Wiring Matters
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Inspection and testing of earth electrodes

Leon Markwell, Senior Engineer at the IET, discusses the inspection and testing of earth electrodes.

An earth electrode and earth electrode resistance are defined in BS 7671 as:

Earth electrode *– conductive part, which may be embedded in the soil or in a specific conductive medium, e.g. concrete or coke, in electrical contact with the Earth.*

Earth electrode resistance *– the resistance of an earth electrode to Earth.*

In a TT system where a connection to earth is not provided by the supply authority it is still necessary for an LV final circuit protective device to disconnect an earth fault within 0.2 s. In order to achieve this, suitable maximum earth fault loop impedance must be provided, as noted in Regulation 411.5.4 of BS 7671. It is generally not possible to comply with this Regulation using only an earth electrode earth return so a residual current device (RCD) is usually installed. Regulation 411.5.3 details the requirements for RCD performance and Table 41.5 provides values of the maximum earth fault loop impedance for different RCD rated residual operating currents.

It should be noted that the terms 'resistance' and 'impedance' are used rather interchangeably in earth fault loops – although they actually have different meanings – as most of the circuit is just resistance with inductive reactance only in the supply transformer and larger supply distribution cables.

Contact with Earth can also be made through other metalwork extraneous-conductive-parts associated with an electrical installation, such as structural steelwork, metal, water or gas supply pipes or other buried metalwork. The effect of this other metalwork may be seen to reduce the overall earth electrode resistance, but it cannot be relied upon as an electrode as it could be removed or replaced at some future time. Regulation 542.2 of BS 7671 details what may be used as an earth electrode. An earth electrode may be in long-term contact with a corrosive environment and so allowance must be made for possible corrosion or the electrode made of material that can withstand corrosion.

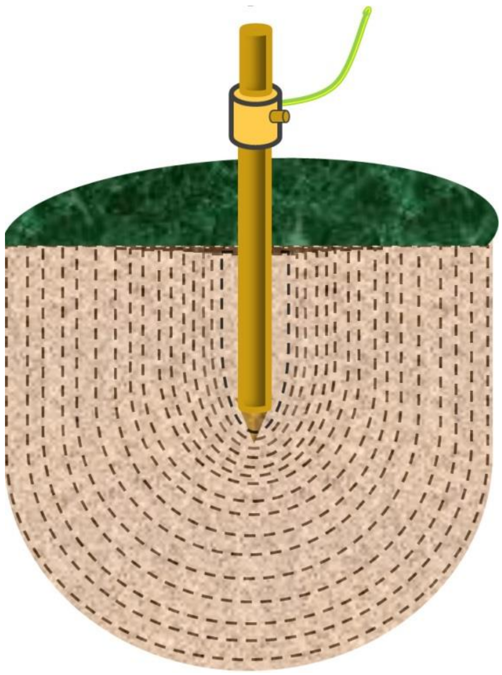
Figure 1 – A simple earth electrode

When a new earth electrode is installed the installer will know its construction and location and some details of the surrounding soil condition, but its earth resistance can only be determined by a test measurement. During a periodic inspection of an existing earth electrode, the situation is less certain as there are unlikely to be details of its construction or its buried location. In addition, it may well have corroded to some degree and the inspector will have no knowledge of the underlying soil conditions so the resistance can only be ascertained by measurement.

The simplest earth electrode used in the UK is a straight rod driven into the ground (see Figure 1). Item 1 is the rod and item 2 identifies the rod/soil contact surface. Initially this contact surface area is quite small and is the surface area of the rod in contact with the soil, but it should be noted that as the current travels away from the rod the surface area 'layers' (item 3) of the soil can be considered to get larger in area. As the resistance at a point is inversely proportional to the area at that point, the electrode resistance can be considered to be in the form of:

$$R = \frac{\rho L}{A}$$

where:

R = electrode resistance in Ohms.
ρ = soil resistivity in Ohm meters (assuming a uniform soil).
L = length of electrode buried in soil in meters.
A = area in square meters.

From the above, if the soil resistivity is known then the theoretical resistance of a single vertically driven earth rod can be approximately calculated using the formula below.

$$R = \frac{\rho}{2\pi L}\left[1n\left(\frac{8L}{d}\right) - 1\right]$$

Where:

d is the diameter of earth rod in meters
other terms are as noted above.

