Principles and testing methods of earth ground resistance

Poor grounding contributes to downtime but a lack of good grounding is also dangerous and increases the risk of equipment failure.

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

Grounding testers are indispensable troubleshooting tools to help you maintain uptime. It is recommended that all grounds and ground connections be checked at least annually as a part of your normal predictive maintenance plan. Should an increase in resistance of more than 20% be measured during these periodic checks, 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?

The US National Electrical Code (NEC) 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”.

Grounding actually encompasses 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 structure is grounded properly.

These two grounding systems must be kept separate except for connections between the two systems. This prevents differences in voltage potential from a possible flashover from lightning strikes. The purpose of a ground is to provide a safe path for the dissipation of fault currents, lightning strikes, static discharges, EMI and RFI signals and interference.

The US National Fire Protection Agency (NFPA) and Institute of Electrical and Electronics Engineers (IEEE) recommend a ground resistance value of 5 or less. The goal in ground resistance is to achieve the lowest ground resistance value possible that makes sense economically and physically.

What affects the grounding resistance?

Four variables affect the ground resistance of a ground system: length or depth of the ground electrode; the diameter of the ground electrode; the number of ground electrodes and ground system design.

Length/depth of the ground electrode

Driving ground electrodes deeper is a very effective way to lower ground resistance. Soil is not consistent in its resistivity and can be unpredictable. The resistance level can generally be reduced by an additional 40% by doubling the length of the ground electrode. It is sometimes impossible to drive ground rods deeper – in areas composed of rock, for instance. In these cases, 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

Using multiple ground electrodes provides another way to lower ground resistance. 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 must be at least equal to the depth of the driven rod.

The ground electrodes' spheres of influence will intersect and the resistance will not be lowered without proper spacing. Table 1 provides various ground resistances which can be used as a rule of thumb.

Table 1: Ground resistances for use as a rule of thumb.

Type of soil	Soil resistivity R_E	Earthing resistance					
		Ground electrode depth (metre)			Earthing strip (metre)		
	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	107	–	–	–	–	–	–

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

Soil resistivity measurement

Soil resistivity is 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. Poor soil conditions can be overcome with more elaborate grounding systems. The soil composition, moisture content and temperature all impact soil resistivity. Soil is rarely homogenous and its resistivity will vary geographically and at different depths. Moisture content changes seasonally, varies according to the nature of the sublayers of earth and the depth of the permanent water table. It is recommended that the ground rods be placed as deep as possible into the earth as soil and water are generally more stable at deeper strata.

Calculating soil resistivity

The measuring procedure described here uses the Wenner method and uses the formula:

$\rho = 2 \pi A R$

where:

ρ = the average soil resistivity to depth A in: ohm-cm.

π = 3,1416.

A = the distance between the electrodes in cm.

R = the measured resistance value in ohm from the test instrument.

Measuring soil resistance

To test soil resistivity, connect the ground tester as shown in Fig. 1. 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. The Fluke1625 earth ground tester generates a known current through the two outer ground stakes and the drop in voltage potential is measured between the two inner ground stakes. The tester automatically calculates the soil resistance using Ohm's Law (*V=IR*).

