FLUKE®

Principles, testing methods and applications

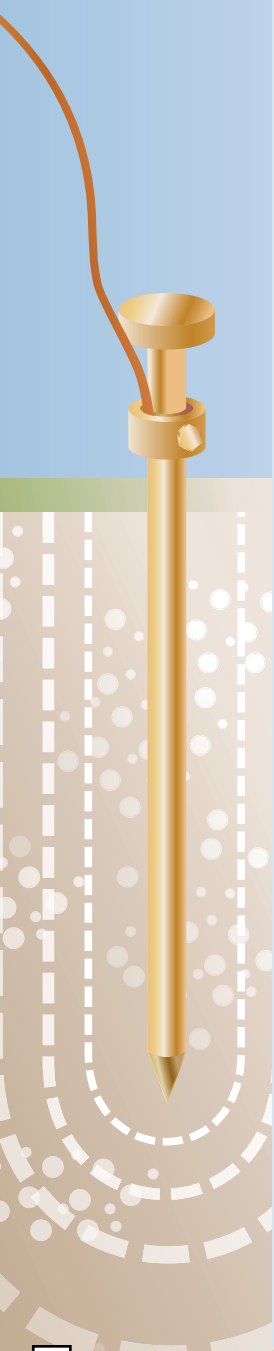
Diagnose intermittent electrical problems

Avoid unnecessary downtime

Learn earth ground safety principles

Earth Ground Resistance

Why Ground, Why Test?



Why ground?

Poor grounding not only contributes to unnecessary downtime, but a lack of good grounding is also dangerous and increases the risk of equipment failure.

Without an effective grounding system, we could be exposed to the risk of electric shock, not to mention instrumentation errors, harmonic distortion issues, power factor problems and a host of possible intermittent dilemmas. If fault currents have no path to the ground through a properly designed and maintained grounding system, they will find unintended paths that could include people. The following organizations have recommendations and/or standards for grounding to ensure safety:

- OSHA (Occupational Safety Health Administration)
- NFPA (National Fire Protection Association)
- ANSI/ISA (American National Standards Institute and Instrument Society of America)
- TIA (Telecommunications Industry Association)
- IEC (International Electrotechnical Commission)
- CENELEC (European Committee for Electrotechnical Standardization)
- IEEE (Institute of Electrical and Electronics Engineers)

However, good grounding isn't only for safety; it is also used to prevent damage to industrial plants and equipment. A good grounding system will improve the reliability of equipment and reduce the likelihood of damage due to lightning or fault currents. Billions are lost each year in the workplace due to electrical fires. This does not account for related litigation costs and loss of personal and corporate productivity.

Why test grounding systems?

Over time, corrosive soils with high moisture content, high salt content, and high temperatures can degrade ground rods and their connections. So although the ground system when initially installed, had low earth ground resistance values, the resistance of the grounding system can increase if the ground rods are eaten away.

Grounding testers, like the Fluke 1623 and 1625, are indispensable troubleshooting tools to help you maintain uptime. With frustrating, intermittent electrical problems, the problem could be related to poor grounding or poor power quality.

That is why it is highly recommended that all grounds and ground connections are checked at least annually as a part of your normal Predictive Maintenance plan. During these periodic checks, if an increase in resistance of more than 20 % is measured, the technician should investigate the source of the problem, and make the correction to lower the resistance, by replacing or adding ground rods to the ground system.

What is a ground and what does it do?

The NEC, National Electrical Code, Article 100 defines a ground as: "a conducting connection, whether intentional or accidental between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of the earth." When talking about grounding, it is actually two different subjects: earth grounding and equipment grounding. Earth grounding is an intentional connection from a circuit conductor, usually the neutral, to a ground electrode placed in the earth. Equipment grounding ensures that operating equipment within a

FLUKE®

structure is properly grounded. These two grounding systems are required to be kept separate except for a connection between the two systems. This prevents differences in voltage potential from a possible flashover from lightning strikes. The purpose of a ground besides the protection of people, plants and equipment is to provide a safe path for the dissipation of fault currents, lightning strikes, static discharges, EMI and RFI signals and interference.

What is a good ground resistance value?

There is a good deal of confusion as to what constitutes a good ground and what the ground resistance value needs to be. Ideally a ground should be of zero ohms resistance.

There is not one standard ground resistance threshold that is recognized by all agencies. However, the NFPA and IEEE have recommended a ground resistance value of 5.0 ohms or less.

The NEC has stated to "Make sure that system impedance to ground is less than 25 ohms specified in NEC 250.56. In facilities with sensitive equipment it should be 5.0 ohms or less."

The Telecommunications industry has often used 5.0 ohms or less as their value for grounding and bonding.

The goal in ground resistance is to achieve the lowest ground resistance value possible that makes sense economically and physically.

Why Test? Corrosive soils.

Why Ground? Lightning strikes.

Use the Fluke 1625 to determine the health of your earth ground systems.

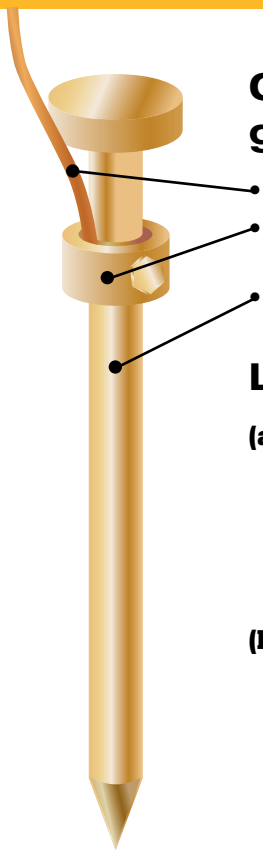
Table of contents

2
Why Ground? Why Test?

4
Grounding basics

6
Methods of earth ground testing

12
Measuring ground resistance



Components of a ground electrode

- Ground conductor
- Connection between the ground conductor and the ground electrode
- Ground electrode

Locations of resistances

(a) The ground electrode and its connection

The resistance of the ground electrode and its connection is generally very low. Ground rods are generally made of highly conductive/low resistance material such as steel or copper.

(b) The contact resistance of the surrounding earth to the electrode

The National Institute of Standards (a governmental agency within the US Dept. of Commerce) has shown this resistance to be almost negligible provided that the ground electrode is free of paint, grease, etc. and that the ground electrode is in firm contact with the earth.

(c) The resistance of the surrounding body of earth

The ground electrode is surrounded by earth which conceptually is made up of concentric shells all having the same thickness. Those shells closest to the ground electrode have the smallest amount of area resulting in the greatest degree of resistance. Each subsequent shell incorporates a greater area resulting in lower resistance. This finally reaches a point where the additional shells offer little resistance to the ground surrounding the ground electrode.

So based on this information, we should focus on ways to reduce the ground resistance when installing grounding systems.

What affects the grounding resistance?