The derivation details of this and other electrode formulae can be found in BS 7430:2011+A1:2015 *Code of Practice for Protective Earthing of Electrical Installations*.

The above formula can only give an approximate value as there are always other factors to consider. For example, the soil resistivity is unlikely to be known with any accuracy and it may vary with depth. Seasonal changes in moisture content will also have an effect. The depth that the rod can be driven will depend on the soil conditions (rocks etc.) and the need to get to soil of suitable resistivity. For example, in the Middle East it is usual to drive a rod to below the level of the summer water table as the dry ground above has an extremely high resistivity.

It should also be noted that the length of the rod has significantly more effect on the electrode resistance value than the rod diameter. General data for a range of expected UK soil resistivities can be found in BS 7430:2011+A1:2015.

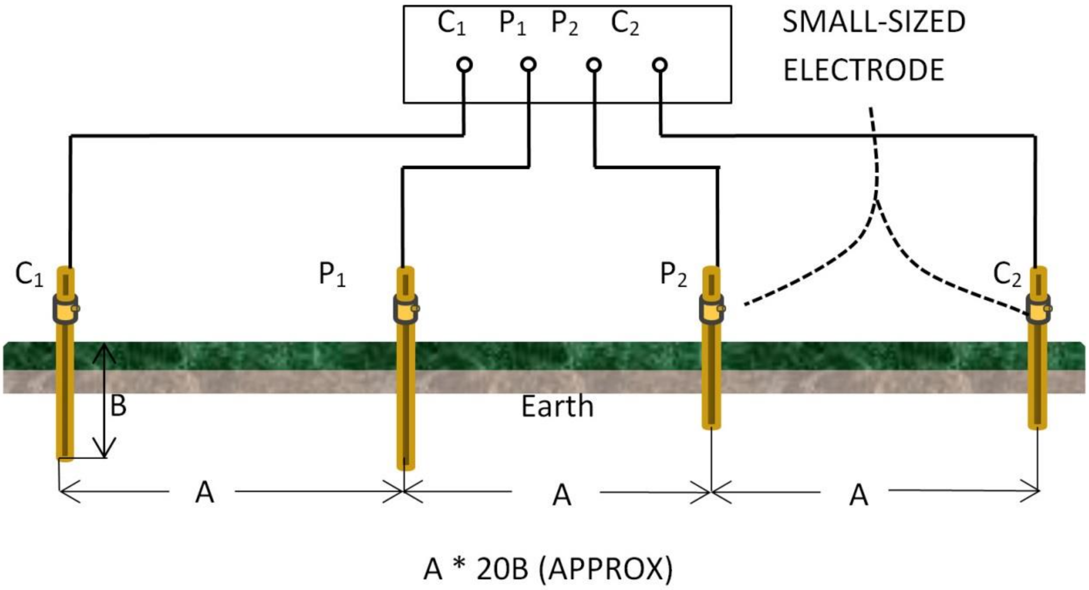

Figure 2 – Four-terminal method of measuring earth resistivity

From these basic electrode calculations it can be seen, as detailed in Figure 2, that if the spacing (A) between the actual installed electrode C1, the temporary C2 test electrode and the intermediate P1 and P2 test electrodes was large compared with the driven depth (B) of the installed electrode C1 (say, A is more than 20 x B) the general soil resistivity can be calculated from:

$$\rho = 2\pi \mathrm{AR}$$

where:

ρ is the resistivity in Ohm metres.
R is the earth electrode resistance reading in Ohms.
A is the spacing in metres between the test electrodes.

This is known as the ‘fall of potential’ method and it can be seen in Figure 3 below that most of the voltage is dropped around the electrodes where, as outlined above, the soil ‘layers’ are small around the electrode and therefore holds the majority of resistance. In the area between the electrodes there are is multitude of current ‘paths’ and the area (A) is very large so the change in resistance is very small.

