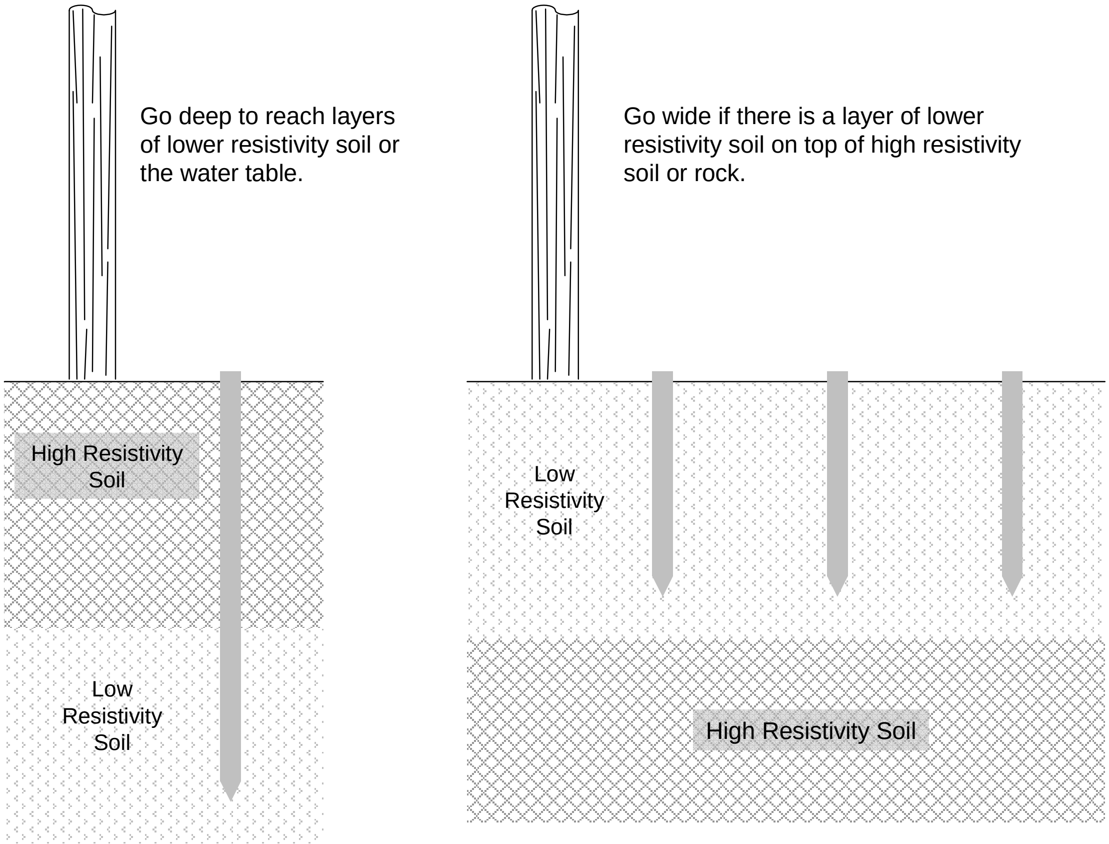


Figure 6-1
Local Soil Conditions Often Dictate Whether to Use Fewer Long Ground Rods or More Short Ground Rods – Go Wide versus Go Deep

Use Ground Rods Long Enough to Reach Below the Frostline

As the water in soil freezes, it restricts ion mobility and rapidly increases soil resistivity. Freezing can increase soil resistivity by one to two orders of magnitude.

Only the upper layer of soil freezes in most areas. The soil deeper down is better insulated from fluctuations in air temperature and tends to stay at a constant yearly temperature. In regions that experience freezing of the upper soil layer it is important to use ground electrodes that extend below the frostline to contact soil that remains unfrozen year round.

Other advantages of using long ground rods include:

- More likely to reach the water table
- Intercept multiple soil layers
- Reach moisture stable layers

Do Not Put Ground Rods in the Pole Hole

Ground rods should be driven in undisturbed soil. Driving ground rods in undisturbed soil provides maximum contact between the rod and the soil and helps achieve lower grounding resistance.

Ground rods do not make good contact with earth when placed in the pole hole and surrounded with backfill. The backfill soil around the rod is not sufficiently compacted and this configuration leads to higher grounding resistance. Over time, pole movement can also reduce soil compaction around ground rods placed in the pole hole which also adversely effects their ability to discharge lightning current.

Ground rods placed in the pole hole can also be impacted by preservatives that may leach out of treated wood poles into the surrounding soil. These chemicals increase the resistivity of the surrounding soil and cause a significant increase in grounding resistance. Ground rods should be placed a minimum of two feet from the pole to avoid the effects of wood pole preservatives.

Maintain Sufficient Ground Rod Separation

Maintaining proper ground rod spacing is crucial to avoid overlapping ionization zones and ensure optimal performance during lightning discharge events. Separate ground rods by a distance equal to twice the ground rod length. If separation of twice the length is not possible then maintain as large a separation as possible and at least equal to the ground rod length. Also consider using a single longer ground rod.

Avoid Butt-Wrap Electrodes

Although easy to fit during pole installation, butt wraps often do not provide sufficiently low ground resistance and their use is not recommended. If butt-wrap electrodes are used, the NESC dictates that two butt-wrap electrodes count as one ground in the “four grounds-per-mile” rule (Rule 97C) for multi-grounded distribution systems.

Wiring Considerations to Reduce Surge Exposure

Equipment mounting location and grounding configuration play a significant role in surge exposure.

Arrester Lead Length

Arrester lead length includes both the primary lead and the ground lead length. The total lead length is measured from the point at which the arrester line connection is made to the point where interconnection is made between the arrester ground lead and the protected equipment ground lead, excluding the arrester length.

- Lead lengths must be kept as short as possible, optimally less than three feet in total.
- Arresters should be mounted as close as possible to the objects they are protecting. When possible, arresters should be mounted directly on or next to the equipment ports they are protecting.

Avoid Ground Loops

For devices that get control power from an auxiliary control power transformer, such as a capacitor controller, ground loops can be created by grounding both the secondary-side of the control power transformer and the power input terminal to the controller.

Location of Power Supply Transformers

The placement of sensitive electronic equipment in relation to the control power transformer from which it is supplied plays a prominent role in the magnitude of transients reaching the equipment. Locating the control power transformer on the same pole as the electronic equipment helps keep surge exposure to a minimum.

Consider Adding Secondary-Side Surge Protection

Depending on installation considerations (mounting location, ground loops, and so on), it may be desirable to add auxiliary surge suppression to protect pole-mounted electronic equipment. All surge modes for all equipment ports should be covered for optimal surge protection. This means that the incoming lines need to be protected for line-to-line and line-to-neutral surge modes. Furthermore, the surge protection is best added directly across the equipment ports rather than at points further away.

A
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