First, the NEC code (1987, 250-83-3) requires a minimum ground electrode length of 2.5 meters (8.0 feet) to be in contact with soil. But, there are four variables that affect the ground resistance of a ground system:

1. Length/depth of the ground electrode
2. Diameter of the ground electrode
3. Number of ground electrodes
4. Ground system design

Length/depth of the ground electrode

One very effective way of lowering ground resistance is to drive ground electrodes deeper. Soil is not consistent in its resistivity and can be highly unpredictable. It is critical when installing the ground electrode, that it is below the frost line. This is done so that the resistance to ground will not be greatly influenced by the freezing of the surrounding soil.

Generally, by doubling the length of the ground electrode you can reduce the resistance level by an additional 40 %. There are occasions where it is physically impossible to drive ground rods deeper—areas that are composed of rock, granite, etc. In these instances, alternative methods including grounding cement are viable.

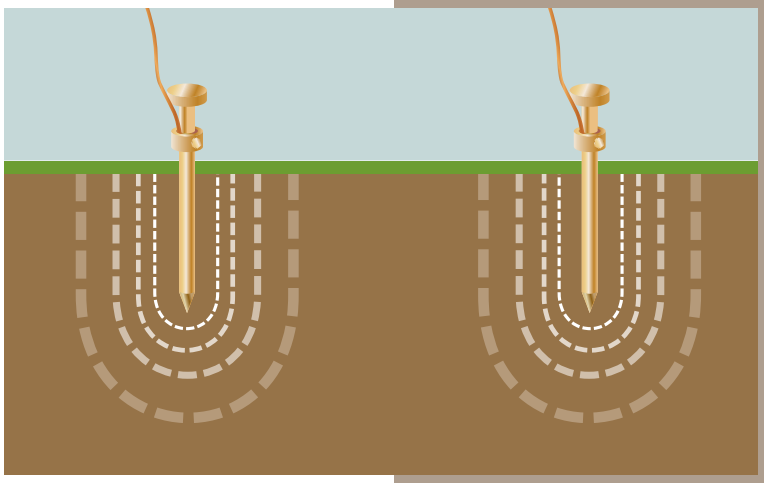
Diameter of the ground electrode

Increasing the diameter of the ground electrode has very little effect in lowering the resistance. For example, you could double the diameter of a ground electrode and your resistance would only decrease by 10 %.

Number of ground electrodes

Another way to lower ground resistance is to use multiple ground electrodes. In this design, more than one electrode is driven into the ground and connected in parallel to lower the resistance. For additional electrodes to be effective, the spacing of additional rods need to be at least equal to the depth of the driven rod. Without proper spacing of the ground electrodes, their spheres of influence will intersect and the resistance will not be lowered.

To assist you in installing a ground rod that will meet your specific resistance requirements, you can use the table of ground resistances, below. Remember, this is to only be used as a rule of thumb, because soil is in layers and is rarely homogenous. The resistance values will vary greatly.



Each ground electrode has its own 'sphere of influence'.

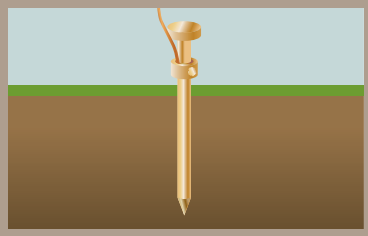
Ground system design

Simple grounding systems consist of a single ground electrode driven into the ground. The use of a single ground electrode is the most common form of grounding and can be found outside your home or place of business. Complex grounding systems consist of multiple ground rods, connected, mesh or grid networks, ground plates, and ground loops. These systems are typically installed at power generating substations, central offices, and cell tower sites.

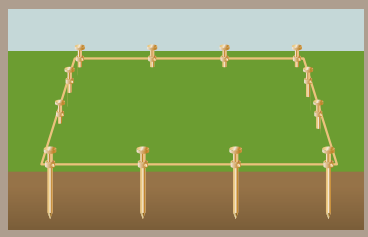
Complex networks dramatically increase the amount of contact with the surrounding earth and lower ground resistances.

Type of soil	Soil resistivity R_E	Earthing resistance					
		Ground electrode depth (meters)			Earthing strip (meters)		
	ΩM	3	6	10	5	10	20
Very moist soil, swamplike	30	10	5	3	12	6	3
Farming soil loamy and clay soils	100	33	17	10	40	20	10
Sandy clay soil	150	50	25	15	60	30	15
Moist sandy soil	300	66	33	20	80	40	20
Concrete 1:5	400	–	–	–	160	80	40
Moist gravel	500	160	80	48	200	100	50
Dry sandy soil	1000	330	165	100	400	200	100
Dry gravel	1000	330	165	100	400	200	100
Stoney soil	30,000	1000	500	300	1200	600	300
Rock	10^7	–	–	–	–	–	–

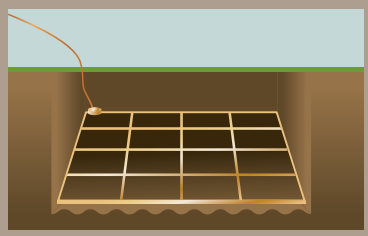
Ground systems



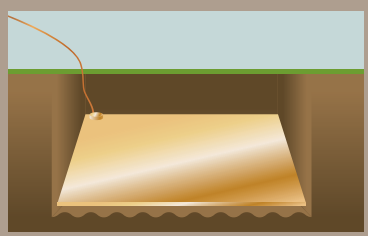
Single ground electrode.



Multiple ground electrodes connected.



Mesh network.



Ground plate.

What are the Methods of Earth Ground Testing?

There are four types of earth ground testing methods available:

- **Soil Resistivity** (using stakes)
- **Fall-of-Potential** (using stakes)
- **Selective** (using 1 clamp and stakes)
- **Stakeless** (using 2 clamps only)

Soil resistivity measurement

Why determine the soil resistivity?

Soil Resistivity is most necessary when determining the design of the grounding system for new installations (green field applications) to meet your ground resistance requirements. Ideally, you would find a location with the lowest possible resistance. But as we discussed before, poor soil conditions can be overcome with more elaborate grounding systems.

The soil composition, moisture content, and temperature all impact the soil resistivity. Soil is rarely homogenous and the resistivity of the soil will vary geographically and at different soil depths. Moisture content changes seasonally, varies according to the nature of the sub layers of earth, and the depth of the permanent water table. Since soil and water are generally more stable at deeper strata, it is recommended that the ground rods be placed as deep as possible into the earth, at the water table if possible. Also, ground rods should be installed where there is a stable temperature, i.e. below the frost line.

For a grounding system to be effective, it should be designed to withstand the worst possible conditions.

How do I calculate soil resistivity?

The measuring procedure described below uses the universally accepted Wenner method developed by Dr. Frank Wenner of the US Bureau of Standards in 1915. (F. Wenner, A Method of Measuring Earth Resistivity; Bull, National Bureau of Standards, Bull 12(4) 258, p. 478–496; 1915/16.)

