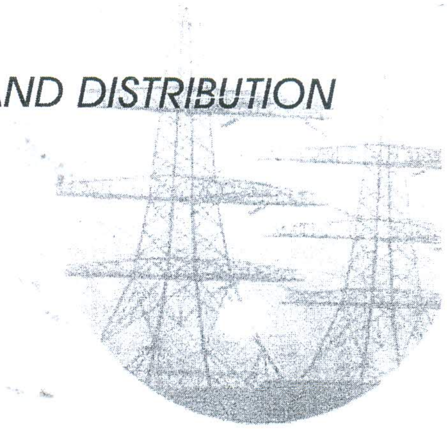

Checking earth electrode impedance

Information from Fluke

Most facilities have earthed electrical systems, so that in the event of a lightning strike or utility overvoltage, current will find a safe path to earth. To ensure a reliable connection to earth, electrical codes, engineering standards, and local standards often specify a minimum impedance for the ground electrode. This application note describes the principle methods for testing earth electrodes and connections.

The primary goal of an earthing system is to ensure personnel safety and protection of installations against damage. Two important phenomena are lightning and power system faults. These can cause circulation of large currents, which might create hazardous voltages in installation structures.

The grounding and bonding systems connect the earth near the building with the electrical system and building steel. In a lightning strike, the facility will be at approximately the same potential. By keeping the potential gradient low, damage is minimised. Fig. 1 shows an earthing system for a commercial building.

Earth electrode impedance

The impedance from the electrode to the earth varies depending on two factors: the resistivity of the surrounding earth and the structure of the electrode.

The resistivity of earth is complicated, because it:

- Depends on composition of the soil (e.g. clay, gravel and sand)
- Can vary even over small distances due to the mix of different materials
- Depends on mineral (e.g. salt) content
- Varies with compression and can vary with time due to settling
- Changes with temperature, freezing (and thus time of year). Resistivity increases with decreasing temperature
- Can be affected by buried metal tanks, pipes, re-bar, etc.
- Varies with depth

Since resistivity may decrease with depth, one way to reduce earth impedance is to drive an electrode deeper. Using an array of rods, a conductive ring or a grid are common ways of increasing the effective area of an electrode. Multiple rods should be outside of each other's areas of influence to be most effective (see Fig. 2).

The acceptable limits for earth electrode impedance for different types of installation are given in the relevant national standards – in this case South African National Standards (SANS.

How do earth impedance testers work?

There are two types of earth impedadance testers: Three and four point testers and clamp-on testers (Fig.3). Both types apply a voltage on the electrode and measure the resulting current. A three or four-pole tester combines a current source and voltage measurement in a multimeter-style package. They use multiple stakes and/or clamps.

Earth testers have the following characteristics:

- AC test current
- Test frequency that is close to, but distinguishable from the power frequency and its harmonics. This prevents stray currents from interfering with ground impedance measurements
- Separate source and measure leads to compensate for the long leads used in this measurement
- Input filtering designed to pick up the test signal and screen out all others
- Clamp-on ground testers are very different because they have both a source transformer and a measurement transformer. The clamp-on ground tester uses advanced filtering to recognise the test signal and screen out all others.

The fall-of-potential method

The fall-of-potential method is the traditional method for testing electrode resistance and is specified in numerous standards. In it's basic form, it works well for small electrode systems like one or two earth rods. We will also describe the Tagg slope technique which can help draw accurate conclusions about larger systems.

How it works

The fall-of-potential method connects to the earth at three places. The connections are made to:

- E/C1 – the earth electrode being tested.
- S/P2 – A voltage (potential) measurement stake driven into the earth some distance away from the electrode.

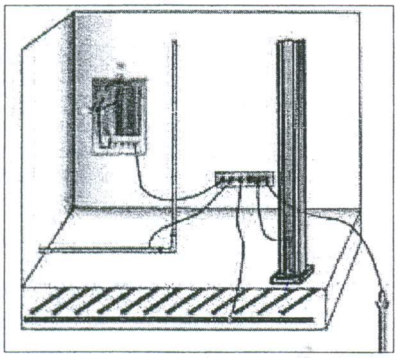

Fig. 1: An earthing system combining reinforcing steel and a rod electrode.