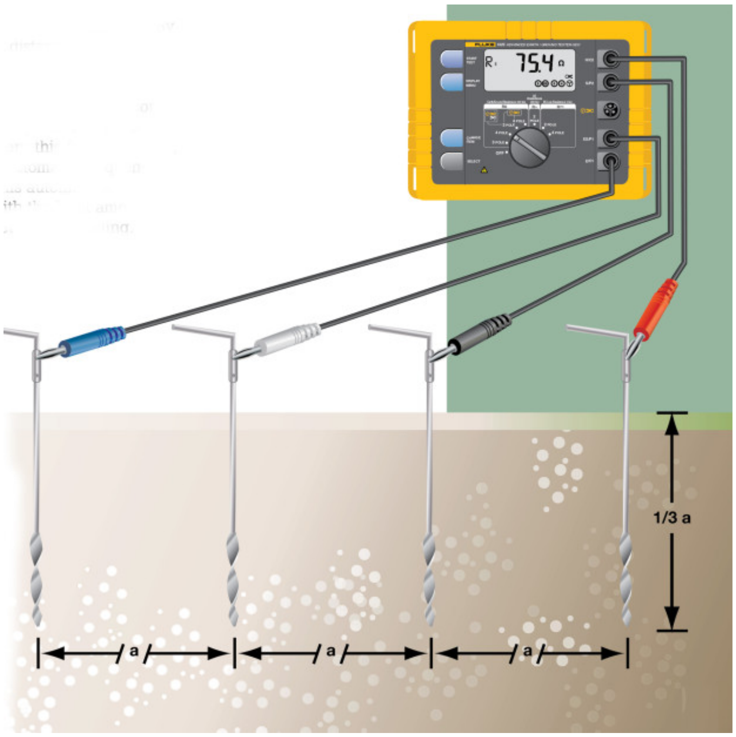

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Fig. 1: Test current paths in the stakeless method.

Additional measurements, where the stake's axes are turned 90°, are always recommended because measurement results are often distorted and invalidated by underground metal, underground aquifers etc.

A profile is produced that can determine a suitable ground resistance system by changing the depth and distance several times. Soil resistivity measurements are often corrupted by the existence of ground currents and their harmonics.

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. The earth electrode of interest must be disconnected. The tester is then connected to the earth electrode. Then, two earth stakes are placed in the soil in a direct line – away from the earth electrode, for the 3-pole fall of potential test. Spacing of 20 m is normally sufficient.

Placing the stakes

It is essential that the probe be placed outside the sphere of influence of the ground electrode under test and the auxiliary earth to achieve the highest degree of accuracy when performing a 3-pole ground resistance test or the effective areas of resistance will overlap and invalidate any measurements.

Table 2 is a guide for setting the probe (inner stake) and auxiliary ground (outer stake). Reposition the inner stake (probe) 1 m in either direction and take a fresh measurement to test the accuracy of the results and to ensure that the ground stakes are outside the spheres of influence. If there is a significant change in the reading (30%), you should 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).

Stakeless measurement

The Fluke 1625 earth ground tester can measure earth ground loop resistances for multi grounded systems using only current clamps. This test technique eliminates the dangerous step 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 is connected to the tester (see Fig. 2). 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, the stakeless method will not provide an acceptable value and the fall-of-potential test method must be used.The earth ground tester works on the principle that in parallel/multi-grounded systems, the net resistance of all ground paths will be extremely low compared to any single path (the one under test). So, the net resistance of all theparallel 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, you will either have an open circuit or be measuring ground loop resistance.

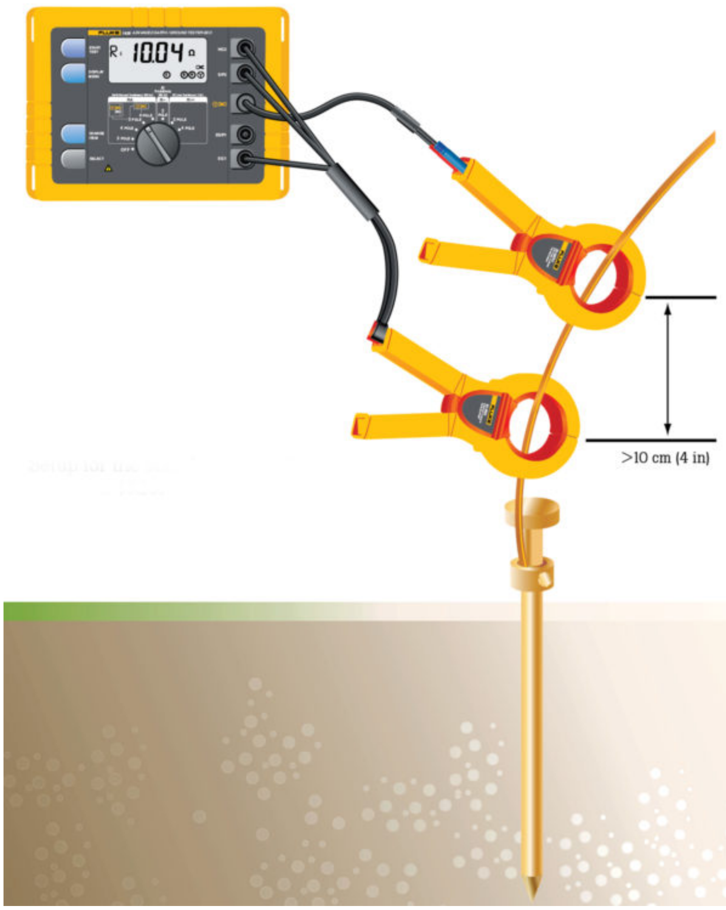

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Fig. 2: Setup for the stakeless method.