The formula is as follows:

$\rho = 2\ \pi\ A\ R$

(ρ = the average soil resistivity to depth A in ohm—cm)

$\pi = 3.1416$

A = the distance between the electrodes in cm

R = the measured resistance value in ohms from the test instrument

Note: Divide ohm—centimeters by 100 to convert to ohm—meters. Just watch your units.

Example: You have decided to install three meter long ground rods as part of your grounding system. To measure the soil resistivity at a depth of three meters, we discussed a spacing between the test electrodes of three meters.

To measure the soil resistivity start the Fluke 1625 and read the resistance value in ohms. In this case assume the resistance reading is 100 ohms. So, in this case we know:

A = 3 meters, and
R = 100 ohms

Then the soil resistivity would equal:

$\rho = 2 \times \pi \times A \times R$

$\rho = 2 \times 3.1416 \times 3$ meters $\times$ 100 ohms

$\rho = 1885\ \Omega m$

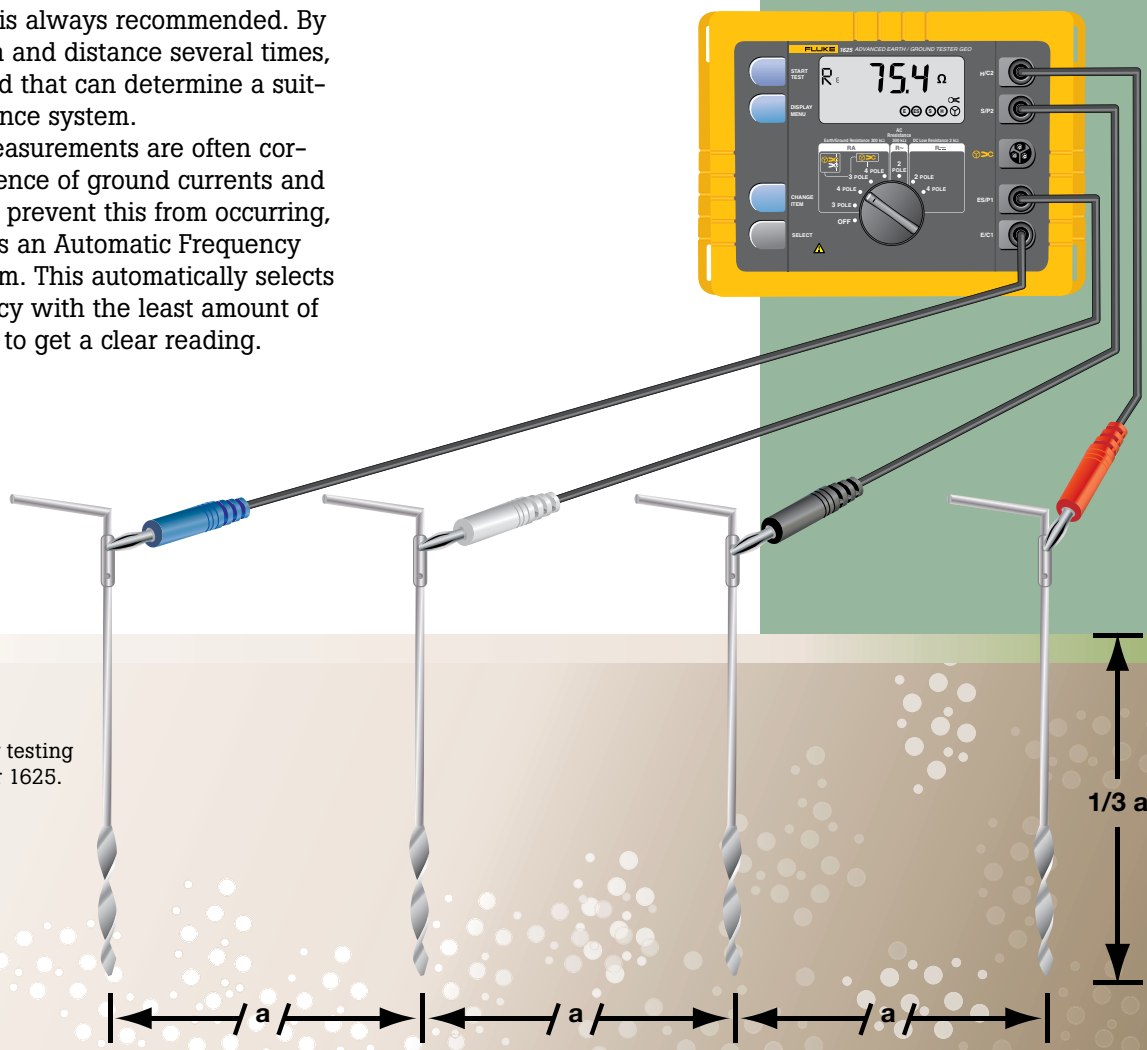
How do I measure soil resistance?

To test soil resistivity, connect the ground tester as shown below.

As you can see, four earth ground stakes are positioned in the soil in a straight line, equidistant from one another. The distance between earth ground stakes should be at least three times greater than the stake depth. So if the depth of each ground stake is one foot (.30 meters), make sure the distance between stakes is greater than three feet (.91 meters). The Fluke 1625 generates a known current through the two outer ground stakes and the drop in voltage potential is measured between the two inner ground stakes. Using Ohm's Law (V=IR), the Fluke tester automatically calculates the soil resistance.

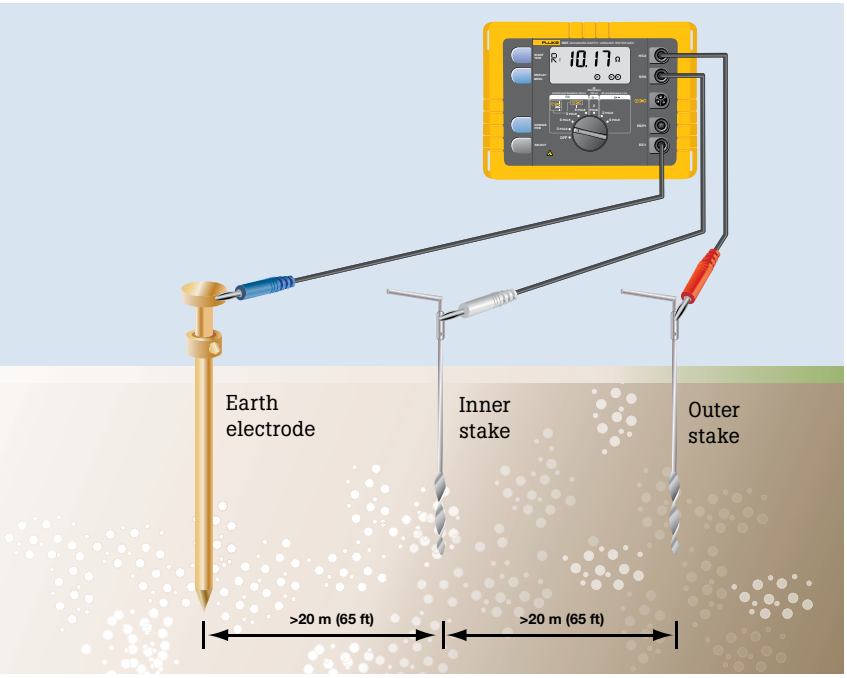
Because measurement results are often distorted and invalidated by underground pieces of metal, underground aquifers, etc. additional measurements where the stake's axis are turned 90 degrees is always recommended. By changing the depth and distance several times, a profile is produced that can determine a suitable ground resistance system.