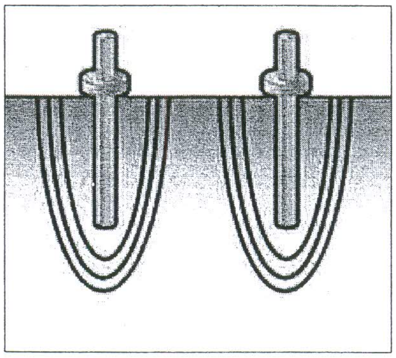

Fig. 2: Earth electrodes have "areas of influence" that surround them.

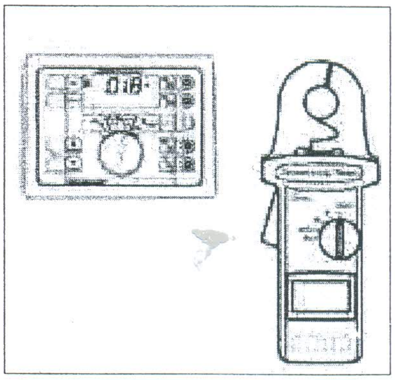

Fig. 3: Clamp-on earth tester.

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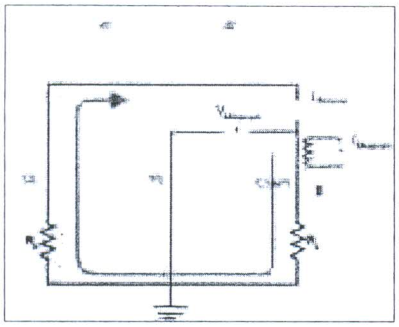

Fig. 4: Schematic for fall-of-potential.

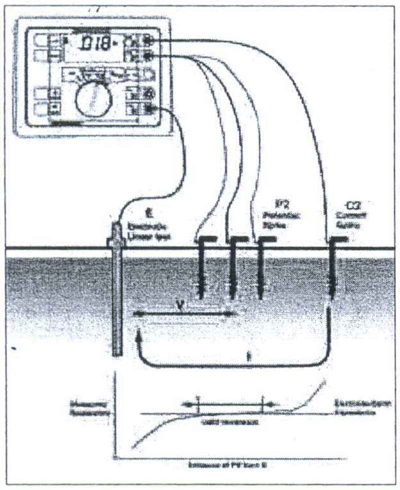

Fig. 5: A plot of measured impedances versus position of the potential stake allows us to see the earth impedance.

- H/C2 – A current stake driven into the earth a further distance away.

Fig. 4 shows this schematically and Fig. 5 shows the three connections made using a typical earth tester.

The tester injects an alternating current into the earth between the electrode under test (E) and the current stake (C2), and measures the voltage drop between the P2 stake and E. It then uses Ohm's law to calculate the impedance between P2 and E. To perform the test position the C2 stake at some distance from the electrode under test. Then, keeping the C2 stake fixed, move the P2 stake along the line between E and C2, measuring the impedance along the way. The tricky part comes in determining where to drive the stakes to get a true reading of the impedance between the electrode and the earth.

The current probe generates a voltage between itself and the electrode under test. Close to the electrode, the voltage is low and the potential probe is said to be within the influence of the electrode. Close to the current probe the voltage is almost the full voltage output by the tester.

Depth of electrode under Test (E)	Distance from E to potential stake (P2)	Distance from E to current stake (C2)
2	15	25
3	19	30
6	25	40
9	31	50

Table 1: Approximate distance to auxiliary stakes using the 62% rule (in meters).

Widest dimension (Diagonal, diameter or straight-line) of electrode array under test (E)	Distance from E to potential stake (P2)	Distance from E to current stake (C2)
20	30	50
25	50	80
30	70	100
50	100	170
70	130	200

Table 2: Approximate distance to auxiliary stakes for electrode arrays (in meters).

But somewhere in the middle, something interesting happens.

As we move from the influence of the electrodes and into the mass of the earth, the test current no longer causes significant change in potential. If you plot a series of measurements, moving the potential stake away from the electrode under test, and towards the current stake you will notice a flattening of the curve. An ideal curve is shown in Fig 5. The flattest part of the curve is where the earth resistance is read. In reality, the curve never goes entirely flat but reaches a very gentle slope where changes in resistance are small.