Ground impedance measurements

When attempting to calculate possible shortcircuit currents in power plants and other highvoltage/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. Power utility 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.

At central offices

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

Before testing, locate the master ground bar (MGB) within the central office to determine the type of grounding system. The MGB will have ground leads connecting to the multi-grounded neutral (MGN) or incoming service, the ground field, water pipe and structural or building steel (see Fig. 3).

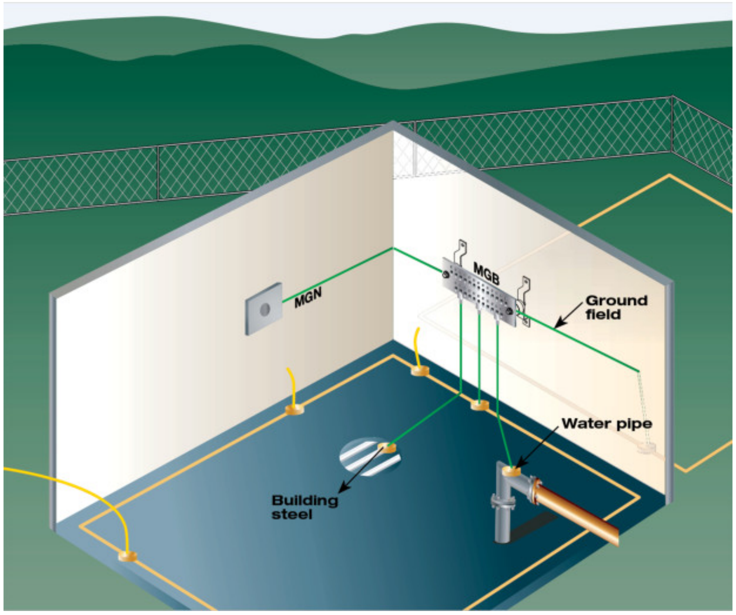

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Fig. 3: The layout of a typical central office.

First, perform the stakeless test on all the individual grounds coming from the MGB (see Fig. 4). 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, but the loop resistance of what you are clamped around. Connect the earth ground tester and both the inducing and sensing clamps, which are placed around each connection to measure the loop resistance of the MGN, ground field, water pipe and the building steel. Second, perform the 3-pole fall-of-potential test of the entire ground system, connecting to the MGB (see Fig 5). To get to remote earth, many phone companies use unused cable pairs going out as much as a mile. Record the measurement and repeat this test at least annually.

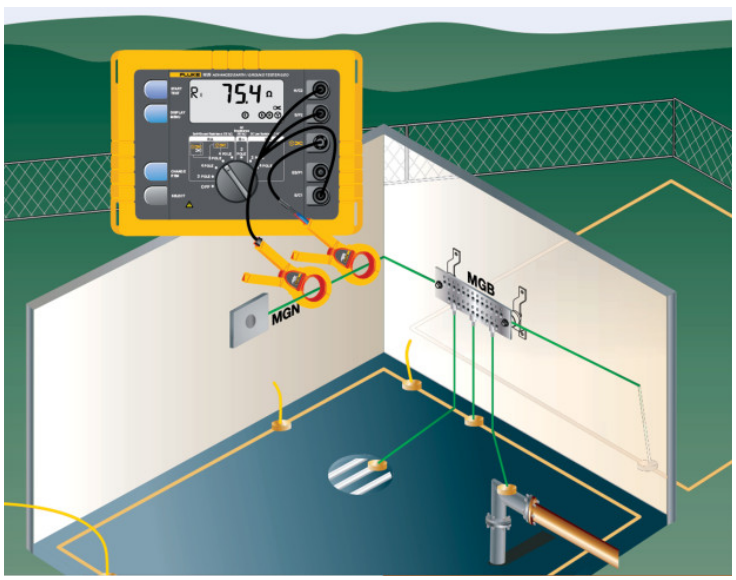

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Fig. 4: Stakeless testing of a central office.