Soil resistivity measurements are often corrupted by the existence of ground currents and their harmonics. To prevent this from occurring, the Fluke 1625 uses an Automatic Frequency Control (AFC) System. This automatically selects the testing frequency with the least amount of noise enabling you to get a clear reading.



Setup for soil resistivity testing using the Fluke 1623 or 1625.

What are the Methods of Earth Ground Testing?



Fall-of-Potential measurement

The Fall-of-Potential test method is used to measure the ability of an earth ground system or an individual electrode to dissipate energy from a site.

How does the Fall-of-Potential test work?

First, the earth electrode of interest must be disconnected from its connection to the site. Second, the tester is connected to the earth electrode. Then, for the 3-pole Fall-of-Potential test, two earth stakes are placed in the soil in a direct line—away from the earth electrode. Normally, spacing of 20 meters (65 feet) is sufficient. For more detail on placing the stakes, see the next section.

A known current is generated by the Fluke 1625 between the outer stake (auxiliary earth stake) and the earth electrode, while the drop in voltage potential is measured between the inner earth stake and the earth electrode. Using Ohm's Law (V = IR), the tester automatically calculates the resistance of the earth electrode.

Connect the ground tester as shown in the picture. Press START and read out the R_E (resistance) value. This is the actual value of the ground electrode under test. If this ground electrode is in parallel or series with other ground rods, the R_E value is the total value of all resistances.

How do you place the stakes?

To achieve the highest degree of accuracy when performing a 3–pole ground resistance test, it is essential that the probe is placed outside the sphere of influence of the ground electrode under test and the auxiliary earth.

If you do not get outside the sphere of influence, the effective areas of resistance will overlap and invalidate any measurements that you are taking. The table is a guide for appropriately setting the probe (inner stake) and auxiliary ground (outer stake).

To test the accuracy of the results and to ensure that the ground stakes are outside the spheres of influence, reposition the inner stake (probe) 1 meter (3 feet) in either direction and take a fresh measurement. If there is a significant change in the reading (30 %), you need to increase the distance between the ground rod under test, the inner stake (probe) and the outer stake (auxiliary ground) until the measured values remain fairly constant when repositioning the inner stake (probe).

Depth of the ground electrode	Distance to the inner stake	Distance to the outer stake
2 m	15 m	25 m
3 m	20 m	30 m
6 m	25 m	40 m
10 m	30 m	50 m

Selective measurement

Selective testing is very similar to the Fall-of-Potential testing, providing all the same measurements, but in a much safer and easier way. This is because with Selective testing, the earth electrode of interest does not need to be disconnected from its connection to the site! The technician does not have to endanger himself by disconnecting ground, nor endanger other personnel or electrical equipment inside a non-grounded structure.

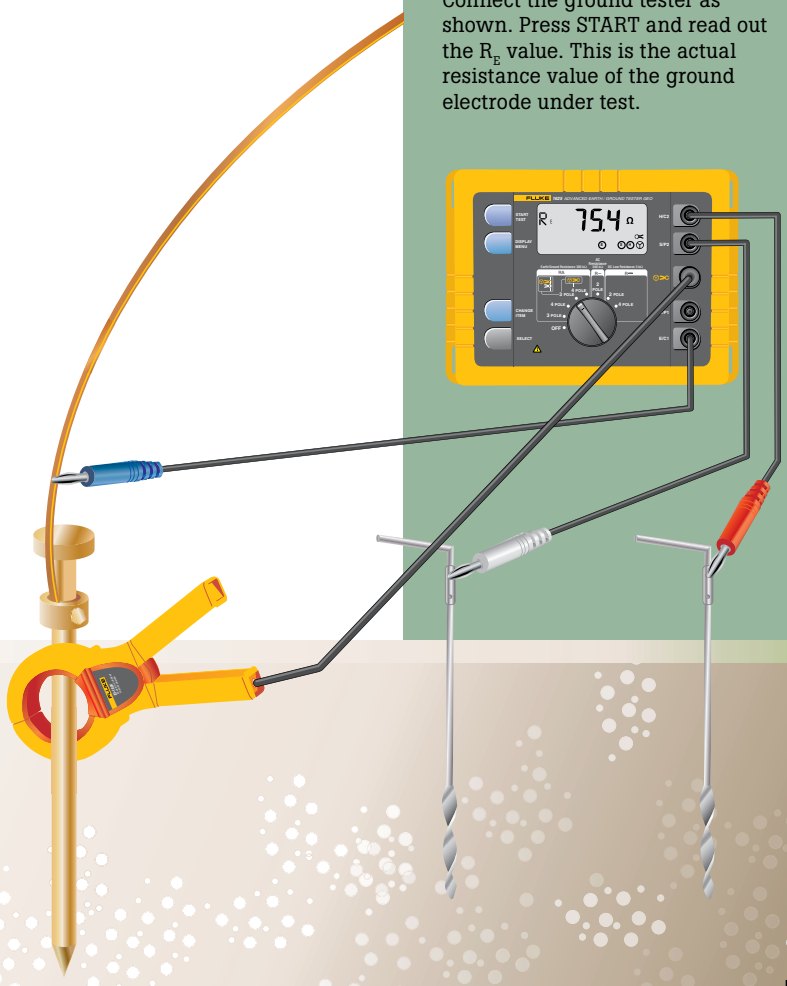
Just as with the Fall-of-Potential test, two earth stakes are placed in the soil in a direct line, away from the earth electrode. Normally, spacing of 20 meters (65 feet) is sufficient. The tester is then connected to the earth electrode of interest, with the advantage that the connection to the site doesn't need to be disconnected. Instead, a special clamp is placed around the earth electrode, which eliminates the effects of parallel resistances in a grounded system, so only the earth electrode of interest is measured.

Just as before, a known current is generated by the Fluke 1625 between the outer stake (auxiliary earth stake) and the earth electrode, while the drop in voltage potential is measured between the inner earth stake and the earth electrode. Only the current flowing through the earth electrode of interest is measured using the clamp. The generated current will also flow through other parallel resistances, but only the current through the clamp (i.e. the current through the earth electrode of interest) is used to calculate resistance (V=IR).