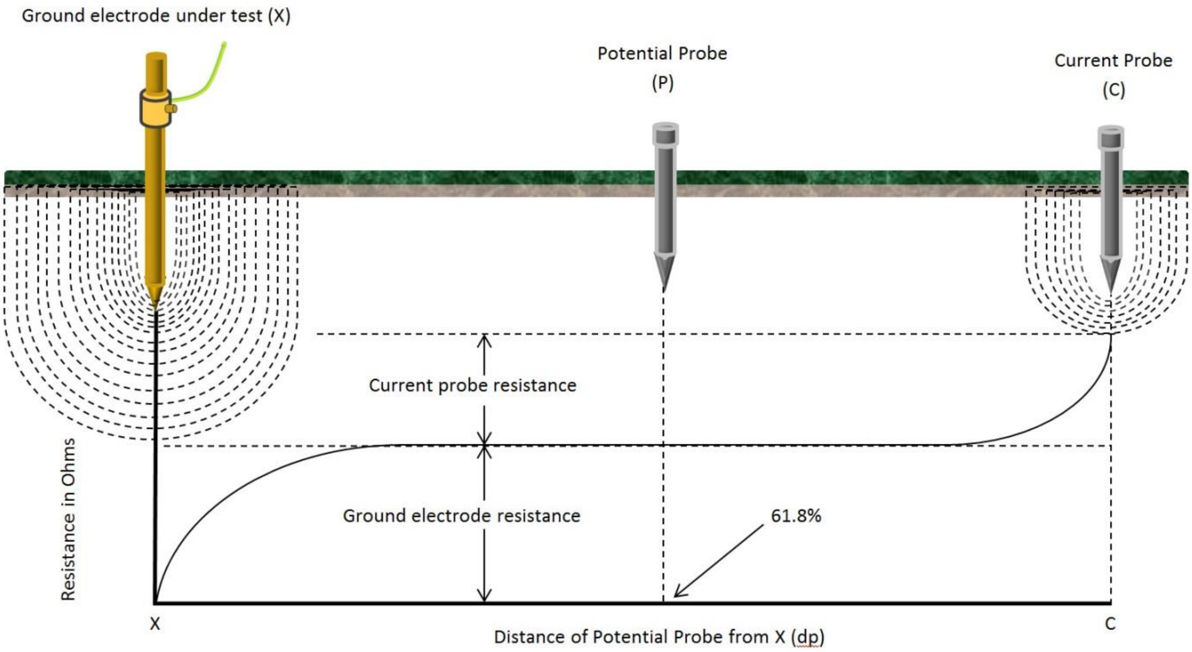

Figure 3 – Illustration of the fall of potential method of electrode resistance measurement

Modern testing equipment works on this principle but it is designed by instrument manufacturers to be more compact and easier to use.

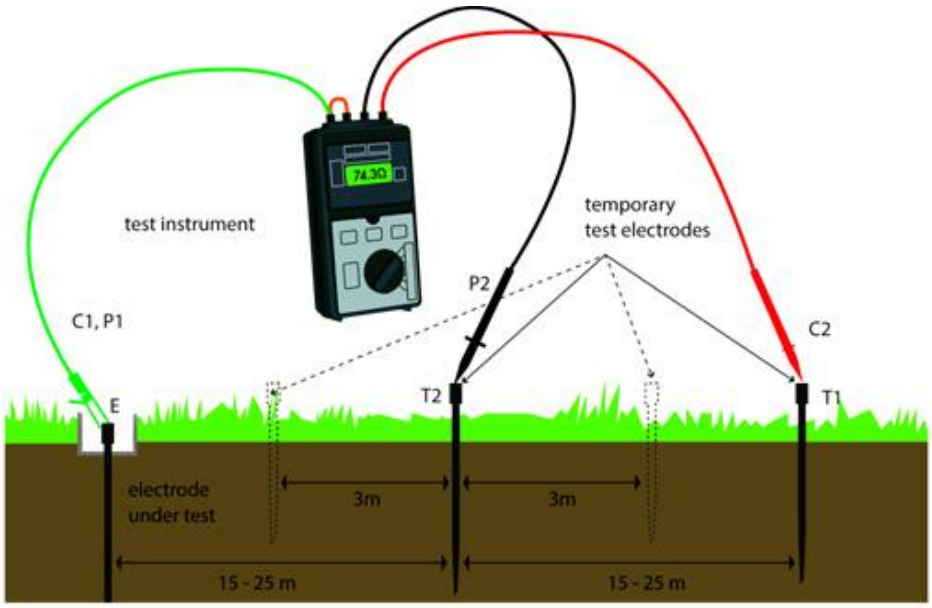

Figure 4 – Typical earth electrode test using a three or four terminal tester