The extent of the influence of the electrode depends on its depth and its area. Deeper electrodes require that the current stake be driven farther away (see Table 1). For large ground rings, grids or arrays, the influence of the electrode may extend for hundreds of meters. Table 2 gives suggested starting points for current and potential stake placement.

The three-wire measurement will deliver good results if you use a short C1 lead, or if you don't mind having a fraction of an ohm of lead resistance in your reading. For earth impedance measurements over 10 Ω, the effect of the resistance of the C1 lead will be small. But for very precise measurements, especially at low resistances, a fourwire tester allows you add a fourth lead to eliminate the contribution of the C1 lead. By running a separate potential lead (P1) to the electrode under test you can take the drop along the C1 current lead out of the measurement.

The 62% Rule

You may be able to use a shortcut if your test meets the following criteria:

- You are testing a simple electrode (not a large grid or plate)
- You can place the current stake 30 m or more from the electrode under test
- The soil is uniform

Under these conditions place the current stake 30 m or more from the electrode under test. Place the potential stake at 62% of the distance between the current stake and the electrode under test and take a measurement. As a check, take two or more measurements: one with the potential probe 1 m closer to the electrode under test, and another 1 m farther away (see Fig. 6). If you are on the flat portion of the fall-of-potential curve, then the readings should be roughly the same and you can record the first reading as your resistance.

The Tagg slope technique

Large electrodes or grounding systems require special consideration. If you've plotted resistance readings for nine different P2 locations and there is no clear flattening on your graph, then the tagg slope technique (also called the slope method) can help establish the earth impedance.

Fig. 7 shows an example dataset for which there is no obvious flat section. There can be a number of reasons for a curve like this:

- For electrode systems that cover large areas it may be difficult to place stakes far enough away
- You may not be able to place the C1 stake at the center of the electrode
- The area you have to place stakes may be limited

If you have resistance readings at the 20%, 40% and 60% points between E and C2, then you can apply the procedure to the data you've already taken. Calculate the slope coefficient (μ) using three resistance measurements from 20%, 40% and 60% of the distance from the electrode under test to the C2 current stake.

$$\mu = \left(\frac{R_{60\%} - R_{40\%}}{R_{40\%} - R_{20\%}}\right)$$

Then go to Table 6 and look up the P2/C2 ratio that corresponds to μ. This will tell you where to look on your graph to ascertain the earth resistance. For the sample data in Fig. 7:

$$\mu = \left(\frac{6{,}8 - 5{,}8}{5{,}8 - 44}\right) = 0{,}71$$

If we go to the table, for μ = 0,71 the corresponding P2/C2 percentage is 59,6%. So the approximate earth impedance would be measured at (59,6% X 100 m), or at 59,6 m. This is very close to our 60% point at 60 m, where we read 6,8 Ω. So it would be safe to say the earth resistance for the electrode under test is roughly 6,8 Ω.

The selective method

The selective method is a variation of the fall-of-potential method, available on high-end earth testers like the Fluke 1625. The supply neutral, building steel and earth electrode are all bonded and earthed. In a traditional fall-of-potential test you have no way of knowing how much current is flowing between any particular electrode and the C2 current stake. Selective testing uses an integrated, high sensitivity clamp-on current transformer to measure the test current in the electrode under test. (Fig. 8). The selective earth tester digitally filters the current measurement to minimise the effects of stray currents.

Stakeless or clamp-on method

The stakeless or clamp-on method allows you to measure the impedance of a series loop of ground electrodes. The test is simple and it may be performed on an electrode that is connected to a working electric service. To make the measurement the tester uses a special transformer to generate a voltage on the earth conductor at a unique test frequency. It uses a second transformer to distinguish the test frequency and measure the resulting current through the circuit, which is determined by the loop resistance.