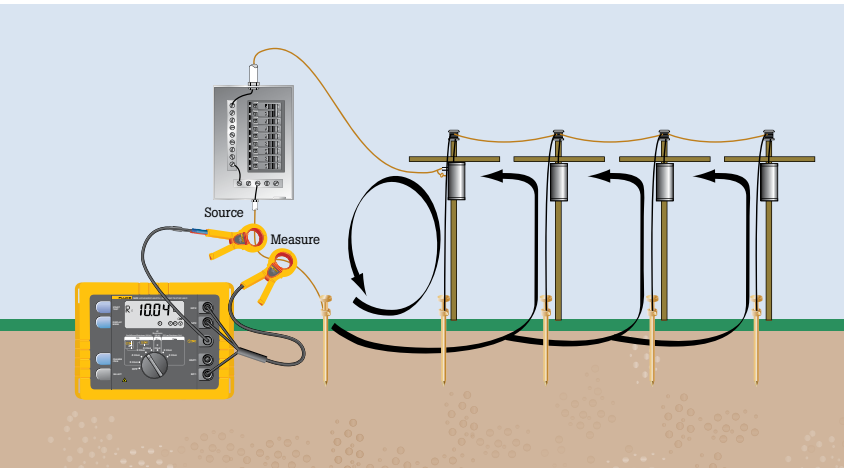
If the total resistance of the ground system should be measured, then each earth electrode resistance must be measured by placing the clamp around each individual earth electrode. Then the total resistance of the ground system can be determined by calculation.

Testing individual ground electrode resistances of high voltage transmission towers with overhead ground or static wire, requires that these wires be disconnected. If a tower has more than one ground at its base, these must also be disconnected one by one and tested. However, the Fluke 1625 has an optional accessory, a 320 mm (12.7 in) diameter clamp-on current transformer, which can measure the individual resistances of each leg, without disconnecting any ground leads or overhead static/ground wires.

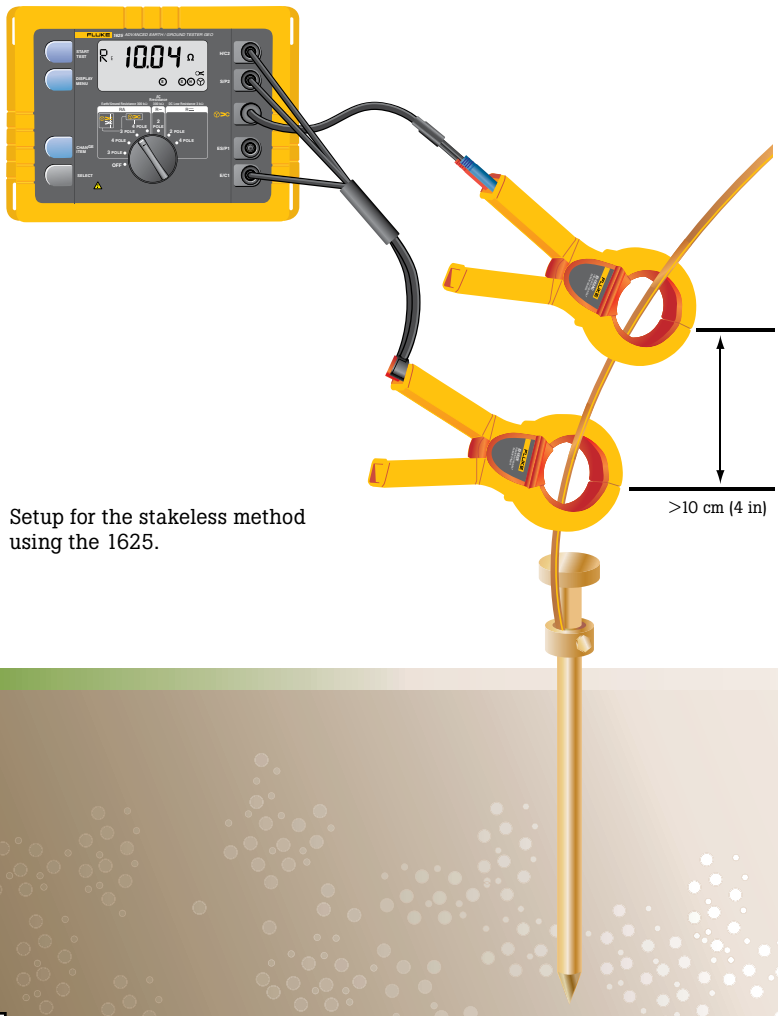
Connect the ground tester as shown. Press START and read out the R_E value. This is the actual resistance value of the ground electrode under test.



What are the Methods of Earth Ground Testing?



Test current paths in the stakeless method.



Setup for the stakeless method using the 1625.

Stakeless measurement

The Fluke 1625 earth ground tester is able to measure earth ground loop resistances for multi-grounded systems using only current clamps. This test technique eliminates the dangerous, and time consuming activity of disconnecting parallel grounds, as well as the process of finding suitable locations for auxiliary ground stakes. You can also perform earth ground tests in places you have not considered before: inside buildings, on power pylons or anywhere you don't have access to soil.

With this test method, two clamps are placed around the earth ground rod or the connecting cable and each are connected to the tester. Earth ground stakes are not used at all. A known voltage is induced by one clamp, and the current is measured using the second clamp. The tester automatically determines the ground loop resistance at this ground rod. If there is only one path to ground, like at many residential situations, the Stakeless method will not provide an acceptable value and the Fall-of-Potential test method must be used.

The Fluke 1625 works on the principle that in parallel/multi-grounded systems, the net resistance of all ground paths will be extremely low as compared to any single path (the one under test). So, the net resistance of all the parallel return path resistances is effectively zero. Stakeless measurement only measures individual ground rod resistances in parallel to earth grounding systems. If the ground system is not parallel to earth then you will either have an open circuit, or be measuring ground loop resistance.

Ground impedance measurements

When attempting to calculate possible short circuit currents in power plants and other high voltage/current situations, determining the complex grounding impedance is important since the impedance will be made up of inductive and capacitive elements. Because inductivity and resistivity are known in most cases, actual impedance can be determined using a complex computation.