Thirdly, measure the individual resistances of the ground system using the selective test of the earth ground tester (see Fig. 6). Connect the tester. 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.

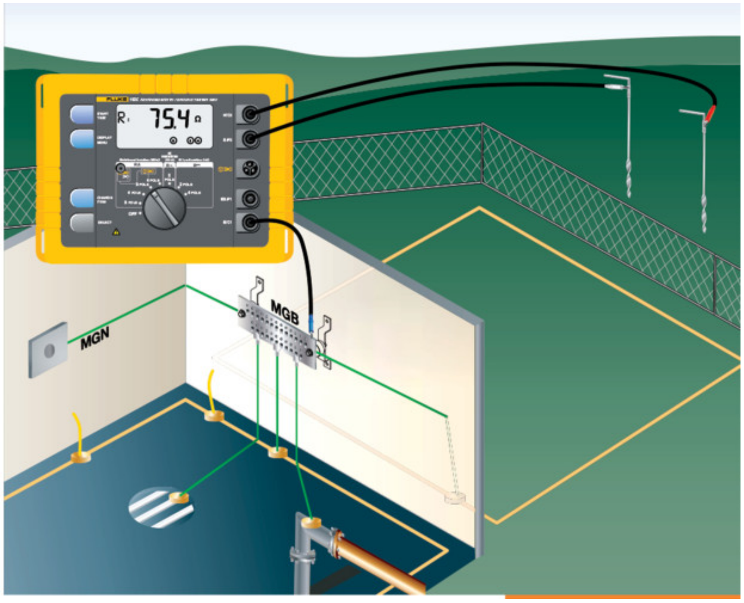

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Fig. 5: Perform the 3-pole fall-of-potential test of the entire ground system.

Now move on to the water pipe and 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).

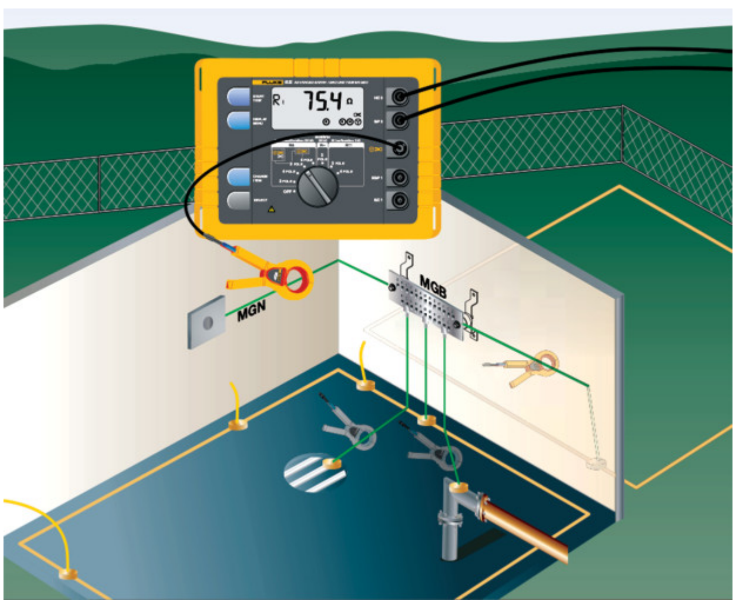

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Fig. 6: Measure the individual resistances of the ground system using the selective test.

These test methods provide the most accurate measure of central offices because it gives you the individual resistances and their actual behaviour 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.

Additional tests

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 between 20 and 30% off the total R_E value.

Table 2: A guide to setting the inner and outer stakes.

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

Finally, measure the resistances of the various legs of the MGB using the selective stakeless method. It works like the stakeless method, but 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.

Place the sensing clamp 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. 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 such as 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.

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