Fig. 10 shows the connection of the source and measure clamps of the Saturn GEO X. Fig. 9 shows the equivalent test circuit for the stakeless method. When you test a building earth electrode using this method, you are actually testing a loop including:

- Electrode under test
- Earth electrode conductor
- The main bonding jumper
- The service neutral
- Utility neutral-to-earth bond
- Utility earth conductors (between poles)
- Utility pole earth

In this method the clamp checks the continuity of the interconnections of all of the components above. An abnormally high reading or an open circuit indication on the instrument points to a poor connection between two or more of the aforementioned critical components. The earth electrode of most facilities is in parallel with numerous distribution earth electrodes.

Two-pole method

The two-pole method uses an auxiliary electrode such as a water pipe.

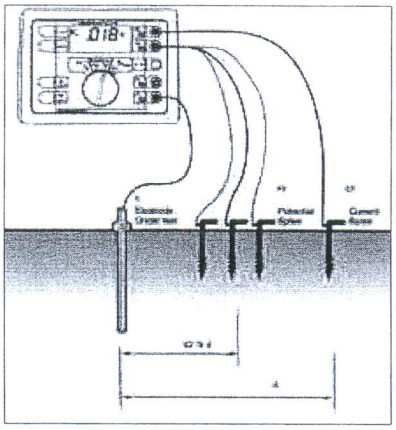

Fig. 6: Stake positions for the 62% rule.

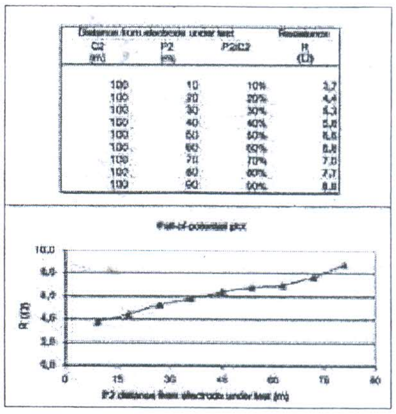

Fig. 7: Earth impedance can be found from this curve by using the Tagg slope technique.

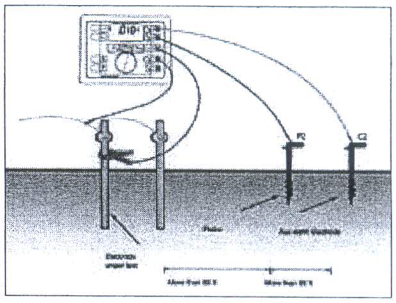

Fig. 8: Connections for selective ground electrode measurement.

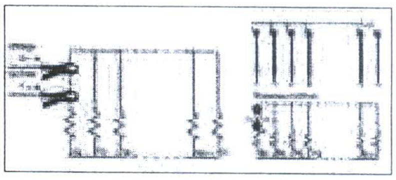

Fig. 9: Connections for selective electrode impedance measurement.

Summary of earth electrode test methods advantages and drawbacks	Advantages	Drawbacks
Fall-of-potential	Widely accepted When you see the characteristic curve you know you've got a good measurement.	You have to disconnect the earth The stakes may not be easy to drive There may not be space around the earth electrode to drive the stakes
Selective method	Don't have to disconnect the electrode Widely accepted When you see the characteristic curve you know you've got a good measurement.	The stakes may not be easy to drive There may not be space around the earth electrode to drive the stakes
Stakeless method	Convenient Saves time No disconnections No stakes	Assumes a low-impedance parallel path Possible to get very low readings by mistakenly measuring on a hard-wired loop
Two-pole method	Convenient Saves time No disconnections No stakes	Impossible to judge the integrity [illegible] auxiliary electrode. Can't be sure you are outside the area of influence

Table 3:

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μ	P2/C2 %	μ	P2/C2 %	μ	P2/C2 %	μ	P2/C2 %	μ	P2/C2 %
0,40	43,3	0,65	60,6	0,90	56,2	1,15	50,7	1,40	43,1
0,41	64,2	0,66	60,4	0,91	56,0	1,16	50,4	1,41	42,7
0,42	64,0	0,67	60,2	0,92	55,8	1,17	50,2	1,42	42,3
0,43	63,9	0,68	60,1	0,93	55,6	1,18	49,9	1,43	41,8
0,44	63,7	0,69	59,9	0,94	55,4	1,19	49,7	1,44	41,4
0,45	63,6	0,70	59,7	0,95	55,2	1,20	49,4	1,45	41,0
0,46	63,5	0,71	59,6	0,96	55,0	1,21	49,1	1,46	40,6
0,47	63,3	0,72	59,4	0,97	54,8	1,22	48,8	1,47	40,1
0,48	63,2	0,73	59,2	0,98	54,6	1,23	48,6	1,48	39,7
0,49	63,0	0,74	59,1	0,99	54,4	1,24	48,3	1,49	39,3
0,50	62,9	0,75	58,9	1,00	54,2	1,25	48,0	1,50	38,9
0,51	62,7	0,76	58,7	1,01	53,9	1,26	47,7	1,51	38,4
0,52	62,6	0,77	58,5	1,02	53,7	1,27	47,4	1,52	37,9
0,53	62,4	0,78	58,4	1,03	53,5	1,28	47,1	1,53	37,4
0,54	62,3	0,79	58,2	1,04	53,3	1,29	46,8	1,54	36,9
0,55	62,1	0,80	58,0	1,05	53,1	1,30	46,5	1,55	36,4
0,56	62,0	0,81	57,9	1,06	52,8	1,31	46,2	1,56	35,8
0,57	61,8	0,82	57,7	1,07	52,6	1,32	45,8	1,57	35,2
0,58	61,7	0,83	57,5	1,08	52,4	1,33	45,5	1,58	34,7
0,59	61,5	0,84	57,3	1,09	52,2	1,34	45,2	1,59	34,1
0,60	61,4	0,85	57,1	1,10	51,9	1,35	44,8		
0,61	61,2	0,86	56,9	1,11	51,7	1,36	44,5		
0,62	61,0	0,87	56,7	1,12	51,4	1,37	44,1		
0,63	60,9	0,88	56,6	1,13	51,2	1,38	43,8		
0,64	60,7	0,89	56,4	1,14	50,9	1,39	43,4		

Table 5: Table for the Tagg slope techniue (for 2 decimal places).

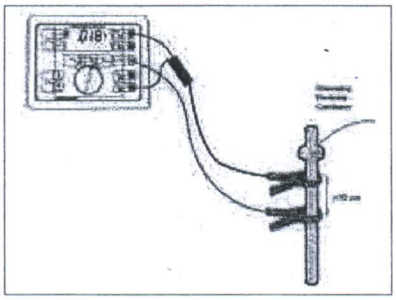

Fig. 10: Connection for a stakeless measurement.

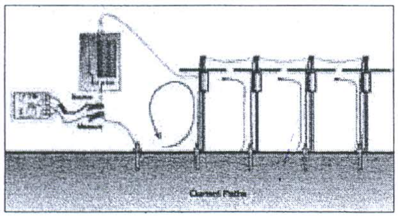

Fig.11: Test current paths in the stakeless method.

Fig. 12 shows the connections. The tester measures the combined earth impedance of the electrode under test, the earth impedance of the auxiliary electrode, and the impedance of the measurement leads. The assumption is that the earth impedance of the auxiliary electrode is very low, which would probably be true for metal pipe without plastic segments or insulated joints. The effect of the measurement leads may be removed by measuring with the leads shorted together and subtracting this reading from the final measurement.

Because of the unknowns involved in this technique, it is recommended only when the earthing system and auxiliary electrode are well known.

$$R_{eq} = \frac{1}{40\ X\ {}^{1}/_{20\Omega}} = {}^{1}/_{2}\ \Omega$$

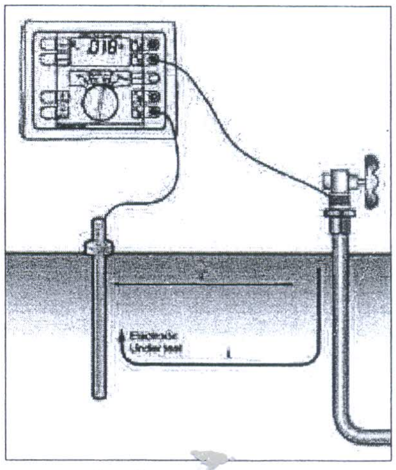

Fig. 12: Equivalent circuit for two-point measurement.

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