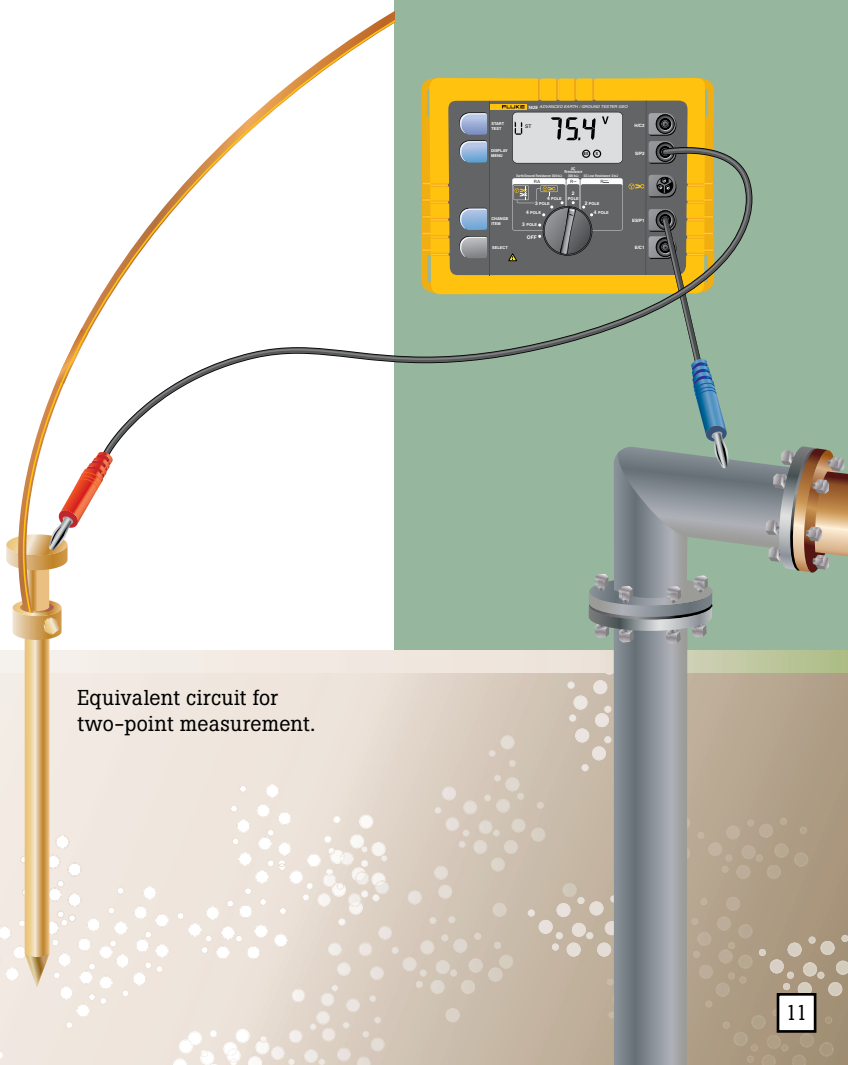
Since impedance is frequency dependent, the Fluke 1625 uses a 55 Hz signal for this calculation to be as close to voltage operating frequency as possible. This ensures that the measurement is close to the value at the true operating frequency. Using this feature of the Fluke 1625, accurate direct measurement of grounding impedance is possible.

Power utilities technicians, testing high voltage transmission lines, are interested in two things. The ground resistance in case of a lightning strike, and the impedance of the entire system in case of a short circuit on a specific point in the line. Short circuit in this case, means an active wire breaks loose and touches the metal grid of a tower.

Two-pole ground resistance

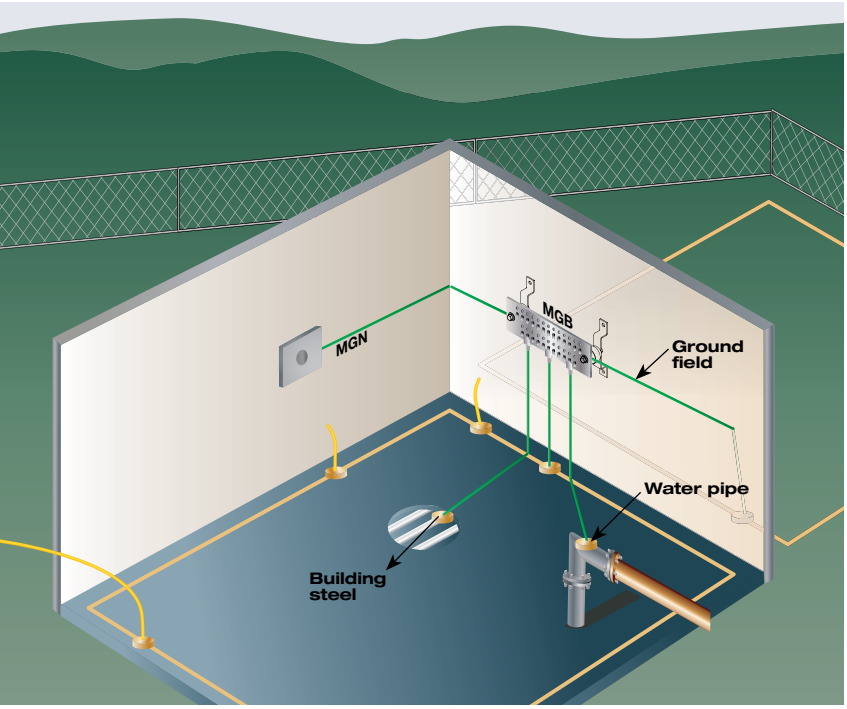
In situations where the driving of ground stakes is neither practical nor possible, the Fluke 1623 and 1625 testers give you the ability to do two-pole ground resistance/continuity measurements, as shown below.

To perform this test, the technician must have access to a good, known ground such as an all metal water pipe. The water pipe should be extensive enough and be metallic throughout without any insulating couplings or flanges. Unlike many testers, the Fluke 1623 and 1625 perform the test with a relatively high current (short circuit current > 250 mA) ensuring stable results.



Equivalent circuit for two-point measurement.

Measuring Ground Resistance



The layout of a typical central office.

At central offices

When conducting a grounding audit of a central office there are three different measurements required.

Before testing, locate the MGB (Master Ground Bar) within the central office to determine the type of grounding system that exists. As shown on this page, the MGB will have ground leads connecting to the:

- MGN (Multi-Grounded Neutral) or incoming service,
- ground field,
- water pipe, and
- structural or building steel

First, perform the Stakeless test on all the individual grounds coming off of the MGB. The purpose is to ensure that all the grounds are connected, especially the MGN. It is important to note that you are not measuring the individual resistance, rather the loop resistance of what you are clamped around. As shown in Figure 1, connect the Fluke 1625 or 1623 and both the inducing and sensing clamps, which are placed around each connection to measure the loop resistance of the MGN, the ground field, the water pipe, and the building steel.

Second, perform the 3-pole Fall-of-Potential test of the entire ground system, connecting to the MGB as illustrated on in Figure 2. To get to remote earth, many phone companies utilize unused cable pairs going out as much as a mile. Record the measurement and repeat this test at least annually.

Third, measure the individual resistances of the ground system using the Selective test of the Fluke 1625 or 1623. Connect the Fluke tester, as shown in Figure 3. Measure the resistance of the MGN; the value is the resistance of that particular leg of the MGB. Then measure the ground field. This reading is the actual resistance value of the central office ground field. Now move on to the water pipe, and then repeat for the resistance of the building steel. You can easily verify the accuracy of these measurements through Ohm's Law. The resistance of the individual legs, when calculated, should equal the resistance of the entire system given (allow for reasonable error since all ground elements may not be measured).

These test methods provide the most accurate measure of a central office, because it gives you the individual resistances and their actual behavior in a ground system. Although accurate, the measurements would not show how the system behaves as a network, because in the event of a lightning strike or fault current, everything is connected.

To prove this, you need to perform a few additional tests on individual resistances.

First, perform the 3-pole Fall-of-Potential test on each leg off the MGB and record each measurement. Using Ohm's Law again, these measurements should be equal to the resistance of the entire system. From the calculations you will see that you are from 20 % to 30 % off the total R_E value.

Finally, measure the resistances of the various legs of the MGB using the Selective Stakeless method. It works like the Stakeless method, but it differs in the way we use the two separate clamps. We place the inducing voltage clamp around the cable going to the MGB, and since the MGB is connected to the incoming power, which is parallel to the earth system, we have achieved that requirement. Take the sensing clamp and place it around the ground cable leading out to the ground field. When we measure the resistance, this is the actual resistance of the ground field, plus the parallel path of the MGB. And because it should be very low ohmically, it should have no real effect on the measured reading. This process can be repeated for the other legs of the ground bar i.e. water pipe and structural steel.

To measure the MGB via the Stakeless Selective method, place the inducing voltage clamp around the line to the water pipe (since the copper water pipe should have very low resistance) and your reading will be the resistance for only the MGN.

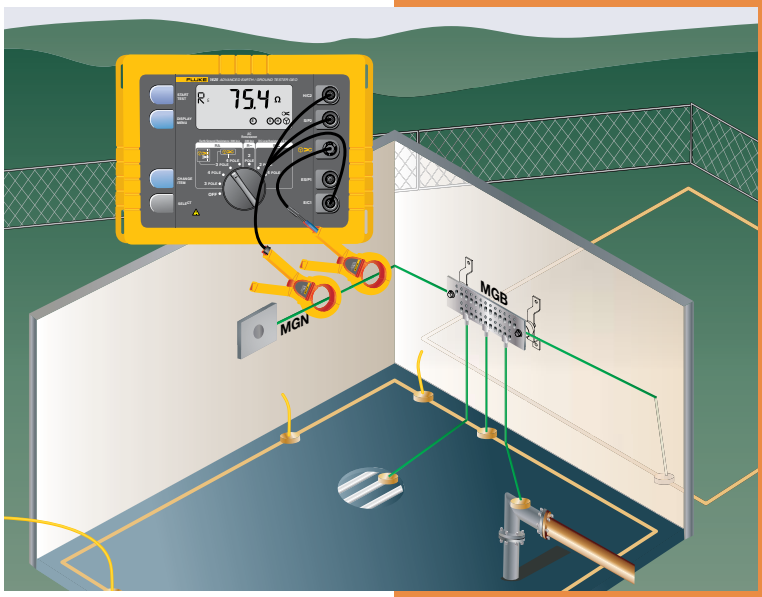


Figure 1: Stakeless testing of a central office.

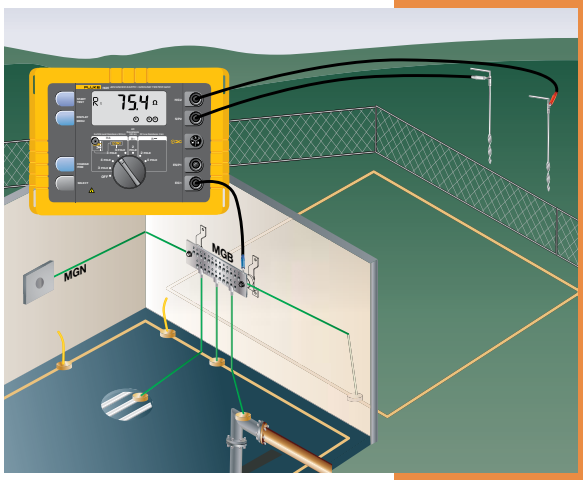


Figure 2: Perform the 3-Pole Fall-of-Potential test of the entire ground system.

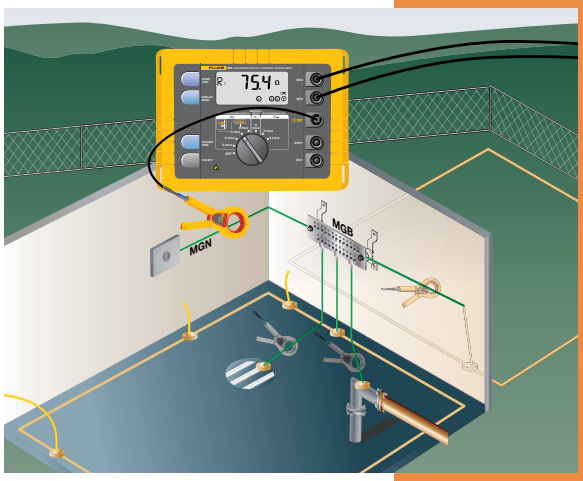
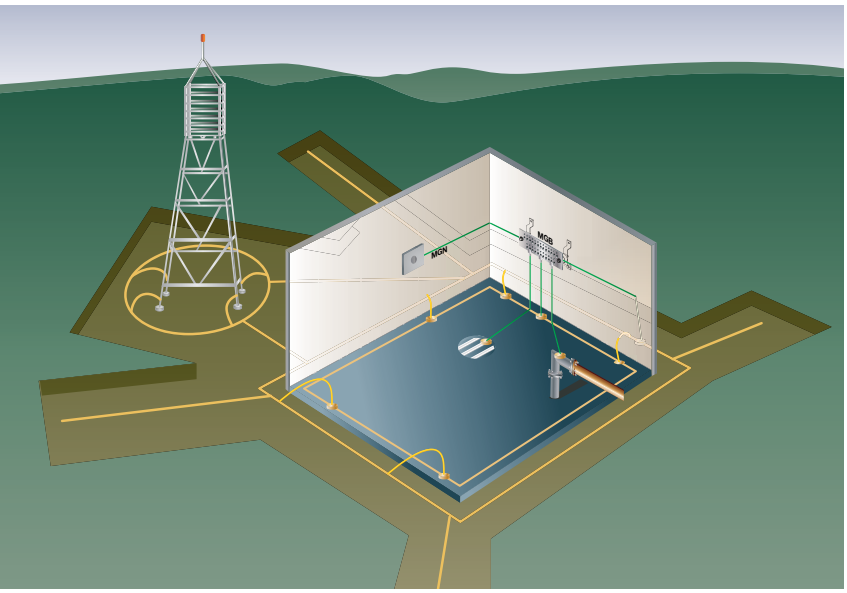


Figure 3: Measure the individual resistances of the ground system using the Selective test.

More Ground Resistance Applications



A typical setup at a cellular tower installation.

Application sites

There are four other particular applications where you can use the Fluke 1625 to measure the capability of the earth ground system.

Cellular sites/microwave and radio towers

At most locations there is a 4-legged tower with each leg individually grounded. These grounds are then connected with a copper cable. Next to the tower is the Cell site building, housing all the transmission equipment. Inside the building there is a halo ground and a MGB, with the halo ground connected to the MGB. The cell site building is grounded at all 4 corners connected to the MGB via a copper cable and the 4 corners are also interconnected via copper wire. There is also a connection between the building ground ring and the tower ground ring.

Electrical substations

A substation is a subsidiary station on a transmission and distribution system where voltage is normally transformed from a high value to low value. A typical substation will contain line termination structures, high-voltage switchgear, one or more power transformers, low-voltage switchgear, surge protection, controls, and metering.

Remote switching sites

Remote switching sites also known as slick sites, where digital line concentrators and other telecommunications equipment is operating. The remote site is typically grounded at either end of the cabinet and then will have a series of ground stakes around the cabinet connected by copper wire.

Lightning protection at commercial/industrial sites

Most lightning fault current protection systems follow the design of having all four corners of the building grounded and these are usually connected via a copper cable. Depending on the size of the building and the resistance value that it was designed to achieve, the number of ground rods will vary.

Recommended tests

End users are required to perform the same three tests at each application: Stakeless measurement, 3-pole Fall-of-Potential measurement and Selective measurement.

Stakeless measurement

First, perform a Stakeless measurement on:

- The individual legs of the tower and the four corners of the building **(cell sites/towers)**
- All grounding connections **(electrical substations)**
- The lines running to the remote site **(remote switching)**
- The ground stakes of the building **(lightning protection)**

For all applications, this is not a true ground resistance measurement because of the network ground. This is mainly a continuity test to verify that the site is grounded, that we have an electrical connection, and that the system can pass current.

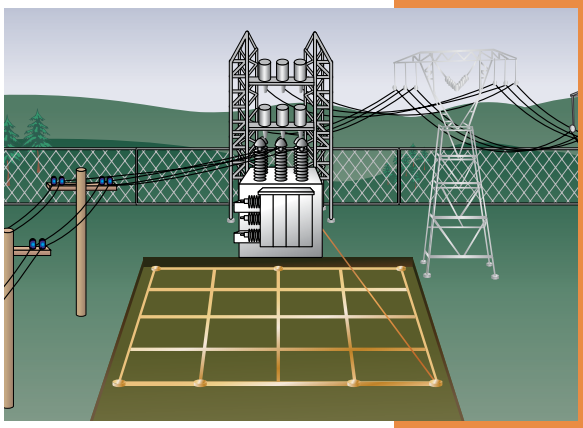
3-pole Fall-of-Potential measurement

Second, we measure the resistance of the entire system via the 3-pole Fall-of-Potential method. Keep in mind the rules for stake setting. This measurement should be recorded and measurements should take place at least twice per year. This measurement is the resistance value for the entire site.

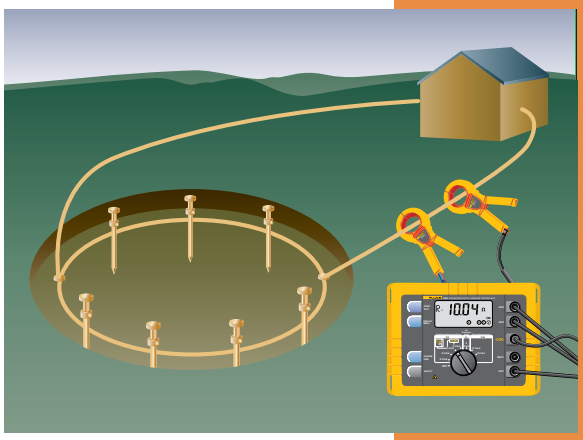
Selective measurement

Lastly, we measure the individual grounds with the Selective test. This will verify the integrity of the individual grounds, their connections, and determine whether the grounding potential is fairly uniform throughout. If any of the measurements show a greater degree of variability than the other ones, the reason for this should be determined. The resistances should be measured on:

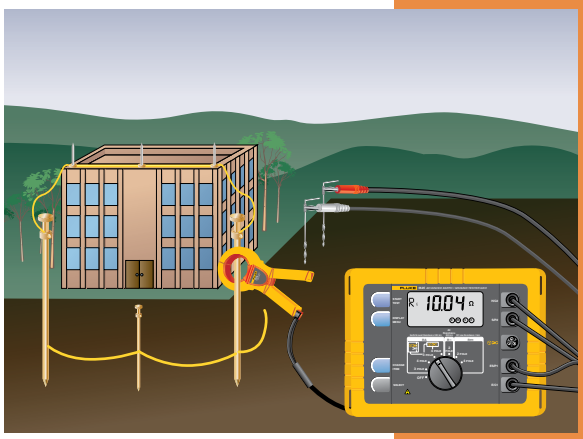
- Each leg of the tower and all four corners of the building (cell sites/towers)
- Individual ground rods and their connections (electrical substations)
- Both ends of the remote site (remote switching)
- All four corners of the building (lightning protection)



A typical setup at an electrical substation.



Using Stakeless testing at a remote switching site.



Using Selective testing on a lightning protection system.

Earth Ground Products

Fluke 1625 Advanced GEO
Earth Ground Tester

Fluke 1623 Basic GEO
Earth Ground Tester

The most complete tester

The Fluke 1623 and 1625 are distinctive earth ground testers that can perform all four types of earth ground measurement:

- 3-and 4-pole Fall-of-Potential (using stakes)
- 4-pole Soil Resistivity testing (using stakes)
- Selective testing (using 1 clamp and stakes)
- Stakeless testing (using 2 clamps only)

The complete model kit comes with the Fluke 1623 or 1625 tester, a set of two leads, 4 earth ground stakes, 3 cable reels with wire, 2 clamps, batteries and manual—all inside a rugged Fluke carrying case.

The complete kit

Fluke 1625 advanced features

Advanced features of the Fluke 1625 include:

- **Automatic Frequency Control (AFC)**—identifies existing interference and chooses a measurement frequency to minimize its effect, providing more accurate earth ground values
- **R* Measurement**—calculates earth ground impedance with 55 Hz to more accurately reflect the earth ground resistance that a fault-to-earth ground would see
- **Adjustable Limits**—for quicker testing

Optional Accessories

320 mm (12.7 in) Split Core Transformer—for performing Selective testing on individual legs of towers.

For more information go to www.fluke.com/1625

Fluke. *Keeping your world up and running.™*

Fluke Corporation
PO Box 9090, Everett, WA USA 98206

Fluke Europe B.V.
PO Box 1186, 5602 BD
Eindhoven, The Netherlands

For more information call:
In the U.S.A. (800) 443-5853 or
Fax (425) 446-5116
In Europe/M-East/Africa
+31 (0) 40 2675 200 or
Fax +31 (0) 40 2675 222
In Canada (800)-36-FLUKE or
Fax (905) 890-6866
From other countries
+1 (425) 446-5500 or
Fax +1 (425) 446-5116
Web access: http://www.fluke.com

©2006 Fluke Corporation. All rights reserved.
Printed in U.S.A. 6/2006 2633834 B-EN-N Rev A